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Upper Cretaceous Formations of Southwestern Arkansas

BY

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LITTLE ROCK, ARK., *May 7, 1929*

HON. HARVEY PARNELL,
Governor, State of Arkansas,
Little Rock, Arkansas.

Sir:

I have the honor to submit herewith the report, "Upper Cretaceous Formations of Southwestern Arkansas," by Mr. Carle H. Dane, Associate Geologist of the U. S. Geological Survey.

A detailed study of the southwest Arkansas area was originally planned as a federal-state co-operative project, but on account of lack of funds the State Survey was unable to pay any part of the expense of the field work and this was met by the U. S. Geological Survey. After the completion of the field work, the publication of the report was undertaken by the Arkansas Geological Survey.

This report provides detailed information concerning the characteristics, sequence and surface distribution of the various formations found in the Upper Cretaceous area of southwestern Arkansas, an area which includes portions of Clark, Pike, Nevada, Hempstead, Howard, Miller, Little River and Sevier Counties. This information is useful for an understanding of the economic possibilities of the area. Also since these formations are the source of nearly all of the oil and gas produced in southern Arkansas where they are covered by considerable thicknesses of younger beds, a detailed knowledge of their characteristics and sequence as determined by a surface examination is of direct value to an understanding of the geology of both the producing and potential oil and gas areas of southern Arkansas.

From a more general geological standpoint, this report is a contribution to the knowledge of the Upper Cretaceous beds of the Gulf Coastal Plain of southern and eastern United States.

Respectfully submitted,

GEORGE C. BRANNER,
State Geologist.

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ABSTRACT

The Cretaceous formations of southwestern Arkansas consist largely of unconsolidated sand, clay, and marl, but include some beds of limestone, sandstone, and chalk. They rest on a pre-Cretaceous erosion surface, which is cut on folded and faulted Paleozoic rocks and dips to the south and southeast at about 100 feet per mile. The Cretaceous beds dip south and southeast from 65 to 80 feet per mile. The Lower Cretaceous Comanche series in the area includes the Trinity formation, 0-2100 feet thick, consisting of novaculite gravel, limestone, gypsum, fine-grained sand, and variegated red and gray clay; the Goodland limestone, of Frederickburg age, a hard, gray sandy limestone, 0-50 feet thick; and the Kiamichi clay, consisting of green-gray marl and fossiliferous shell beds, 0-20 feet thick.

The Upper Cretaceous Gulf series, which this report particularly describes, rests with angular unconformity on the Lower Cretaceous rocks, and the Goodland, Kiamichi, and Trinity are cut out of the stratigraphic section successively eastward. The Woodbine, the basal formation of the Gulf series, is composed of 0-350 feet of novaculite and igneous rock gravel and red and gray clay. It is probably of marine origin. The overlying Tokio formation, 0-300 feet thick, consists chiefly of yellow and white cross-bedded sand and gray sandy clay and, at the base, a persistent bed of novaculite gravel, 1 to 25 feet thick, as well as some higher gravel beds. The formation is largely a marine near-shore deposit and contains invertebrate fossils that suggest its equivalence in age with the Austin chalk of Texas. The Tokio rests unconformably on the Woodbine and cuts it from the section in the eastern part of the region, where it rests successively on the Trinity formation and Paleozoic rocks.

The overlying Brownstown marl, 50-250 feet thick, is a dark gray, in places sandy marl, of the age of the Taylor marl of Texas, and is therefore probably separated by a time break from the underlying Tokio, which it overlaps eastward. The Ozan formation, a marl containing some gray sand, rests on the Brownstown and is 50-250 feet thick. At its base in Sevier, Howard and Hempstead counties, and probably in Little River County, is a marly glauconitic sand, 3-15 feet thick, named the Buckrange sand lentil of the Ozan formation. A glauconitic sandy marl, 50 feet higher stratigraphically, is exposed at some places. The break at the base of the Ozan is interpreted as a submarine surface of erosion or non-deposition. The Ozan formation is tentatively correlated with the lower part of the Annona chalk as exposed near Clarksville, Texas. The Annona chalk in Arkansas is a white, pure chalk. It is 100 feet thick in Little River County, but it thins out and disappears eastward. Its base indicates only a slight interruption of sedimentation. Overlying it conformably is the Marlbrook marl, a gray pure marl, 0-220 feet thick. The thinning northeastward of the Annona and Marlbrook along the outcrop is interpreted as thinning toward shallower water and a shore line trending approximately east-west.

The Saratoga chalk, which rests unconformably, but with approximate parallelism, on the Marlbrook marl, is a very fossiliferous hard, sandy, somewhat glauconitic chalk, ranging in thickness from 20 to 60 feet. It is separated from the underlying marl by a well-exposed and persistent lithologic and faunal break. The base of this formation is the base of the *Exogyra costata* zone, which extends through the Coastal Plain Cretaceous beds. The thinner *Exogyra cancellata* subzone includes the lower part of the Saratoga and extends downward stratigraphically a short distance into the uppermost Marlbrook. The underlying Tokio, Brownstown, Ozan, Annona, and Marlbrook formations are of Taylor age and are included in the *Exogyra ponderosa* zone. In the uppermost part of the Marlbrook, specimens of *Exogyra cancellata,* mostly non-typical, are associated with *Exogyra ponderosa.* The Saratoga chalk marks the base in Arkansas of the beds equivalent in age to the Navarro formation in Texas.

The Nacatoch sand, which overlies the Saratoga chalk, is a complex unit made up of cross-bedded yellowish and gray fine-grained unconsolidated quartz sand, hard crystalline sandy limestone, richly glauconitic sand, and light gray clay and marl. From central Hempstead County to western Clark County it is divisible into three intergradational lithologic units, the lowest of bedded gray clay and marl with some sandy beds, the middle chiefly of dark greenish sand containing from 20 to 80 per cent of glauconite, the upper of unconsolidated gray, fine-grained cross-bedded quartz sand. The Nacatoch is from 150 to 400 feet thick. It rests on an irregular surface having the physical aspect of an unconformity, and toward the east this irregularity locally cuts out the underlying Saratoga chalk and Marlbrook marl. Nevertheless there is in places evidence of transitional relations between the Saratoga and Nacatoch, and the faunal differences between the two formations are so slight that the irregularity at the base of the Nacatoch may be due to submarine scour, and the time that elapsed between the deposition of the Nacatoch and Saratoga may have been relatively short.

The uppermost Cretaceous formation in the area is the dark-gray fossiliferous Arkadelphia marl, 120-160 feet thick. The sharpness of the lithologic break at its base and the distinctive type of *Exogyra costata* found in it suggest that it may be separated from the underlying Nacatoch sand by a slight time break.

The Cretaceous-Eocene contact is physically inconspicuous because of the lithologic similarity of the Arkadelphia marl and the Midway, the basal formation of the Eocene, and the very poor exposures of both formations. The four known outcrops in southwestern Arkansas afford new evidence that there is an erosional unconformity at the base of the Midway, although there is very slight or no angular discordance. The lower 30-50 feet of the Midway in this area is calcareous, abundantly foraminiferal bedded clay and, at the base, a few beds of earthy limestone. A layer of phosphatic nodules and glauconite marks the contact at the localities examined. Above the lower calcareous zone there is at least 200 feet of dark-gray non-calcareous Midway clay. The Wilcox formation, which consists of cross-bedded sand and clay containing large calcareous concretions, overlies the Midway.

Later Tertiary events are not recorded directly in the area, which near the end of the Teritary period stood considerably lower than it does now: it was a low-lying plain of slight relief. This peneplain was uplifted in late Pliocene and early Quaternary time, and since then the present topography has been carved out by stream erosion, which was interrupted for a time by aggradation, by which wide terraces were deposited in the valleys of the principal streams and abnormally flat floors were formed by deposition in the bottoms of the smaller valleys.

The structural deformation is slight, but there have been repetitions and alternations of broad, slight tilting and warping. The tilting of the Paleozoic basement toward the south began in earliest Cretaceous time and continued with interruption until Tertiary time and along the coast until still later. In earliest Cretaceous time the Paleozoic floor was first tilted toward the east, but there was a period of uplift and erosion in the eastern part of the area prior to the transgression of the basal Upper Cretaceous sea. There is some reason to believe that there were structural movements between Lower Cretaceous and Upper Cretaceous time. The geographic and geologic relations of the formations show that the eastward-tilting which developed the western margin of the Mississippi embayment did not begin prior to the deposition of the beds in the time zone of *Exogyra costata,* although the eastern part of the Mississippi embayment extended as far north as Kentucky in early Upper Cretaceous time. This indicates a westward shift of the axis of the embayment.

The most striking topographic features of the region are the east-west ridges, which stand a few hundred feet above the general level and are cuestas coextensive with the outcropping belts of the harder formations. The Centerpoint cuesta follows the outcrop of the basal gravel of the Woodbine formation, and the Highland cuesta follows the outcrop of the basal gravel of the Tokio formation. The Saratoga cuesta is a ridge produced chiefly by the resistance to erosion of the sandy parts of the Nacatoch formation.

Chalk, clay, sand, and gravel are valuable economic resources of the Upper Cretaceous beds. The lignite found in places in the Tokio formation is of little value. The glauconitic deposits of the Nacatoch sand are a potential source of potash for fertilizer if chemical methods of treatment now being tested should prove commercially practicable. The deposits are favorably located geographically but are not of the highest grade. The sandy formations are reservoirs of artesian water, which are extensively exploited, and more than seventy wells have been drilled in the search for oil and gas. The results of this drilling have been unfavorable, and no pronounced anticlinical structures have been found, but small showings of oil and gas have been reported from about twenty wells. Correlations of the drillers' records of 46 wells with the geologic formations penetrated are given in a table; drillers' descriptions of the formations penetrated in a few wells are given in detail; descriptions of samples and cores examined are correlated with some of these descriptions; and a few of the most detailed records are plotted graphically.

CRETACEOUS FORMATIONS OF SOUTHWESTERN ARKANSAS

By Carle H. Dane

INTRODUCTION

The search for hidden oil fields in southern Arkansas and northern Louisiana has been guided principally by the study of the records of deep wells drilled in those regions, and as a correct interpretation of the underground structure controlling the accumulation of oil and gas depends upon the accurate identification in wells of the Cretaceous formations in which these substances are found, it is of great importance that the variations of the formations in character and thickness from place to place be ascertained as accurately as possible. The investigation of the Upper Cretaceous outcrops in southwestern Arkansas upon which this paper is based was therefore undertaken primarily to give an adequate starting point for subsurface correlation, and the lithology and stratigraphic relations of the Upper Cretaceous deposits of the area are described in detail.

The interest in the geology of these Cretaceous formations has been enhanced by a realization of the economic value of the chalk, gravel, and clay found in some of them and by the recognition of the fact that they form reservoirs of artesian water. The stratigraphy of these formations has been described in a general way by R. T. Hill[1] and A. C. Veatch.[2] During the years that have passed since the older comprehensive papers were published several geologists have contributed reports on the stratigraphic relations, our knowledge of the geology of sediments of about the same age in adjoining areas has been made more detailed and accurate, and a large number of facts have been disclosed by the records of prospect holes drilled for oil and gas. The need of a general revision of the stratigraphy has now become evident.

The present report includes not only the results of the writer's detailed field observations, but information given by

[1] Hill, R. T., The Neozoic geology of southwestern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1888, vol. 2, 1888.

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

others, which has been interpreted in the light of our present knowledge. The value of the earlier reports of Robert T. Hill, Joseph A. Taff,[3] and A. C. Veatch, published by the State and the Federal surveys, is increased rather than diminished by the more complete discussion of the stratigraphic relations here presented. Their careful records of field observations and of well logs make them permanently useful sources of information.

The early investigators faced extraordinary difficulties in deciphering the geology of this region. The whole region, except a few small prairies, was forested and covered with underbrush. The terraces of sand and gravel found at many levels provided a widespread blanket which effectually masked the character of the underlying Cretaceous formations over large areas. Outcrops were confined almost entirely to the bluffs along the larger streams and along gullies at the heads of smaller drainage courses, many of them invisible from a distance of a few hundred yards. The population was scanty and travel was difficult. That these investigators obtained as correct a knowledge of the geologic relations as they did is surprising, and their reports form a high tribute to their insight and perseverance. Many of the obstacles to a full understanding of the local geology have been removed since their work was done.

Travel has been greatly facilitated by the construction of gravel highways and the development of a system of public roads, most of them available for use by automobile. The extensive construction of roads has also greatly increased the number of outcrops, for at many places the roads have been cut through a mantle of surficial sand and expose the underlying Cretaceous rocks. The clearing of the land for agriculture has promoted gullying and has produced small outcrops in areas that were once forest covered and that showed no outcrops. The numerous wells drilled for water and oil have also been helpful. Well records, though many of them give vague information, contribute much to our knowledge of the thickness and distribution of the formations where the stratigraphic succession is known, and well cuttings and cores give more valuable information.

[3] Taff, J. A., Chalk of southwestern Arkansas: U. S. Geol. Survey Twenty-second Ann. Rept., 1900-1901, pt. 3, 1902.

SUMMARY OF RESULTS

One of the principal results of the present work is the recognition of a considerable number of breaks in sedimentation, which separate the lithologic units mapped as formations. These breaks have not heretofore been recognized, partly because of the general lithologic similarity of the beds constituting the formations, and partly because of the scarcity of outcrops showing contacts between formations, but perhaps chiefly because of the conception that the Upper Cretaceous series represented continuous sedimentation and the consequent lack of interest in the actual contact relations of the formations.

The recognition of these breaks has made it possible to separate some of the previously recognized units into two formations and has necessitated a general redefinition of the formation names. The "Bingen sand" of Veatch, partly as the result of work done by Stephenson and Miser[4] has been divided into two formations of widely separated age, to which the name Woodbine formation and Tokio formation are here applied. The overlying Brownstown marl of Veatch has also been divided into two formations, to the lower of which the name Brownstown marl is here restricted and to the upper the name Ozan formation is applied. A glauconitic sand bed at the base of the Ozan formation has been separated and named Buckrange sand lentil. The term Marlbrook marl has been restricted to the lower part of the formation as previously defined, and the Saratoga chalk, formerly regarded as a member of the Marlbrook, has been elevated to formation rank, with the recognition of an important break at its base. The complexities of the Nacatoch sand have been accentuated by careful examination of the outcrop, and a three-fold lithologic division has been recognized over part of the area, including in the lower part clays and sandy clays that were formerly considered a part of the Marlbrook formation. Outcrops of the recently recognized Cretaceous-Eocene contact have been discovered, and the Midway formation is now known to crop out in a belt extending across the southern part of the area.

From the data collected by the writer and from that pre-

[4] Ross, C. S., Miser, H. D., and Stephenson, L. W., Water-laid volcanic rocks of early Upper Cretaceous age in southwestern Arkansas, southeastern Oklahoma and northeastern Texas.—U. S. Geol. Survey Prof. Paper 154 (in press).

viously assembled by others it is now possible to give a fairly complete and accurate picture of the character of the Cretaceous formations exposed in southwestern Arkansas, of their mutual stratigraphic relations, and of their areal distribution.

Despite the considerable advance in knowledge that has been made, it should not be supposed that the work done is final. More detailed study will doubtless bring to light new problems, and the present report should be regarded only as one step forward in the advance toward the ultimate solution of the geologic history of Cretaceous sedimentation in even this rather narrow area.

FIELD WORK

During the first two weeks of October, 1925, some of the stratigraphic relations were studied in a general reconnaissance by Dr. L. W. Stephenson and the writer. H. D. Miser was also a member of the party for a few days. During the remainder of the fall and winter of 1925 and in January, 1926, the writer, who was ably assisted by P. D. Torrey, studied the stratigraphic relations and made a geologic map, which is as accurate as it could be made with the available base maps. In April, 1926, the writer and L. W. Stephenson spent two weeks in revisiting certain critical areas both in southwestern Arkansas and northeastern Texas.

The resulting geologic map varies in accuracy with the type of base available. For Hempstead and Howard counties the soil maps prepared by the U. S. Department of Agriculture were accurate and reliable. The northwest corner of the Gurdon topographic sheet of the U. S. Geological Survey was used for such of the area as it covered, although because of its large contour interval (50 feet) it was useful principally for the drainage and culture. County ownership maps, based largely on old Land Office surveys, were used for the remainder of the area. The sketched position of most of the contacts in areas covered by these county ownership maps is only approximately accurate. North of latitude 34° and west of longitude 93° 30′ the geologic mapping of H. D. Miser on the De Queen and Caddo Gap topographic sheets of the U. S. Geological Survey was used.

A few outcrops along river banks in the middle of alluvial flood plains have not been indicated on the map, although some are described in the text. The terrace sands have been shown on the map in order to indicate the practically complete concealment of the underlying Cretaceous formations. Large areas of surficial sand derived from eroded terraces have been shown as terrace sand, although they no longer have the terrace form.

ACKNOWLEDGMENTS

The writer wishes to express his indebtedness to Dr. L. W. Stephenson, Chief of the Section of Coastal Plain Investigations of the U. S. Geological Survey, for general guidance at the beginning of the work, for constructive criticism during its progress in the field, and for generous assistance in the preparation of the report. The fossils collected by the writer and others have been identified by Dr. Stephenson, and the plates showing fossils, which accompany the report, were prepared by him with the assistance of the writer. Thanks are due Dr. T. W. Stanton for the use of his material in preparing the plate of Trinity fossils. Acknowledgments are also due to H. D. Miser, chief of the Section of Geology of Fuels of the U. S. Geological Survey, for his co-operation in the field and for advice in the office. Dr. W. T. Thom, Jr., also of the Geological Survey, has at all times given thoughtful criticism and advice.

For the well records tabulated in the appendix the writer is indebted to many commercial geologists in Shreveport, La., but particularly to Messrs. L. P. Teas, of the Humble Oil & Refining Company, C. C. Clarke, of the Roxana Petroleum corporation, and J. P. D. Hull, formerly of the Louisiana Oil & Refining Corporation. These geologists and many others in the employment of the oil companies have given generously their personal knowledge of the geology of the area.

GEOGRAPHY

LOCATION, RELIEF, AND DRAINAGE

The Cretaceous formations crop out in southwestern Arkansas in parts of Little River, Sevier, Howard, Hempstead, Pike, Clark, and Nevada counties (see Pl. I, in pocket). The area of outcrop is a dissected upland, which forms part of the inner belt of the Gulf Coastal Plain and borders the Ouachita Mountains to the north. Its geographic position is shown in Figure 1. According to H. D. Miser,[5] the

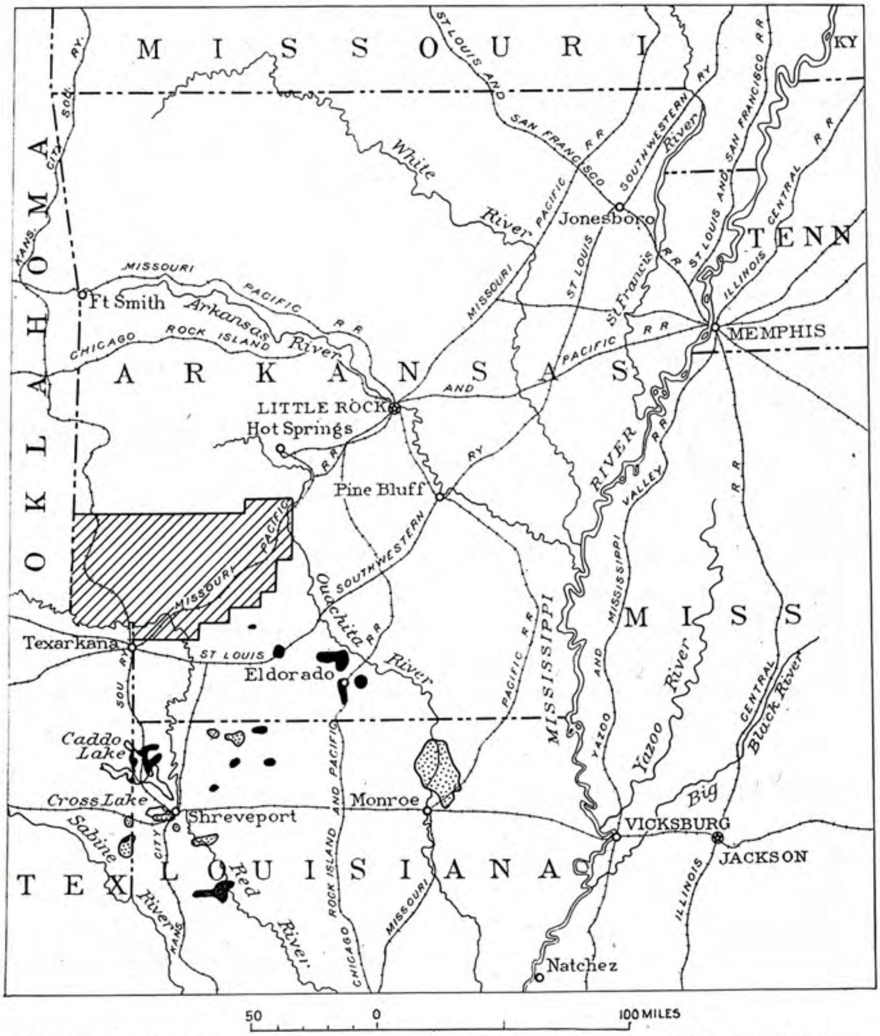

FIGURE 1.—Sketch map showing location of area represented on Plate I and of the principal oil and gas fields in northern Louisiana and southern Arkansas.

part of the Ouachita Mountain region adjoining the Coastal Plain is a dissected piedmont plateau fifteen miles wide. This

[5] Miser, H. D., and Purdue, A. H., Gravel deposits of the De Queen and Caddo Gap quadrangles, Arkansas: U. S. Geol. Survey Bull. 690, p. 16, 1919.

plateau, which is lowest on its southern border, ranges in height above sea level from about 750 to 1,100 feet, and the valleys of the larger streams that trench it are about 350 feet deep.

The inner belt of the Coastal Plain extends outward from this dissected plateau as a gently undulating surface of low relief, with irregular hilly interstream areas, most of them between 400 and 600 feet in elevation, and broad, shallow valleys having wide alluvial bottoms and broad terraces. The gentle southward slope of the surface is interrupted by several persistent ridges, trending north of east, which follow outcropping belts of the more resistant formations. These ridges are not continuous, but are interrupted by the wide bottoms of the principal streams, which drain the area in a general southerly and southeasterly direction. Little River rises in the Ouachita Mountains, to the northwest, in Oklahoma, enters the area about 22 miles north of its southwest corner, and flows southeastward, receiving successively as tributaries the southward-flowing Rolling Fork, Cossatot River, and Saline River. It joins the Red River near Fulton. Little Missouri River, which is farther east, rises in the mountain province to the north and flows southeastward, receiving one rather large southward-flowing tributary, Antoine Creek, and empties into the Ouachita River southeast of the area here described. Terre Noire Creek, a few miles east of Antoine Creek, roughly parallels the Little Missouri River and joins it a few miles above its junction with the Ouachita River. The Ouachita River rises farther north, in the Ouachita Mountains, and flows a little east of south across the northeast corner of the area. Red River forms the boundary between Oklahoma and Texas, and for more than 20 miles the boundary between Arkansas and Texas. Then it flows eastward into Arkansas for about 12 miles and, after receiving the flow of Little River, turns southeastward and southward through Arkansas into Louisiana, eventually receiving the flow of the Ouachita and joining the Mississippi. Red River differs from the other streams mentioned in that its headwaters are far to the west, and the local rains which may fill the other large streams with flood waters may not cause a corresponding rise in Red River, but it may reach flood stage by heavy precipitation in its upper drainage area, although there may be no local rain.

The streams that flow in winding, steep-sided but mature valleys through the hard rocks of the mountain province run out into broad, shallow valleys having wide alluvial bottoms at the points where they cross the contact of the hard rocks with the soft, easily eroded Cretaceous formations. At the same points their gradient and velocity are considerably lessened and they become more heavily charged with sediment. The smaller streams that flow out of the mountain province into the coastal plain show a similar change in character.

The alluvial "first bottoms" of the streams include the areas that are subject to overflow at periods of highest flood. They are nearly flat, or they slope slightly downward away from the streams. Some of these bottoms are poorly drained and swampy; others are well drained because of the natural levees they have formed in intervals between flood stages of the rivers. The bottoms of the larger streams range in width from 1 to 6 miles. Over these wide bottoms the streams meander in irregular courses, forming here and there cutoffs and oxbow lakes, which are largest and most numerous in the bottoms of Little River and Red River. Where a river has built up a natural levee the tributary streams and bayous may flow parallel to it for miles along the lowest level of the river bottom. The Cossatot and Saline Rivers, in part of their courses, have a double channel, each carrying some of the flow, although the two channels are separated by a half-mile to a mile of bottom land.

A summation of a table of percentage of soil types given in a report on a soil survey of Hempstead County[6] shows that 23.5 per cent of the total area of the county is subject to overflow by flood water. This county is altogether in the Coastal Plain province. A similar summation for Howard County[7] shows 14.8 per cent of alluvial first bottom land. About one-third of Howard County lies within the mountain province.

At small and varying elevations above the alluvial flats there are extensive level second bottoms or terraces along

[6] Taylor, A. E., and Cobb, W. B., Soil survey of Hempstead County, Arkansas: U. S. Dept. Agriculture Bureau of Soils, Advance Sheets, Field Operations of the Bureau of Soils, p. 18, 1917.

[7] Beck, M. W., Longacre, M. Y., Hayes, F. A., and Carter, W. T., Sr., Soil survey of Howard County, Arkansas: U. S. Dept. Agriculture Bureau of Soils, Advance Sheets Field Operations of the Bureau of Soils, p. 16, 1919.

the principal streams, which, however, aggregate considerably less in area than the first bottoms. There are still higher terrace levels, and the tops of the highest divides may be flat gravel-strewn surfaces, old terrace levels not yet dissected by the present drainage system.

The wide bottoms of the principal rivers form effective geographic barriers and partly isolate the interstream areas, particularly in rainy weather.

The highest elevations within the area of the Cretaceous outcrop are found along its north edge, where outliers of the Cretaceous formations occur as high as 800 feet above sea level. Ten or 15 miles south of this the highest ridges of Cretaceous rock reach elevations of nearly 700 feet. Toward the southern edge of the Cretaceous outcrop its highest elevations are about 500 feet. The larger streams flow in valleys cut 200 to 300 feet below the average upland surface. The lowest elevations are on the stream bottom land along the southern edge of the Cretaceous outcrop. Typical figures[8] are 163 feet at the zero of the United States Engineer's gage of the Ouachita River at the Missouri Pacific Railroad bridge near Arkadelphia, 165 feet on the Terre Noire bottom at the Missouri Pacific Railroad crossing, 198 feet at the Little Missouri River bottom at the Missouri Pacific Railroad bridge, and 224 feet at the zero of the United States Engineer's gage at Fulton, on the Red River.

The steepest slopes are found along the bluffs of the large streams, which, while flowing either on their present or on older bottoms, have cut to the edges of their valleys and then back into the upland. Some such bluffs, well over a hundred feet high, border the rivers for several miles.

VEGETATION

Originally nearly all the area was covered by forest or heavy undergrowth. There were a few small prairies, most of them on gravelly terrace land. A large proportion of the area has now been cleared for cultivation, but extensive tracts of timber land still remain in the sandy hill land and the poorly drained first bottoms. The upland forest includes

[8] These elevations are taken from Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, 1906.

principally short-leaf pine, several species of oak and gum, hickory, elm, ash, walnut, and dogwood. The more calcareous soils support chiefly a scattered growth of bois d'arc. In the bottom lands cypress, willow, cedar, and cottonwood are common in addition to the upland forest types.

CULTURE

The area is mostly agricultural land and contains few large towns. The principal crops are cotton and corn, but hay, oats, cowpeas, and other forage crops, vegetables, and fruits are also cultivated. The stock raised is insufficient to supply the local demand.

The area is well supplied with means of transportation. The Missouri Pacific main line from St. Louis to points in Texas runs southwestward across its southeastern part, and the main line of the Kansas City Southern Railroad from Kansas City to Port Arthur, Texas, runs southward across its western part. There are numerous branch lines, so that few points in the area are more than 10 miles from a railroad. The public road system is extensive and the roads are kept in fair condition, although in wet weather many of them are impassable for short periods. Gravelled highways connect most of the more important points and are being extended.

The largest town in the area is Hope, in Hempstead County, which, according to the Census of 1920, had a population of 4,790. This town is a railroad center and a shipping point on the Missouri Pacific Railroad. De Queen, in Sevier County; Ashdown, in Little River County; Nashville, in Howard County; Prescott, in Nevada County; and Arkadelphia, in Clark County, are places that had over 2,000 inhabitants each at the time of the census of 1920. The location of the towns was evidently controlled by the geology. No town having a population of more than 1,000 is on the outcrop of the Cretaceous chalks or marls, which have an irregular surface and afford poor natural roads.

GENERAL GEOLOGY

The Cretaceous formations of southwestern Arkansas consist largely of unconsolidated sand, clay, and marl but include some beds of limestone, sandstone, and chalk. They rest on the truncated edges of the intensely folded and faulted Paleozoic rocks, which crop out in the Ouachita Mountains, to the north. The pre-Cretaceous erosion surface dips south and southeast at low angles and forms the basement upon which later deposits were laid down. The overlying Cretaceous rocks also dip south and southeast at low angles and are thus successively younger coastward, eventually dipping beneath the overlying Eocene beds (see Pl. II, in pocket).

The thick Paleozoic sediments that crop out to the north were folded and faulted during the later part of the Pennsylvanian epoch and elevated into a high mountain range extending east and west. This deformation was nearly contemporaneous with that of the Appalachian system, of which the Ouachita Mountains are believed by some to be a southwestward extension. Throughout the early part of the Mesozoic era, including the Triassic and Jurassic periods, the Ouachita region doubtless underwent continuous erosion. Although no detailed record of the events of these periods has been preserved, it is clear that at the conclusion of the Jurassic period the high land had been worn down to a land surface that stood only a little above sea level. The subsequent Comanche epoch was initiated by crustal warping, which gradually tilted this nearly level surface to the south and at the same time depressed it so much that it was covered by the sea, in which sedimentation was resumed.

The present inclination of this floor as it is exposed along the northern strip of the outcrop, where outliers of the partly removed Comanche formations rest upon its southward-sloping surface, ranges, as stated by H. D. Miser,[9] from 60 to 100 feet to the mile, but averages about 80 feet to the mile. The inclination increases slightly toward the south. A well at Nashville, 15 miles south of the north edge of the Coastal Plain, reached the Paleozoic rocks at a depth of about 1,250 feet, indicating a dip of about 100 feet to the mile.[10] The McAlpine well of the Arkansas Natural Gas Company, near Gurdon, in Clark County, which was 2,950 feet deep, probably went into the Paleozoic rocks, but at what depth is not definitely known.[11] Deep wells drilled at points south of these places failed to reach the Paleozoic basement, so that

[9] Miser, H. D., and Purdue, A. H., Asphalt deposits and oil conditions in southwestern Arkansas: U. S. Geol. Survey Bull. 691, p. 275, 1918.
[10] Miser, H. D., op. cit.
[11] Teas, L. P., personal communication.

for these points only minimum estimates of the dip can be given. The Tarver Swofford No. 1 well, in Sec. 14, T. 11 S., R. 25 W., about 15 miles southeast of the Nashville well, was drilled to a depth of 2,988 feet and did not reach the Paleozoic rocks, a fact indicating a dip of the floor of more than 110 feet to the mile between the two wells, in a direction at a considerable angle with the regional dip. A well at White Cliffs, 2,635 feet deep, did not pass completely through the Cretaceous rocks; nor did a well near Fulton, 3,025 feet deep. Toner No. 1 well of Robinson and Spofford, in Sec. 29, T. 12 S., R. 23 W., in Hempstead County, did not reach the Paleozoic rocks at 2,900 feet, nor did a well drilled by Herman L. Grote in Sec. 2, T. 13 S., R. 31 W., in Little River County, to a depth of 3,406 feet.

The top of the basement rocks exposed at the northern edge of the Cretaceous area in Arkansas shows minor irregularities, but has generally a smooth surface, and presumably the same smooth surface exists at depths beyond observation. In Oklahoma there are larger irregularities, and hills of Jackfork sandstone (Mississippian) 250 feet in height are completely surrounded by basal Cretaceous Trinity sand, in which large talus blocks are embedded.[12]

Upon this subsiding floor of folded and truncated older rocks there were deposited, during the Cretaceous period, a thick series of sediments, largely of marine origin. The shifting of the shore line due to the regression and transgression of the sea, and probably changes in the rate of erosion of the exposed land area to the north, diversified the resulting sediments into separable lithologic units called formations. The formations of Cretaceous age have been long divided into two series, which are separated by an unconformity representing a considerable interval of time.[13]

The relations of the outcrops and the thickness and general character of the formations now recognized in the area are summarized in the accompanying table, and a diagrammatic representation of their stratigraphic relations is given in Plate III.

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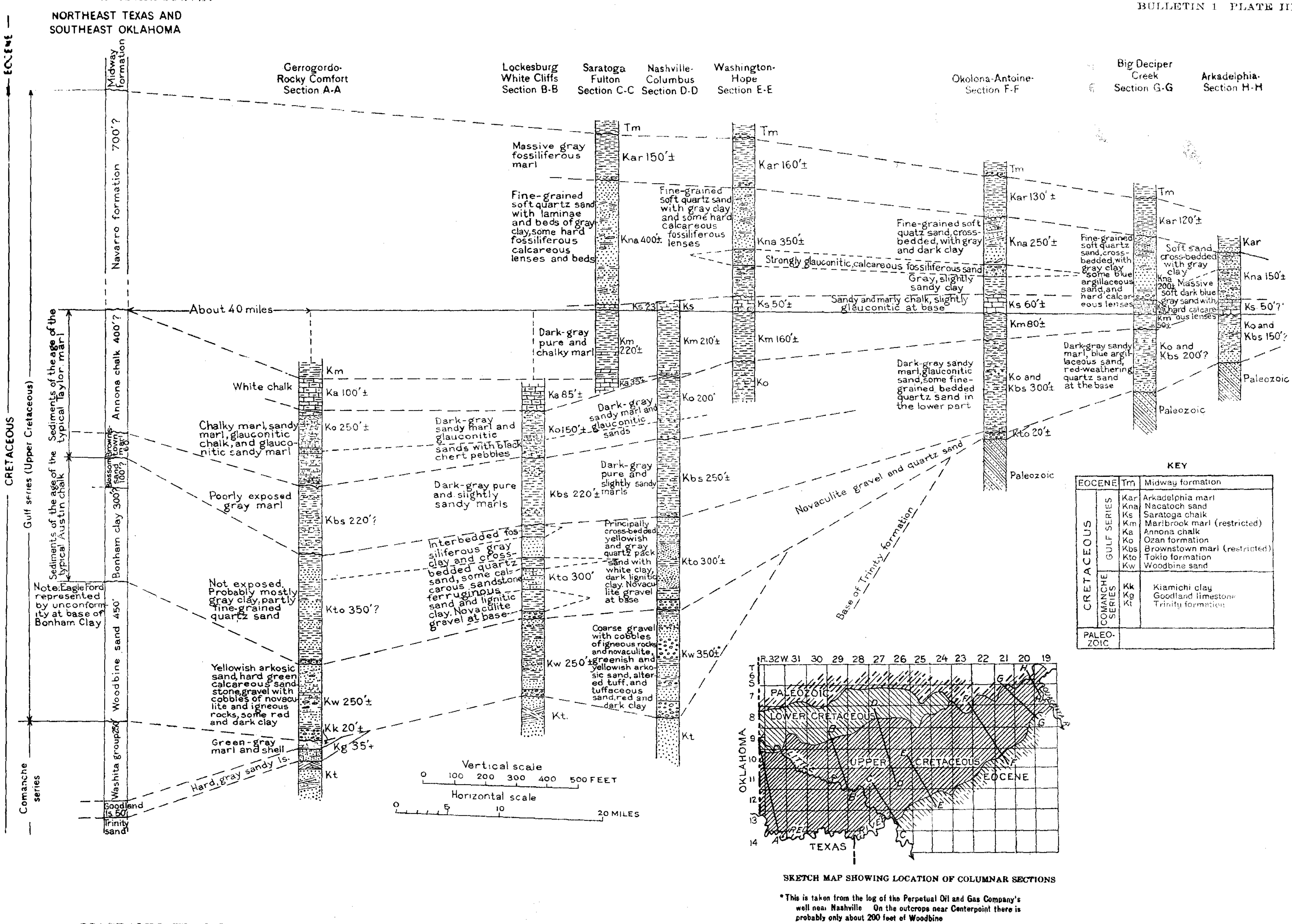
[12] Honess, C. W., Geology of southern Ouachita Countains of Oklahoma: Oklahoma Geological Survey Bull. 32, pp. 204, 264, 1913.

[13] Hill, R. T., The topography and geology of the Cross Timbers and surrounding regions in northern Texas: Am. Jour. Sci., 3d ser., vol. 33, No. 196, p. 298, 1887.



DIAGRAMMATIC REPRESENTATION OF THE STRATIGRAPHIC RELATIONS OF THE UPPER CRETACEOUS FORMATIONS OF SOUTHWESTERN ARKANSAS

CRETACEOUS SYSTEM

COMANCHE SERIES (LOWER CRETACEOUS)

GENERAL CHARACTER

The Comanche series consists of beds of sand, clay, marl, and limestone having an estimated thickness in northeastern Texas of 800 to 1,000 feet.[14] The series has been subdivided in Texas, on lithologic and paleontologic grounds, into three groups, named in ascending order, Trinity, Fredericksburg, and Washita.[15] Representatives of each of these groups crop out within the Cretaceous area in Arkansas.

Recently an attempt has been made to show that the lower part of the Gulf series should be classified with the Comanche rather than with the Gulf series and that the unconformity or "disconformity" between the Washita and the Gulf series is only local.[16] Stephenson,[17] in 1918, expressed the view that the Comanche constituted a closely related lithologic and paleontologic unit, and the subsequent work of Miser, Stephenson, and others[18] has emphasized the importance of the unconformity between the Comanche and the overlying Gulf series as the plane of separation of two major stratigraphic divisions.

TRINITY FORMATION

The Trinity formation is the basal division of the Cretaceous sediments in Arkansas as well as in Oklahoma and Texas. The Trinity deposits in Arkansas are described in detail in a report by H. D. Miser[19] now in preparation, and shorter descriptions of it have been given in other papers.[20] The deposits consist of beds of gravel, sand, limestone, and red or variegated clay, which attain a thickness of perhaps

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[14] Stephenson, L. W., A contribution to the geology of northeastern Texas and southern Oklahoma: U. S. Geol. Survey Prof. Paper 120, p. 134, 1918.

[15] Originally thus grouped by Hill, R. T., The topography and geology of the Cross Timbers and surrounding regions in northern Texas; Am. Jour. Sci., 3d ser., vol. 33, p. 298, 1887. The Trinity formation, called "Dinosaur sand" in the previous citation, was defined by Hill in Science, Jan. 13, 1888.

[16] Scott, Gayle, The Woodbine sand of Texas interpreted as a regressive phenomenon: Am. Assoc. Petrol. Geol. Bull., vol. 10, No. 6, pp. 613-624, 1926.

[17] Stephenson, L. W., A contribution to the geology of northeastern Texas and southern Oklahoma: U. S. Geol. Survey Prof. Paper 120, p. 134, 1918.

[18] Stephenson, L. W., Notes on the stratigraphy of the Upper Cretaceous formations of Texas and Arkansas: Am. Assoc. Petrol. Geol. Bull., vol. 11, No. 1, pp. 2-5, 1927.

[19] Miser, H. D., and Purdue, A. H., Geology of the De Queen and Caddo Gap quadrangles of Ark.-Okla.: U. S. Geol. Survey Bull. 808 (in press).

[20] Miser, H. D., and Purdue, A. H., Gravel deposits of the De Queen and Caddo Gap quadrangles: U. S. Geol. Survey Bull. 690, 1919. Miser, H. D., and Purdue, A. H., Asphalt deposits and oil conditions in southwestern Arkansas: U. S. Geol. Survey Bull. 691, 1918.

PLATE IV

(Figures natural size unless otherwise marked)

FIGURES 1-5. *Ostrea franklini* Coquand.

1. From the Dierks limestone lentil 1.5 miles northeast of Murfreesboro, Pike County.

2-4. From the Dierks limestone lentil at Wolf Creek postoffice, 2.5 miles northwest of Delight, Pike County.

5. From the Dierks limestone lentil near the old Muddy Creek postoffice, Pike (?) County.

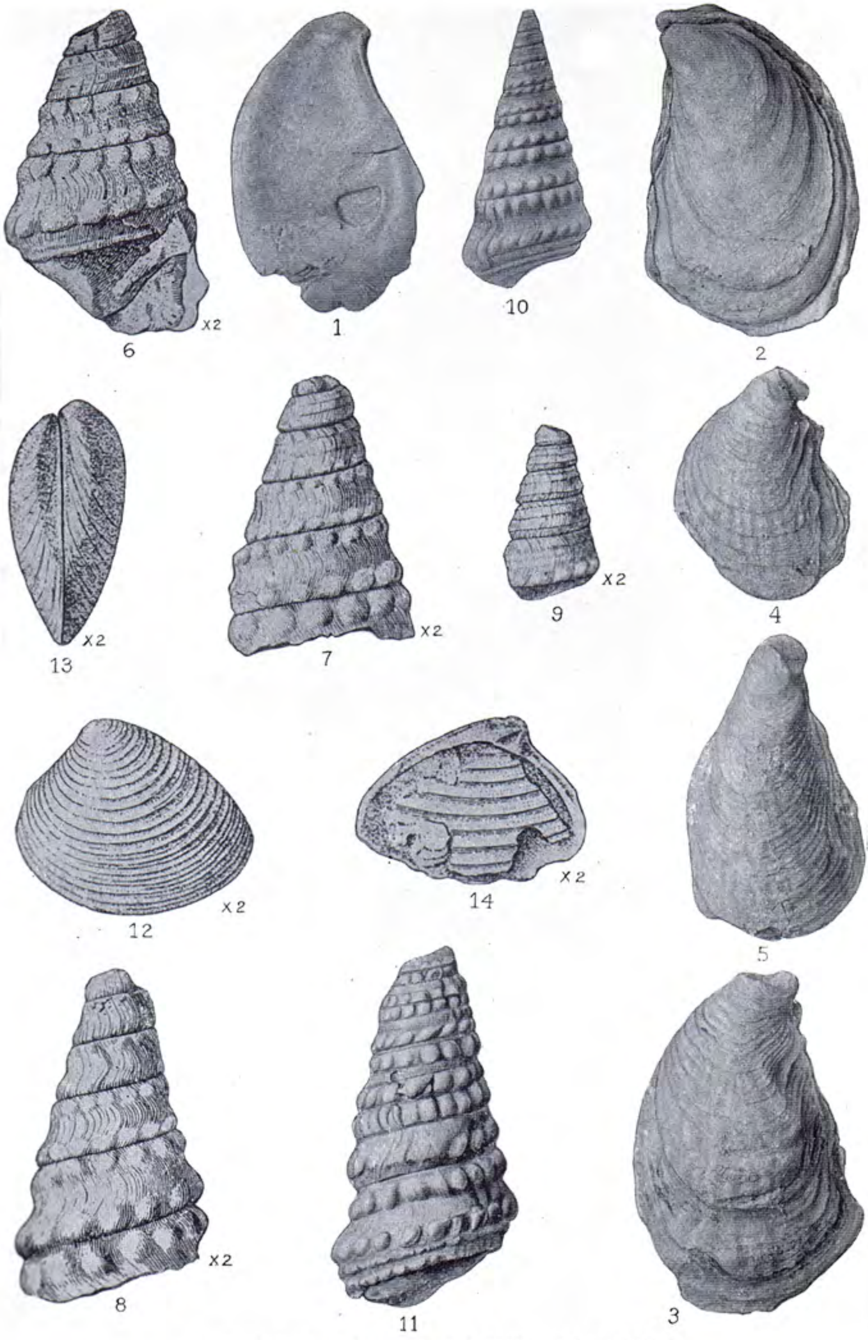
6-9. *Glauconia branneri* (Hill). Reproduced from R. T. Hill's "Paleontology of the Cretaceous formations of Texas; The invertebrate paleontology of the Trinity division": Proc. Biol. Soc. Washington, vol. 8, pp. 34-36, Pl. 5, figs. 1-4, 1893. These specimens are from the De Queen limestone member at Plaster or Gypsum Bluff, on Little Missouri River 3 miles northeast of Tokio, Pike County.

10, 11. *Glauconia branneri* (Hill).

10. From the Glen Rose limestone on the right bank of Paluxy River 2.5 miles above Glen Rose, in Sommervell County, Texas.

11. From the Glen Rose limestone 18 miles southwest of Decatur, Wise County, Texas.

12-14. *Eriphyla* (?) *pikensis* Hill. Reproduced from R. T. Hill's "Paleontology of the Cretaceous formations of Texas; The invertebrate paleontology of the Trinity division": Proc. Biol. Soc. Washington, vol. 8, p. 28, Pl. 4, figs. 4-6, 1893. These specimens are from one of the limestone members in Pike County; exact locality not stated.



FOSSILS FROM THE TRINITY FORMATION

1,000 feet along the Arkansas-Oklahoma line but are cut out entirely further east, along the outcrop. The gravel occurs in two beds, which in places attain a thickness of 100 feet each. The Pike gravel member, at the base of the formation, is exposed in an almost continuous though irregular belt extending from the east end of the outcrop to the western part of the state, where it apparently thins out. The higher gravel bed, the Ultima Thule gravel lentil, is exposed in an irregular belt extending from the Cossatot River westward into Oklahoma, where it apparently rests on the Paleozoic rocks. Between these two gravels, in addition to variegated clay and fine quartz sand, is the Dierks limestone lentil, which in thickness ranges from a feather edge to 40 feet, and extends from a point about 2 miles north of Delight westward to Cossatot River, where it thins out. This lentil lies 50 to 200 feet above the base of the formation. An upper limestone, the De Queen limestone member, is found near the middle of the formation in Arkansas. It ranges in thickness from a feather edge to 72 feet and extends from Plaster Bluff, on the Little Missouri River near Murfreesboro, westward into Oklahoma. Along the outcrop it contains lenticular masses of celestite and thin beds of gypsum, which thicken and become massive beds of anhydrite farther south under cover. Both limestone members contain interbedded gray and green-gray fossiliferous marls and beds containing abundant fossil oysters. The upper part of the Trinity along the outcrop is mostly fine-grained, uncemented but packed quartz sand, weathering red and distinctly cross-bedded. It contains also variegated gray and red sandy clays. South of the outcrop the formation thickens. A well drilled in Sec. 15, T. 13 S., R. 29 W., in Little River County, shows a thickness of probably more than 2,500 feet of Trinity. The lower part of the Trinity, under cover, consists largely of hard brick-red and mauve sandstone. Some typical fossils found in the limestone members of the Trinity formation are shown in Plate IV.

FREDERICKSBURG GROUP—GOODLAND LIMESTONE

The only representative of the Fredericksburg group exposed in Arkansas is the Goodland limestone, which crops out north of the village of Cerro Gordo and extends for a mile and a half east of it, along the "breaks" of Little River.

A little over half a mile north of Cerro Gordo, along the Arkansas-Oklahoma State-line road, the Goodland outcrops below the Kiamichi clay on the road near the edge of the alluvial bottom of Little River, where it consists of 10 feet of bedded, hard, light gray sandy limestone in beds 6 to 16 inches thick, showing a finely crystalline fracture. The limestone contains rather numerous fossils, which are poorly preserved as coarsely crystalline calcite casts. Some parts of the Goodland are thinner bedded, yellowish gray, calcareous sandstone. In the south-central part of Sec. 1, T. 10 S., R. 33 W,. about half a mile northeast of Cerro Gordo, the Goodland makes a low cliff along a small stream at the edge of the bottom land. As much as 35 feet of it is exposed below the Kiamichi clay. Here it is a thick-bedded gray, sandy limestone containing some beds of hard, yellow-gray calcareous sandstone. At some horizons the Goodland beds are notably lenticular; lentils of limestone 6 feet long and a foot thick, of varying degrees of sandiness, stand at small angles with the normal bedding. The upper 8 feet of the formation is usually concealed, but where it is exposed it consists of a less sandy limestone. At its top is a ledge, only a foot thick, of hard, white limestone, which weathers into cavernous slabs.

Four miles down Little River from Cerro Gordo, in Sec. 4, on the south bank of the river, Hill [21] noted a short bluff composed of "rapidly corroding chalky lime rock," which he correlated with the lower part of the Fredericksburg group. This is almost certainly the eastermost exposure of the Goodland, for it is not found east of Little River. The total thickness of the Goodland in this area cannot be determined, for its basal contact with the Trinity is not exposed, but it is probably not more than 50 feet.

WASHITA GROUP—KIAMICHI CLAY

Above the Goodland limestone in the vicinity of Cerro Gordo there are outcrops of marls and shell beds that Hill,[22] in the report on his reconnaissance survey, refers to the Washita group. The extent of the outcrop and the reported thickness of over 250 feet, given by Hill in his original report

[21] Hill, R. T., The Neozoic geology of southwestern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1888, vol. 2, p. 112, 1888.

[22] Hill, R. T., idem, p. 111.

and later cited by Veatch,[23] are, however, erroneous. The beds of Washita age in Arkansas include only about 20 feet of marl and shell beds, which contain almost exclusively fossils identified by T. W. Stanton as *Gryphaea navia* Hall, a species characteristic of the Kiamichi clay, the lowest formation of the Washita group in southern Oklahoma and northeastern Texas.

A few feet of the Kiamichi crop out above the Goodland limestone half a mile north of Cerro Gordo, along the State-line road. Hard beds, a foot thick, of closely packed gryphaeas set in a scant matrix of dense, hard, gray-green marl alternate with poorly exposed softer gray and green marls. Above the Goodland in the south-central part of Sec. 1, T. 10 S., R. 33 W., half a mile northeast of Cerro Gordo, the full thickness of the Kiamichi is exposed, though poorly. At this place blue-gray and green-gray marls alternate with discontinuous beds and lenses of gray fossiliferous limestone. The Kiamichi is not exposed east of Little River.

GULF SERIES (UPPER CRETACEOUS)

WOODBINE FORMATION

HISTORICAL SUMMARY

The basal formations of the Gulf series in Arkansas consist of a mixture of gravel, sand, and bedded clay of nearshore marine origin for the most part, though probably containing some alluvial deposits as well. These beds have long presented puzzling problems of interpretation and correlation. Strikingly unlike the overlying and underlying Cretaceous marls and superficially similar to the sandy deposits of the Tertiary period, they were originally regarded by Hill[24] as an outlier of the lower Eocene beds and were called by him the "Bingen sands." Later Veatch[25] recognized the fact that these beds are of Cretaceous age, but retained the name "Bingen sand," which he described as "white or brown sands and clays containing some greensand and considerable lignite or lignitiferous matter." Basing his conclusions

[23] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 21, 1906.

[24] Hill, R. T., The Neozoic geology of southwestern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1888, Vol. 2, pp. 56-58, 1888. Geology of parts of Texas, Indian Territory and Arkansas adjacent to the Red River: Geol. Soc. America Bull., Vol. 5, p. 309 and pl. 12, 1893. Geology of the Black and Grand Prairies, Texas: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 7, p. 195, fig. 21, 1901.

[25] Veatch, A. C., Geology and underground water of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 23-24, 1906.

mainly on well records, Veatch decided that the deposit, "while the lithological counterpart of the Woodbine, is apparently the time equivalent of all the beds of the Upper[26] Cretaceous below the Brownstown and Taylor formations," thus regarding the "Bingen sand" as including sandy near-shore representatives of the "Woodbine, the Eagle Ford, and the sub-Clarksville sand" (Blossom sand). In 1919 H. D. Miser and A. H. Purdue[27] recognized the composite nature of the beds included in the "Bingen sand," which they more correctly termed the "Bingen formation," separating 100 to 150 feet of quartz sand in its upper part as the Tokio sand member, which in areas farther east overlapped the lower part of the formation. This lower part was shown to contain sands and gravels as well as numerous pebbles and cobbles of near-surface intrusives and lavas of unusual type, and deposits of volcanic ash and tuff were later found in it.[28] Soon thereafter L. W. Stephenson recognized similar deposits of volcanic material in the Woodbine sand of northeastern Texas, and reconnaissance work by Miser in southeastern Oklahoma showed the geographic continuity of the volcanic material in the two areas.

A detailed petrographic description of the unique sediments of these beds in Arkansas and Texas and a presentation of the regional evidence of their correlation with the Woodbine sand of Texas has recently been given in a report to be published by the U. S. Geological Survey.[29] In the present report the Woodbine of Arkansas is described briefly, with particular reference to outcrops west of the Saline River, in Arkansas, where the formation had not previously been examined in detail.

LITHOLOGY AND OUTCROPS

In southwestern Arkansas the Woodbine consists chiefly of gravel and cross-bedded sand, a large part of which is waterlaid volcanic material, and minor amounts of red, dark-gray, and brown clay. Much of the formation, particularly in the eastern part of the outcrop, consists of nearly pure vol-

[26] The original reads "lower," which is obviously erroneous.

[27] Miser, H. D., and Purdue, A. H., Gravel deposits of De Queen and Caddo Gap quadrangles: U. S. Geol. Survey Bull. 690, p. 24, 1919.

[28] Miser, H. D., and Ross, C. S., Volcanic rocks in the Upper Cretaceous of southwestern Arkansas and southeastern Oklahoma: Am. Jour. Sci., vol. 9, Feb., 1925.

[29] Ross, C. S., Miser, H. D., and Stephenson, L. W., Water-laid volcanic rocks of early Upper Cretaceous age in southeastern Oklahoma, southwestern Arkansas and northeastern Texas: U. S. Geol. Survey Prof. Paper 154 (in press).

canic material, which includes only a slight mixture of grains of quartz and of novaculite, and a large part of it is only slightly reworked volcanic tuff of several types. These beds are separated from the underlying Comanche series by a marked unconformity, in consequence of which they rest upon the Kiamichi clay along the Arkansas-Oklahoma line, whereas farther east, across Little River, they rest upon successively lower members of the Trinity formation.

At the base of the formation in Arkansas is a persistent bed of gravel of variable thickness, which gradually becomes thinner westward. Between the Little Missouri and Saline rivers it is usually between 30 and 50 feet thick, and it reaches its maximum thickness, which is a little more than 60 feet, about 3 miles southwest of Center Point.[30] West of the Saline River the gravel at the base of the Woodbine is much thinner, and in the vicinity of Lockesburg it is only about a foot thick. Where the lower part of the formation is exposed north of Horatio, in Sevier County, the basal gravel is not more than 2 or 3 feet thick. It changes rapidly upward to sand containing some pebbles. The gravel pits of the Kansas City Southern Railroad, half a mile west of Horatio, however, expose 25 feet of gravel which is very near the base of the formation, although the contact is not exposed (Pl. V, A). The material composing this gravel ranges in size from small grains to cobbles as much as 5 inches in diameter, the average diameter being about 2 inches. The pebbles are well rounded or subrounded, and most of them are novaculite, though some are quartzite and chert. A few pebbles of soft, light-buff and white, thoroughly kaolinized igneous rock are found at this place and elsewhere in the basal gravel. These are porphyritic, showing a dense groundmass and scattered phenocrysts of glassy clear orthoclase and less abundant phenocrysts of ferromagnesian minerals. The gravel is horizontally bedded in the mass, but shows a strongly developed low-angle cross bedding. The grains and pebbles are loosely bound by a soft, yellow ferruginous clay, the product of the deep weathering of finely divided volcanic material. Above the Kiamichi at Cerro Gordo, in Little River County, the basal gravel is not found.

The Woodbine formation above the basal gravel consists

[30] Miser, H. D., and Purdue, A. H., Gravel deposits of the De Queen and Caddo Gap quadrangles: U. S. Geol. Survey Bull. 690, p. 23, 1919.

typically of soft, cross-bedded sand, olive-yellow in even slightly weathered outcrops, in which grains of green volcanic rock, quartz, glassy or kaolinized feldspar, and biotite are embedded in a clay matrix. Variable amounts of novaculite, in grains and pebbles, are scattered through the sandy beds, and gravelly sand occurs in lenses and beds. The gravels and conglomerates in the upper part of the Woodbine in the vicinity of Nashville[31] have not been found in exposures west of that area.

The beds in fresh exposures are dark green or olive-green, but in weathered outcrops olive-brown and greenish brown are more frequently seen. Weathering eventually reduces the beds to crumbly but plastic bright-red clay, and most of the belt underlain by the formation has a red soil and subsoil derived from the surficially oxidized tuff-bearing sands. This red soil is particularly well shown in the broad belt of outcrop of low relief just west of the Saline River, in the district having the suggestive name of Red Colony.

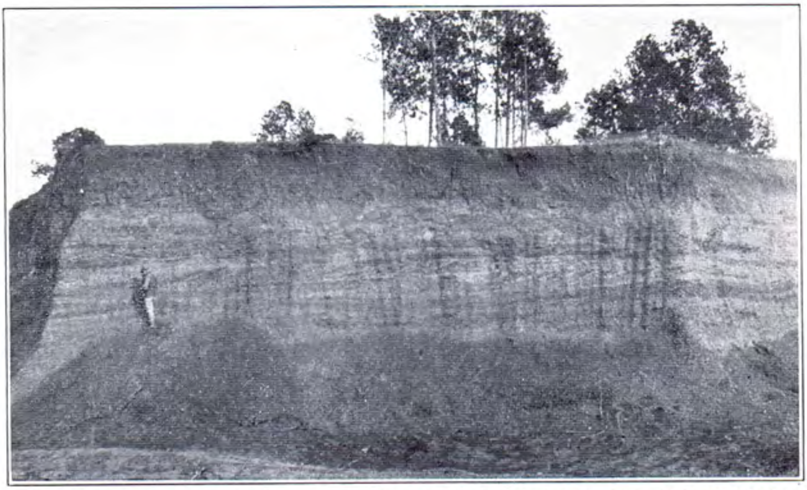
Throughout the formation there are irregular beds and lenses of hard, calcareous sandstone, in which the grains and pebbles are cemented by white crystalline calcite. The pebbles are commonly surrounded by thin shells of calcite, in the outer part of which grains of sand are embedded. The appearance of these calcite cemented lenses and their relation to the variable lithology of the sands in which they occur indicate that they were formed contemporaneously with the deposition of the sediments and are not subsequent concretionary additions. According to Ross[32] these lenses have preserved the most delicate microscopic tuff structure, whereas the tuff in the uncemented lenses was altered to bentonite soon after deposition.

The unconsolidated sand contains some pockets of massive red clay, which are evidently contemporaneous deposits of oxidized and thoroughly decomposed volcanic material. Pebbles of hard, red clay as much as 3 inches in diameter have also been found in the tuffaceous sand.

Beds of very dark, leaf-bearing clay have been found in

[31] Miser, H. D., and Ross, C. S., Volcanic rocks in the Upper Cretaceous of southwestern Arkansas and southeastern Oklahoma: Am. Jour. Sci., vol. 9, Feb., 1925.

[32] Ross, C. S., Miser, H. D., and Stephenson, L. W., Water-laid volcanic rocks of early Upper Cretaceous age in southwestern Arkansas, southeastern Oklahoma and northeastern Texas: U. S. Geol. Survey Prof. Paper 154 (in press).



A. CROSS-BEDDED BASAL GRAVEL OF THE WOODBINE FORMATION IN PIT OF THE KANSAS CITY SOUTHERN RAILROAD NEAR HORATIO, SEVIER COUNTY.

Photograph by P. D. Torrey

B. CROSS-BEDDED QUARTZ SAND OF THE TOKIO FORMATION IN ROAD CUT IN THE SE. 1/4 SEC. 22, T. 9 S., R. 26 W., JUST WEST OF DOYLE, HEMPSTEAD COUNTY.

Photograph by L. W. Stephenson

the Woodbine formation,[33] and the stratigraphic significance of the flora has been considered by Berry.[34]

Invertebrate fossils have not yet been reported from the Woodbine in Arkansas, although distinctive Woodbine species, such as *Ostrea soleniscus*, are found in similar beds in northeastern Texas.[35]

The contact at the base of the Woodbine has been observed at several places. Northeast of Cerro Gordo, in the NE¼ NW¼ Sec. 12, T. 10 S., R. 33 W., there is Kiamichi clay and limestone 8 feet thick, in the bed of a small gully that cuts "the Rock cave" in the cliff of Goodland limestone along the breaks of Little River. The uppermost limestone bed of the Kiamichi makes a small ledge in the bottom of the gully, and immediately above it coarse-grained tuffaceous Woodbine sand crops out. The contact was under water and not well exposed, but is certainly sharp and probably only slightly irregular.

East of Little River the Woodbine rests on an irregular surface cut in the Trinity formation. The contact is exposed in a cut on the Horatio-De Queen highway 1.6 miles north of Horatio, where gravelly Woodbine sand rests on red-brown sandy Trinity clay. About a mile and a half farther north along this road, toward De Queen, the contact is again exposed. Here the gravelly Woodbine sand rests on an irregular surface of soft, red, massive Trinity sand.

The best exposures of the Woodbine-Trinity contact are found east of the Cossatot River. Two miles south of Lockesburg, on the east side of the road to Ben Lomond, on the south side of the bottom of a small creek, the tuffaceous Woodbine sand rests on broken and slickensided Trinity sand and clay. The relief of the erosion surface is 5 feet in a horizontal distance of 15 feet, but in some places it is as much as 1 foot to 1 foot horizontally, and gravel concentrations are found at places where the slope is steepest. At the top of the Trinity is a thin zone of white clay containing small pebbles, black fragments of plants, and small, poor impressions of leaves.

[33] Miser, H. D., and Purdue, A. H., Gravel deposits of the De Queen and Caddo Gap quadrangles: U. S. Geol. Survey Bull. 690, p. 24, 1919.

[34] Berry, E. W., Contributions to the Mesozoic flora of the Atlantic Coastal Plain, XII, Arkansas: Torrey Bot. Club Bull. 44, pp. 167-190, 1917. Berry, E. W., Flora of the Woodbine at Arthurs Bluff, Texas: U. S. Geol. Survey Prof. Paper 192, pp. 157, 1922.

[35] Ross, C. S., Miser, H. D., and Stephenson, L. W., Water-laid volcanic rocks of early Upper Cretaceous age in southwestern Arkansas, southeastern Oklahoma, and northeastern Texas: U. S. Geol. Survey Prof. Paper 154 (in press).

The Woodbine is also exposed on the west side of the same road, where it rests on an irregular surface cut in gray clay. A quarter of a mile down the creek from this outcrop, in a small bluff on the south side of the creek bottom, the Woodbine rests on an irregular erosion surface cut in fine-grained, massive quartz sand. Below this sand the exposed Trinity is bedded blue clay containing irregular layers of soft, white, medium-grained sand, which includes broken pieces of black, carbonized wood, some as much as 2 feet long and 3 inches by 1 inch in cross section. There is a good outcrop of the contact six-tenths of a mile east of the center of Lockesburg, along the road to Center Point, where the gravelly sand, of the Woodbine rests on fine-grained red sand and red and light-green clay of the Trinity. The contact here is also very irregular, dropping 5 feet to the east in 50 feet horizontally with sharp breaks in places where the contact drops a foot vertically in a foot horizontally.

The westernmost outcrop of the Woodbine in Arkansas is the 8-foot exposure of tuffaceous sand above the Kiamichi northeast of Cerro Gordo, at the locality mentioned on page 17. This is a weathered crop and is olive-yellow in color. The material varies from very fine to medium coarse grained sand. The coarser material, when examined under a hand lens, shows a very large percentage of well-rounded pellets of soft, altered volcanic rock, the largest 5 mm. in diameter. On a freshly broken surface these pellets are gray, green, or reddish brown. The next most abundant constituent is clear orthoclase, whose crystal form is preserved, though most of the crystals are broken and are notably rounded by abrasion. Rounded grains of novaculite of various colors constitute less than 10 per cent of the rock. Minor constituents are small flakes of biotite and grains of a green ferromagnesian mineral. The rock is bound by a ferruginous clay but is crumbly and easily broken.

In Little River County the Woodbine formation is represented only by the exposure already described and a few small outcrops south of Cerro Gordo. It is mostly concealed by surficial sand, although the reddish gravelly soil in places suggests that the cover is not very thick. A short distance west of the State line, in Oklahoma, outcrops of the tuffaceous sands are again abundant, especially along the road from Cerro Gordo westward to Idabel, Okla.

The outcrop of the Woodbine at Morris Ferry, on Little River, was originally described by Hill[36] as composed of fine grains of greensand, calcite, and siliceous sand, but was assigned to no stratigraphic position. This outcrop extends 400 feet along the south bank of the river, beginning a thou sand feet west of the Kansas City Southern Railroad bridge across Little River and forming a ledge about 15 feet above the level of moderately high water. The principal part of the outcrop is a cross-bedded, hard, green, calcareous sandstone, in which the individual beds are a quarter to a half an inch thick. The rock is composed of medium to coarse grains of subrounded and subangular greenish-stained quartz and perfectly rounded pellets and grains of altered volcanic rock. Most of the grains are green, but a few are red and brown. The rock contains also scattered grains of pink quartz. In some irregular lenses the white crystalline calcite that cements the grains is so abundant that the beds weather like cavernous limestone. Veinlets of calcite an eighth of an inch to half an inch thick cut the rock. Interbedded with these hard sandstones are soft, dark-green beds in which almost 90 per cent of the grains are rounded pellets of green, soft, altered volcanic rock. Subrounded greenish-stained quartz grains comprise the rest. There are some pebbles of the green altered rock from an eighth of an inch to three-eighths of an inch in diameter, with smoothly rounded surfaces. In these softer layers there are broken pieces of black fossil wood, as much as a foot in length, which are now composed chiefly of clay and finely divided carbonaceous material. The calcareous cement in the harder beds was apparently added during or soon after deposition and is not of later concretionary introduction, for lenses of the hard calcareous sandstone rest on clay-pebble material and in one place directly on a large piece of wood.

At the outcrop mentioned on page 21, two miles south of Lockesburg, on the road to Ben Lomond, and at a place a short distance farther south, in the vicinity of Bellville, there are good exposures of somewhat weathered olive-yellow tuffaceous sand at the base of the Woodbine. The basal foot of

[36] Hill, R. T., The Neozoic geology of southwestern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1888, vol. 2, p. 87, 1888.

the formation contains abundant pebbles of novaculite, the largest 3 inches in diameter, set in the tuffaceous sand, and such pebbles are sparingly distributed through the lower 20 feet. Pebbles of soft, kaolinized porphyritic igneous rock as much as 3 inches in diameter, though usually smaller, are common. The sand consists mostly of small rounded pellets of altered volcanic rock, but includes also grains of quartz, crystals of orthoclase, and crystals and flakes of biotite. It contains also thin beds of white clay and, at some places, numerous rounded pebbles of hard, dark-red clay, the largest 3 inches in diameter.

By careful petrographic study of the volcanic material Ross[37] has differentiated two principal types of it, the most widespread containing a large proportion of small, rounded pellets of phonolite and accessory crystals of orthoclase and augite, some of them euhedral but most of them slightly rounded. Less widely distributed are pumiceous glassy tuffs, which contain, in addition to the pumice, abundant crystals of glassy orthoclase and minor amounts of euhedral biotite. Associated with them are lithic tuffs of equivalent chemical composition which consists of fragments of trachyte, and of euhedral and broken crystals of orthoclase. The volcanic materials have been at many places transported and redeposited by water, and the various types have been intermixed with one another and, in varying proportions, with quartz and novaculite sand.

The outcrops already described clearly belong to the group of phonolite tuffs and tuffaceous sands. Other good outcrops of this class occur 3 miles east of Horatio, on the road to Dilworth; southeast of Horatio; north of Horatio, along the road to De Queen; in the south half of Sec. 33, T. 9 S., R. 29 W., on the road from Milford School to Red Colony; and at several places along the road from Lockesburg to Rosedale. In general the proportion of quartz and novaculite sand increases westward from Howard County, and the abrasion shown by the volcanic constituents, such as phenocryst feldspar, is also greater to the west.

Tuffaceous sand of the trachyte type crops out 3 miles southwest of Centerpoint, on the road to Rosedale, a little

[37] Ross, C. S., Miser, H. D., and Stephenson, L. W., Water-laid volcanic rocks of early Upper Cretaceous age in southwestern Arkansas, southeastern Oklahoma, and northeastern Texas: U. S. Geol. Survey Prof. Paper (in press).

below the basal gravel bed of the Tokio formation. This outcrop is weathered, but the composition of the sand is readily discernible. Clear orthoclase in slightly water-worn crystals and angular grains is its most conspicuous constituent, comprising about one-third of it. Rounded white kaolinized grains are common; flakes of biotite are rare. The sand contains a small percentage of detrital quartz and novaculite. The grains are loosely bound by a red-brown altered clay matrix, which forms a large percentage of the total volume of the sand.

A weathered outcrop in the NE¼ SE¼ Sec. 23, T. 9 S., R. 19 W., a mile southwest of Rosedale, on the road to Lockesburg, may be of this type, although more than half of the bed consists of subrounded and rounded grains of novaculite and quartz. The rock contains orthoclase in crystalline form, some euhedral flakes of biotite, and here and there a few green rounded pellets of the phonolite type.

A well dug on the property of R. S. Gardner, in the middle of the SW¼ Sec. 30, T. 9 S., R. 28 W., near the bottom of Rock Creek, goes through 6 feet of stream gravel into the "red dirt," a very fine grained crumbly rock showing abundant angular white patches (probably kaolinized feldspar) and detrital quartz grains in a dark-red matrix. Near the bottom of the well is "blue dirt," a light green-gray, fine grained soft clay, consisting mostly of kaolinized material in small, white, angular grains, but containing a few small flakes of biotite. Ross, who examined this material microscopically, states that although it is much altered it showed evidence of affiliation with the trachytic type. The material from this well is the westernmost exposure of the trachytic type of tuff yet observed and is in the uppermost part of the Woodbine.

THICKNESS

The Woodbine is about 250 feet thick on its outcrop in Sevier County. Farther east, in Howard County, its thickness apparently increases to about 350 feet, as recorded in the log of the well of the Perpetual Oil and Gas Company, near Nashville, but on the outcrop farther north, in the vicinity of Centerpoint, it can be scarcely more than 200 feet thick. Toward the east it becomes thinner rather abruptly, and it does not crop out east of the Little Missouri River.

ORIGIN

The tuffaceous sands and gravels of the Woodbine are clearly waterlaid, a fact shown by the rounding of the pebbles and their assortment into lenses. They were in part deposited in shallow water in which there were strong currents, as is indicated by the cross-bedding of the tuffaceous sand and the presence of lenticular beds of gravel. The proximity of land is shown by the presence of beds of leaf-bearing clay and the occasional presence of carbonized wood in the tuffaceous sand. Some of the volcanic material in Texas carries fossils which show that it was deposited in marine or brackish water. No such fossils have yet been found in Arkansas, but the physical character of the beds shows conclusively that most of the formation there was also deposited in marine or brackish water. The general occurrence in it of calcite-cemented lenses, which were formed while the beds were being deposited or immediately afterward, indicates deposition in saline water. The marine character of the formation elsewhere and the persistent occurrence of a bed of gravel at its base points to marine transgression in this area, the cross-bedding of the basal gravel is in places of a type compatible with the hypothesis of off-shore deposition (Pl. V, A). The wide and uniform distribution of the volcanic material is in part indicative of marine deposition. In addition the occurrence in the formation of sedimentary glauconite, a marine deposit, has been noted by Ross.[38]

Parts of the Woodbine formation may be of subaerial origin. The pockets and beds of red clay it contains probably represent volcanic material, which was completely oxidized and decomposed during its deposition. The pebbles of red clay found in the formation may have been derived by erosion from beds of such clay. In places the unconformity at the base of the Woodbine suggests, by its irregularity and by the distribution of the material above the unconformity, that it was produced by subaerial channeling. The absence of beds of lignite or of any large amount of lignitiferous material militates somewhat against the view that there may have been alternations of marine and continental deposition, but perhaps the environment was unfavorable to an abun-

[38] Ross, C. S., Miser, H. D., and Stephenson, L. W., Water-laid volcanic rocks of early Upper Cretaceous age in southwestern Arkansas, southeastern Oklahoma, and northeastern Texas: U. S. Geol. Survey Prof. Paper 154 (in press).

dant shore flora during the volcanic epoch. The weight of the evidence favors the view that the formation was laid down in the sea or in a marine embayment, though possibly some of its materials, such as the red clay and the coarser lenticular gravel, were subaerial deposits.

The time value of the unconformity at the base of the Woodbine becomes increasingly greater from west to east. The later epochs of Washita time, which are represented in east Texas, are not represented at all on the outcrop in Arkansas, and toward the east progressively older rocks have been eliminated. The break between the Washita and the Woodbine—that is, between the Comanche series and the Gulf series—clearly involved a broad warping or tilting of the surface toward the west, so the subsequent transgression of the sea in Woodbine time bevelled the older formations diagonally and produced a slight angular unconformity, which is not visible in single outcrops but can be recognized by the successive eastward truncation of the formations.

PHYSIOGRAPHIC EXPRESSION

The hardness of the basal gravel of the Woodbine formation caused the development of one of the east-west ridges that form striking features of the topography of the area. These ridges, which stand a few hundred feet above the general level and are coextensive with the outcropping belts of the harder formations, were termed *wolds* [39] by Veatch, who first applied this term to similar topographic ridges on the coastal plain of New Jersey.[40] The older usage of the term *cuesta* by Hill,[41] as extended by Davis [42] to include the entire topographic form developed by the resistance of a gently dipping hard bed or formation, is now generally preferred. This form includes a broad, gentle slope, which coincides in direction with the dip of the hard bed or formation but has a lower inclination, and a more abrupt opposite slope or escarpment, which terminates the gentle dip slope at its higher points. The belt of sandy and gravelly hill land including the beds then comprised in the "Bingen sand" was

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

[40] Veatch, A. C., Underground water resources of Long Island, N. Y.; U. S. Geol. Survey Prof. Paper 44, p. 29, 1906.

[41] Hill, R. T., Description of topographic terms of Spanish America: Nat. Geog. Mag., vol. 7, p. 295, 1896.

[42] Davis, W. M., The drainage of cuestas: Geol. Assoc. London Proc., vol. 16, pp. 76-77, 1899.

called by Veatch[43] the Lockesburg wold, so named from the town of Lockesburg, in Sevier County, which, however, stands on the outcrop of the underlying Trinity formation and at a place where the northward-facing escarpment is poorly developed. The name Lockesburg cuesta has been used for this topographic feature by Ross, Miser, and Stephenson.[44] Actually it includes two cuestas, which are as conspicuous and as readily separable as the two formations once called the "Bingen sand" and which were developed upon the basal beds of these formations. Were it not for the fact that a single name has already been somewhat incorrectly applied to a composite feature, these two cuestas could be considered without the use of special names, but in order to eliminate the earlier name, which is now unsatisfactory, it is desirable to provide names for each of these topographic features. The northward-facing escarpment formed by the basal gravel of the Woodbine sand is particularly striking in the vicinity of Centerpoint, in Howard County, and accordingly the more northerly feature is here termed the Centerpoint cuesta. The escarpment follows the outcrop of the basal gravel of the Woodbine generally westward from a point in Sec. 22, T. 8 S., R. 26 W., passes about a mile north of Centerpoint, and then swings southwest to the Saline River bottoms. It is well developed as a steep slope, 100 to 200 feet high, facing northward over the adjacent lower-lying Trinity formation. Centerpoint stands about a mile south of the northern edge of the scarp, at an elevation of about 590 feet. West of Saline River the cuesta is well developed, but has a comparatively low escarpment which passes through Holly Springs in Sec. 20, T. 9 S., R. 29 W., and diminishes in height westward until it nearly disappears southeast of Lockesburg.

The escarpment again increases in height west of Cossatot River, where the cuesta is strongly developed. The road running southward from De Queen to Horatio goes up over the escarpment about 3 miles south of De Queen. Here the escarpment is about 200 feet high and the crest reaches a height above sea level of about 750 feet. In this part of the area the cuesta slope is most extensively devel-

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

[44] Ross, C. S., Miser, H. D., and Stephenson, L. W., Water-laid volcanic rocks of early Upper Cretaceous age in southwestern Arkansas, southeastern Oklahoma, and northeastern Texas: U. S. Geol. Survey Prof. Paper 154 (in press).

A. PEACH ORCHARD ON THE DIP SLOPE OF THE CENTERPOINT CUESTA WEST OF CORINTH, HOWARD COUNTY, SHOWING TYPICAL ROLLING SURFACE

Orchard covers 3,700 acres. Gravel in foreground.

Photograph by M. W. Beck, Bureau of Soils, Department of Agriculture

B. EXPOSED VERTEBRAL COLUMN AND SCATTERED BONES OF A MOSASAUR IN THE MARLBROOK MARL IN THE SE. ¼ SEC. 17, T. 11 S., R. 26 W.

Geologic hammer shows scale. The sticks bearing pieces of cloth were used in marking off the area before the fossil was removed.

oped and exhibits typical cuesta drainage down the dip. The cuesta slope on which the gravelly sands of the Woodbine crop out provides in places a soil suitable for large peach orchards (see Pl. VI, A). The profile along the Kansas City Southern Railroad from De Queen to Horatio (Fig. 2) shows

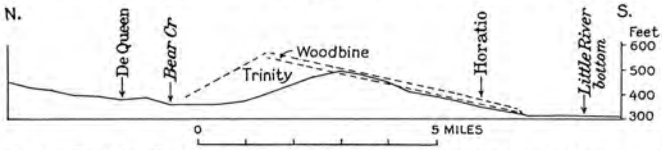


FIGURE 2.—Profile along the Kansas City Southern Railroad through De Queen and Horatio, Sevier County, and diagrammatic profile of the Centerpoint cuesta about a mile east of the railroad.

the effect of the cuesta, although it does not show the normal cuesta form, because the railroad goes up the scarp at a lower angle, along a stream course that is cut deep into the escarpment, and down a similar stream course at a higher angle than the cuesta slope. The so-called freight detour of the railroad avoids these steep grades by travelling a more circuitous route from De Queen down the edge of the bottom lands of Bear Creek and Little River and rejoining the main line a little south of Horatio.

TOKIO FORMATION

HISTORICAL SUMMARY

Unconformably upon the Woodbine formation lies a formation consisting principally of dark-gray lignitic, fossilliferous clay and cross-bedded gray and brown coarse quartz sand. This is the upper of the two formations included by Veatch [45] in the "Bingen sand," and it agrees closely in lithologic character with that formation as described by him.

Miser,[46] as a result of his investigation of the eastern part of the outcrop during his study of the Caddo Gap quadrangle, separated from the "Bingen formation" an upper quartz sand member, which he termed the Tokio sand member, so named from the village of Tokio, in northern Hempstead County. Further study has shown that the gravel bed then included in the upper part of the "lower Bingen" should be consid-

[45] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 23-24, 1906.

[46] Miser, H. D., and Purdue, A. H., Gravel deposits of the De Queen and Caddo Gap quadrangles, Arkansas-Oklahoma: U. S. Geol. Survey Bull. 690, p. 23, 1919.

ered the basal gravel of the Tokio beds. In April, 1925, L. W. Stephenson obtained invertebrate fossils from hard calcareous sandstone lenses in the upper part of the "Bingen" near Ben Lomond. Of particular significance was a species of *Inoceramus* that is elongated parallel to the hinge lime, a characteristic of species of the age of the typical Austin chalk and later beds (see Pl. VIII, p. 40).

The present investigation has shown that the upper part of the "Bingen formation" along its entire outcrop is a lithologic unit clearly separable from the Woodbine below, and that it contains throughout its thickness fossiliferous beds bearing species of Austin age. It has therefore been made a new formation, and the term "Bingen," which included two units of different lithology and age, has been abandoned. This upper part of the former "Bingen formation," of Austin age, is the equivalent of the Tokio sand member of Miser and Purdue [47] plus the underlying heavy bed of gravel. The name Tokio formation is therefore here used to include both the sand and the underlying gravel.

LITHOLOGY AND OUTCROPS

The bed of gravel at the base of the Tokio formation probably extends entirely through its outcrop, but diminishes in thickness in Sevier County. The work of tracing with certainty the Cretaceous gravels is extremely difficult. The entire surface of the area has been mantled with a variably abundant surficial cover of sand and gravel, deposited on several terraces of late Tertiary, Pleistocene, and Recent age. This cover has been only in part removed. The gravels of these later periods closely resemble the underlying Cretaceous gravels in composition, the enormously predominating constituent of all being pebbles or cobbles of novaculite derived from the Arkansas novaculite of the Ouachita Mountains.

These surficial gravels, as well as those of the underlying Cretaceous deposits, are usually unconsolidated, and either may be in places cemented to conglomerate with abundant reddish brown iron oxide. Gravels of both types are cross bedded. In addition the Cretaceous gravels are usually of variable thickness from place to place and may even disappear

[47] Miser, H. D., and Purdue, A. H., idem, pp. 23, 24.

for short distances. Actual cross section outcrops in which the structure can be seen are rare. At many places the gravels have been distributed by creep on slopes and even redeposited.

Where the two kinds of gravels are exposed in cuts and banks they may show slight differences in character. The Cretaceous gravels are generally cleaner—that is, they are not mixed with clay or loam, but the interstices between the pebbles are filled rather with a sandy clay or a fine gravelly sand. Probably also the surficial gravel contains a larger content of carbonaceous matter. The older gravels possibly show a slight tendency towards more thorough consolidation by packing.

These older Cretaceous gravels are also at some places separated into layers, a foot to a few feet thick, by nearly horizontal bedding surfaces, but are cross-bedded within these layers. The younger gravels, on the contrary, show more irregular cross-bedding and contain more lenses.

The gravels of the Woodbine formation differ strikingly in composition from the surficial gravels by their inclusion of pebbles of thoroughly decomposed lava and a mealy matrix of bentonite derived from decomposed volcanic material. The Cretaceous gravels, however, can be best distinguished from those of more recent age by noting whether the topographic form is a continuous one, such as would be produced by the erosion of a persistently outcropping bed of gravel, by considering the likelihood that terrace gravels would occur at certain topographic elevations and locations, and by observing the continuity of gravels at a definite position in the geologic section as indicated by outcrops of other types of material.

The basal gravel of the Tokio formation, where best exposed, consists almost entirely of pebbles and cobbles of translucent, homogeneous, dense novaculite. Most of the pebbles are white and light gray, but dark gray and brown pebbles are common. Red, green, and blue pebbles are more rare. Pebbles of quartz, quartzite, and sandstone are found, but they are not abundant. The gravel contains cobbles as much as 6 inches in diameter, but the average diameter of its constituents is about an inch. Most of the pebbles are subrounded or have irregular surfaces, but the edges of nearly all are rounded. Many of the cobbles are well rounded and a few are almost spherical. The surfaces of some show percussion marks, and some cobbles of novaculite have apparently been cracked or broken in transportation, for that rock is brittle and breaks easily with a smooth, slightly conchoidal fracture. The broken edges of such cobbles have usually been rounded.

There is a good exposure of this gravel in the large pit about 3 miles north of Nashville, on the road to Corinth, and another in the bank of Blue Bayou, in the NW.¼ Sec. 26, T. 9 S., R. 28 W., where the road from Forgy to Rosedale by way of Kennedy's store crosses the creek.

The thickness of this gravel in Hempstead and Howard counties is about 25 feet; east of Little Missouri River it varies from 1 foot to 25 feet,[48] and in its easternmost exposure it is thin and variable in its thickness, which is never more than a few feet. Its thickness farther west, in Sevier County, is not precisely known, but is probably from 10 to 20 feet.

Above the basal gravel bed in Howard County and farther east the Tokio formation consists chiefly of coarse brown and gray quartz sand, with which are interbedded some light and dark clays. Beds of gravel may probably also be found above the base of the formation in Hempstead County and farther east.[49] The typical sand of the Tokio is a medium-grained gray or light-brown quartz sand, usually weathering yellow, red, or brown. The grains, mostly quartz, are subrounded to subangular. The sand contains also some grains of feldspar and some small black grains, probably mostly magnetite. The grains are not well assorted as to size, and there is a variation in the size of grain from fine to coarse in different layers. The beds contain disseminated particles of kaolin and in some places angular and rounded pellets of white clay, as well as some scattered small rounded pebbles of novaculite. The sand is usually clean, without a matrix of silt and clay, and firmly packed, but incoherent, although in some places it is slightly bonded by a scant, ferruginous cement. This cement is found abundantly in rare, thin beds of yellow or red sandstone. The sand is typically cross bedded, at some places on a large scale, the inclined layers running 20 feet or more at angles as high as 18°. Where the angle is smaller,

[48] Miser, H. D., and Purdue, A. H., idem, p. 23.
[49] Idem, p. 23.

as it generally is, individual layers may extend for as much as 50 feet, and such layers may also show cross bedding. The larger cross bedding is usually emphasized by the presence of thin layers of white clay or light-gray sandy clay. At many places the sand is apparently massive, in beds as much as 20 feet thick. There are some lenses of concretionary sand, from 1 foot to 3 feet long, flattened parallel to the bedding. These lenses are slightly harder than the mass of the bed, because they contain a somewhat greater percentage of ferruginous cement. Pyritiferous sandy concretions as much as 2 inches in diameter have also been noted. These are usually weathered on the outer surfaces to hard red sand.

Typical outcrops of the sandy phase of the Tokio occur in the SE. ¼ of sec. 22, T. 9 S., R. 26 W., just west of Doyle (Pl. V, B), and in the SE. ¼ of Sec. 10, T. 10 S., R. 28 W., about 2 miles south of Nashville, on the road to Washington. Among the variants of the typical sand are strongly ferruginous fine-grained sand, argillaceous greenish gray micaceous sand, glauconitic sand, and brown, strongly carbonaceous sand. It has long been known that the beds now termed the Tokio formation include layers of clay as well as of sand, but the outcrops of the sandy beds are relatively so conspicuous and the soil over the belt of outcrop is generally so sandy as to obscure the significance and the thickness of the clayey part of the formation. A diagram attached to the writer's preliminary statement of the stratigraphy[50] shows that more than half of the total thickness of the Tokio formation in Sevier County consists of clay..

Associated with the sands in the eastern part of the outcrop, where the sandy phase is predominant, are beds of white clay ranging in thickness from a few inches to 3 feet. Some of these beds of white clay are derived from volcanic ash.[51] Some show violet streaks due to carbonaceous material, and some show dark-purple to black streaks, from 1 to 8 inches wide, due to carbonaceous and lignitic material.

Other clays associated with the sands are dark gray and bedded and are marked with impressions of leaves and stems of plants. Such clays are found here only in thin beds in a

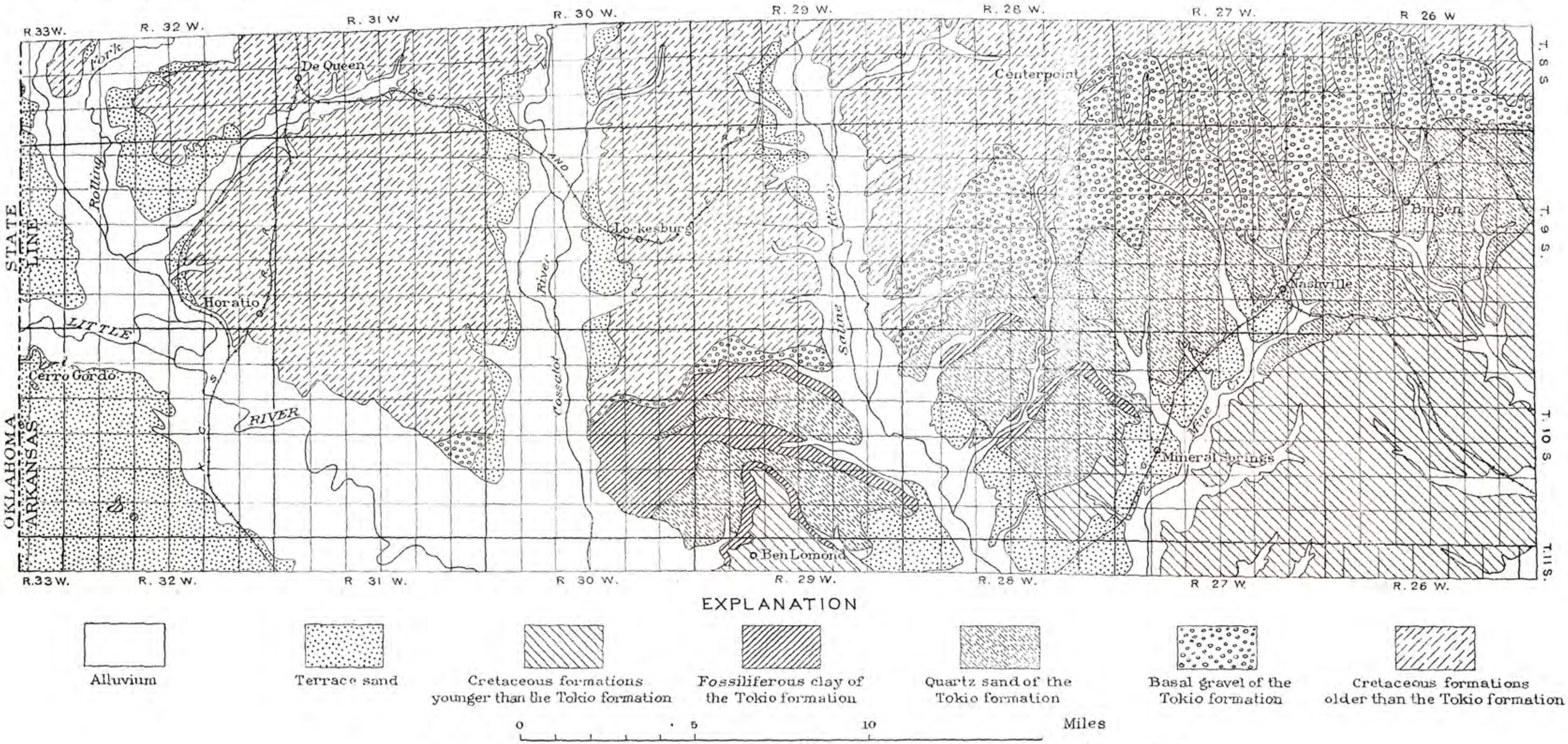
[50] Dane, C. H., Oil-bearing formations of southwestern Arkansas: U. S. Dept. Interior Memo. for the press 8823, Sept., 1926.

[51] Ross, C. S., Miser, H. D., and Stephenson, L. W., Water-laid volcanic rocks of early Upper Cretaceous age in southwestern Arkansas, southeastern Oklahoma, and northeastern Texas: U. S. Geol. Survey Prof. Paper 154 (in press).

formation that consists mainly of sand, but farther west along the outcrop the number of exposures of clay increases as well as the thickness of the beds exposed. These beds consist mainly of dark-gray bedded clay containing abundant small, lignitic imprints of plants and widely distributed small imprints of shells, which are in some places sparse, in others very abundant. These beds of clay are exposed at but few places, and they have almost no striking individual peculiarities by which their isolated outcrops could be traced and correlated. The field relations of their outcrops as now known justify the conclusion that the beds containing the fossil imprints extend eastward into the sandy phase of the formation in three tongues, which are not sharply delimited and terminated, and that the clay beds are mixed with sandy beds of variable thicknesses from place to place. The accompanying sketch map (Pl. VII) shows the hypothetical areal distribution of the three tongues. The lowest tongue is near the base of the formation, just above the basal gravel. Another tongue, which extends farther east, is near the middle of the formation. The third is at the top and includes sandy clay, some glauconitic sand, and lenses of hard, calcareous fine-grained gray sandstone containing numerous fossils. It is believed that the two lower tongues coalesce toward the west and consequently that the lower half of the formation where they are joined consists principally of clay, although sufficient outcrops have not yet been discovered to substantiate this belief, which is based largely on well records, inference, and the absence of contradictory evidence. The principal outcrop of the lower tongue is in the center of the NW. ¼ of Sec. 10, T. 10 S., R. 29 W., where the road from Brownstown to Lockesburg goes down over the steep hill a little more than a half mile south of Milford school. At this place road cuts and ditches expose the following section:

Partial Section of the Tokio Formation in the NW. ¼ Sec. 10, T. 10 S., R. 29 W.

	Feet
Top not exposed.	
Fine-grained, massive, thick-bedded sand, weathering yellow and red and including some interbedded gray clay containing a very few imprints of fossils	15
Light-gray clay and greenish-gray argillaceous sand. The clays are bedded but break into round and ellipsoidal lumps. Nearly all the clay contains flakes of muscovite and brown macerated fragments of plants. It is sparingly fossiliferous throughout. Includes a few yellow sandy layers	82
Base not exposed.	



SKETCH MAP SHOWING DISTRIBUTION OF LITHOLOGIC TYPES OF THE TOKIO FORMATION

A short distance north on this road the surface is thickly strewn with gravel, which was presumably derived from the basal gravel bed of the Tokio formation, and in the vicinity of Milford school the Woodbine crops out. West of the large outcrop of clay just described exposures are very poor, but in the SE. ¼ NW. ¼ Sec. 8, T. 10 S., R. 29 W., there are small outcrops of bedded gray sandy micaceous clay in about the same stratigraphic position, and half a mile south of the basal gravel of the Tokio in the NW. ¼ Sec. 13, T. 10 S., R. 30 W., the character of the subsoil and some questionable outcrops indicate that the underlying formation is principally clay near the base of the Tokio.

East of Saline River sand crops out immediately above the basal gravel, but a short distance above the base are clays that probably represent the eastern extension of the lowest clay tongue. These occur on the south side of Starchy Creek, in the NE. ¼ NW. ¼ Sec. 4, T. 10 S., R. 28 W., along the road from Mineral Springs to Rosedale by way of Bluff Springs church. They are the easternmost outcrops of fossiliferous clay yet discovered along this lowest tongue. A poor composite section at this place gives some idea of the exposure.

Partial Section of the Tokio Formation in the NW. ¼ Sec. 4, T. 10 S., R. 28 W.

	Feet
Top not exposed.	
Bedded sandy gray clay. Fairly coarse grains of clear quartz thinly distributed along bedding planes. Contains small fossil prints and a little macerated plant material	5
Yellow sand, weathering light buff; carbonaceous in irregular patches; contains fossil prints marked in black carbonaceous films	5 to 10
Interbedded and cross-bedded micaceous, fossiliferous, sandy lignitic clay and green-gray, fine grained micaceous sand. Some ferruginous red and yellow sand, white clay, and hard, chocolate-brown carbonaceous sandstone	16
Principally bedded gray clay, micaceous, sandy, fossiliferous, containing brown lignitic fragments. Interbedded with fine grained gray sand	13
Base not exposed.	

Near the middle of the formation there is a series of outcrops of clay at about the same stratigraphic position. These are at no place as thick as the thickest section of the lower tongue, but there are more individual outcrops of the clay. This series has been interpreted as a thin tongue of clay that extends eastward to the vicinity of Mineral Springs. Clay of this tongue crops out in the SE. ¼ NW. ¼ Sec. 22, T. 10 S.,

R. 29 W., about half a mile south of Lyons school, on the road from Brownstown to Lockesburg by way of Milford school. At this place the following section is exposed:

Partial Section of the Tokio Formation in the NW. ¼ Sec. 22, T. 10 S., R. 29 W.

	Feet
Top not exposed.	
Principally reddish and yellowish sands, interbedded with white and light-gray, thin-bedded clays. Some black carbonaceous sand	12
Principally poorly bedded, greenish, irregularly alternating sandy clay and argillaceous sand, carrying brown ferruginous layers along the bedding planes. Fossiliferous (prints and soft casts). The clays contain brown macerated fragments of plants. Some beds of harder ferruginous sand contain grains of glauconite	23
Principally reddish and yellow sand and interbedded light-gray thin-bedded clay	4
Dark-gray thin-bedded clay containing black fragments of plants and fragments of leaves	4
Principally gray-green micaceous sand interbedded with thin beds of gray clay. At the base a 6-inch layer of coarse quartz sand containing glauconite and slightly cemented by ferruginous material. Contains gray and white quartz pebbles, the largest three-quarters of an inch in greatest diameter, some well rounded, many subrounded, and clay pebbles. Numerous casts and prints of shells. Decomposed shark teeth, some broken and rounded by attrition	4
Poorly exposed, thin-bedded light-gray clay containing some fragments of plants	11
Very fine grained, massive, soft yellow sand	3
Base not exposed.	

Outcrops of clay at this general stratigraphic position have not been found farther west. An outcrop of gray, sandy micaceous clay containing fragments of plants and imprints of fossils found 5.2 miles from Ben Lomond, along the road to Lockesburg, is probably somewhat lower in stratigraphic position, although it is considerably above the base of the formation. The presence of this outcrop at a stratigraphic position at which clay does not occur farther east in Sevier County tends to substantiate the belief that the lower half of the Tokio is here principally clay.

East of the outcrop near Lyons school (see above) the middle tongue is probably represented by a small outcrop of bedded sandy brown clay, containing scattered lignitic fragments and some imprints of fossils, just west of the Saline River bottom, 7.3 miles from Mineral Springs, on the road to Ben Lomond.

East of Saline River, in Howard County, a good outcrop of clay of this tongue occurs in the SE. ¼ Sec. 10, T. 10 S.,

R. 28 W., where the road from Mineral Springs to Rosedale by way of Bluff Springs church goes down the steep hill on the south side of Blue Bayou. At the base of the exposure is 25 feet of bedded gray-green clay mixed with considerable very fine sand and much muscovite, in small flakes. Disseminated through the clay are small, black carbonaceous flakes and a few small, poorly preserved impressions of stems of plants. Very thin yellow ferruginous sandy layers mark the rippled bedding surfaces. The clay contains imprints of small fossils and poorly preserved casts, some of which have ferruginous coatings. In its upper two feet there are layers of thin, green-gray, micaceous fine-grained sand and some layers of brown and black sand containing fragments of plants. Above this bed is a red concretionary layer of sandy clay, whose irregular under surface cuts across the local bedding. Above this lies 6 feet of alternating gray bedded clay and yellow medium-grained sand, and still farther up is 85 feet of typical Tokio sand. At the top of the hill a few feet of gray clay are interbedded with the sand.

The fossiliferous clay crops out a quarter of a mile farther southwest, at the next lower crossing of Blue Bayou. Outcrops of similar lignitic clays, but without fossils, were found 3.1 miles north of Mineral Springs, on the road to Forgy, and also a mile north of Mineral Springs on the road to Nashville, and these are tentatively included in the eastward extension of this tongue. An isolated outcrop of sandy gray clay containing fragments of plants, possibly the easternmost extension of this clay tongue, occurs in the bed of Mine Creek a quarter of a mile north of the bridge over which the Missouri Pacific branch line comes in to the town of Nashville.

Clay is exposed at the top of the Tokio formation 0.9 mile north of Ben Lomond, on the road to Lockesburg, in road cuts on the hill south of Wilson Creek.

Partial Section of the Tokio Formation 0.9 Mile North of Ben Lomond

	Feet
Brownstown marl.	
Contact not exposed.	
Tokio formation:	
Poorly exposed green-gray, very sandy clay, with red ferruginous concretions, some sand and pure clay, and scattered lenses of hard calcareous sandstone up to 2 feet long............	30
Cross-bedded soft, very fine grained gray sand, with some slightly indurated yellow sand and some slightly glauconitic	

sand. Halfway up this bed, and thence sparingly to its top, there are lenses of very hard, fine-grained gray calcareous sandstone, which weather light buff. They are variably fossiliferous, some only very sparingly so; a few are nearly coquina. These lenses range in length from 1 foot to 6 feet and some attain a thickness of 1½ feet. Their upper surfaces are in places marked with current ripples having a wave length of 2 to 4 inches. In detail these lenses show thin bedding and cross bedding	25
Thin-bedded, cross-bedded sand and sandy clay (mostly clay). The sand is very fine grained argillaceous gray sand laminated and cross bedded with yellow sand. The clay is well-bedded, thin-bedded gray clay, which contains a few macerated fragments of plants and some imprints of fossils	30
Base not exposed.	

There should be added to this section, below its base, a small exposure a short distance north, in the bank of Wilson's Creek, west of the bridge.

	Feet
Irregular thin-bedded brown sandy clay containing macerated fragments of plants and numerous imprints of fossils	5
Massive or thick-bedded, white, fine-grained sand containing some beds of brown and yellow laminated lignitic sand	15
Bedded pure clay, sandy gray clay, black clay containing numerous black carbonaceous fragments; fine-grained greenish sand interbedded with brown and black very lignitic sand. A few beds, only half an inch thick, of dense gray limestone	6
Base not exposed.	

About a mile north of Ben Lomond, near the center of Sec. 32, T. 10 S., R. 29 W., immediately below the Brownstown marl, is an outcrop that carries lenses of hard, calcareous gray sandstone as much as 8 feet long and 3 feet thick. Only a few are fossiliferous. These lenses are embedded in micaceous, medium-grained, greenish-gray argillaceous sand that includes some carbonaceous brown sand. Below this there are a few feet of yellow, cross-bedded sand, then small exposures of gray fossiliferous sandy clay and argillaceous sand. About 2.3 miles east of Ben Lomond, along the Mineral Springs road, a single large boulder of similar very hard gray sandstone containing fragments of white, limy shells lies in a road ditch, but its relations to the original enclosing rock could not be determined. This is the easternmost indication of the presence of this tongue, although across the Saline River, a mile east of Mineral Springs, on the road to Ben Lomond, a few feet of gray sandy clay crop out near the top of the Tokio.

Across Little River County the outcrop of the Tokio formation is almost concealed by surficial sand and gravel. The only indications of the outcrop that have been discovered are just north of Jewel, on the road to Horatio, and 0.7 of a mile northwest of Jewel, on the road to Cerro Gordo. Here the surficial wash contains flat, rounded pebbles, the largest 1½ inches in longest diameter, of soft, dark-gray, slightly sandy micaceous clay of Tokio type. Across the Oklahoma line, 9 miles west of Arkinda, on the road to Idabel, Okla., there are excellent outcrops of gray Tokio clay containing abundant imprints of fossils.

THICKNESS

The thickness of the formations in the area can be determined only approximately from the surface indications. The extremely low southward dip, the similar southward slope of the surface, and the absence of marked topographic relief makes it possible to measure directly the thickness of only the relatively thin formations. The absence of continuous distinctive planes of division within the formations makes it impossible to obtain a composite section by direct measurement. The only available method of determining the thickness of a bed appears to be that of calculating its thickness from the width of the outcrop, the dip of the formation, and the surface elevation of the upper and the lower contact along the line of dip selected for the calculation. The inaccuracy of this method is evident; and in addition it is rarely possible to obtain accurate measurements of the dip. The difficulties of determining dip will be considered later. More accurate information may at some places be obtained from the records of wells that have penetrated the formation, but this method also involves possible errors. Inaccurate measurements and vague descriptions by the driller or recorder, and more particularly incorrect interpretation of the record, may lead to very erroneous ideas of thickness. Therefore a careful estimate of thickness from the surface indications serves as a useful check on interpretation by well records. Most of the thicknesses stated for formations have therefore been estimated from such surface indications. The thicknesses indicated by a number of well records are given in Appendix A, p. 182.

The Tokio formation is about 300 feet thick in Sevier and Howard counties, and its thickness probably increases slightly

PLATE VIII

(All figures natural size)

FIGURES 1-4. Specimens of *Inoceramus* sp. from near the top of the Tokio formation on the Lockesburg road a mile northwest of Ben Lomond, Sevier County. These belong to a group of the genus which is not known in beds as old as the Eagle Ford clay.

5. *Thracia* sp. from the same locality.

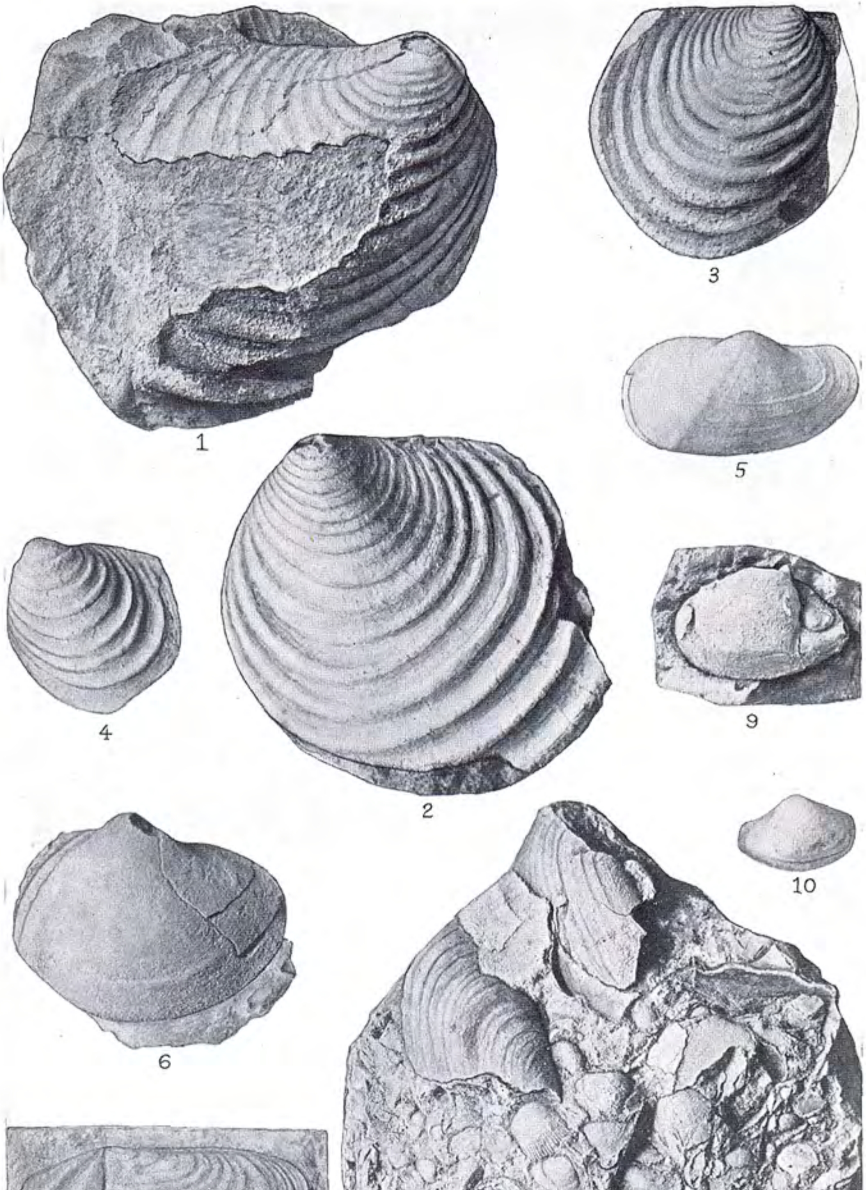
6. *Cymbophora* sp. from the same locality.

7. *Leptosolen* aff. *L. biplicatus* Conrad from the same locality.

8. Fragment of a coquina-like rock full of fragments of shells; part of a large mass of concretionary sandstone at the same locality.

9. *Corbula* aff. *C. oxynema* Conrad from the old Brownstown-Lockesburg road 5.7 miles north of its intersection with the Ben Lomond-Mineral Springs highway, Sevier County.

10. *Corbula* aff. *C. subgibbosa* Conrad from the Lockesburg road 5.5 miles northwest of Ben Lomond, Sevier County.



FOSSILS FROM THE TOKIO FORMATION

toward the west. It thins rapidly toward the east and is overlapped by the Brownstown marl.

FAUNA AND CORRELATION

Invertebrate fossils have been found in the Tokio formation in three types of material, the hard calcareous sandstone of the upper tongue; the soft, gray lignitic and micaceous clays; and the red, richly ferruginous sands. Dr. Stephenson has identified the following fossils collected from the formation by him, H. D. Miser, and the writer.

From hard calcareous sandstone on Lockesburg road, 0.9 miles northwest of Ben Lomond, Sevier County, Ark.:

Pelecypoda:
- Leda sp.
- Striarca?
- Inoceramus aff. I. barabini Morton.
- Leptosolen aff. L. biplicatus Conrad.
- Cymbophora?

From soft gray clay on Lockesburg road, 5.2 miles northwest of Ben Lomond, Sevier County, Ark.

Pelecypoda:
- Nucula sp.
- Leda sp. (large).
- Yoldia sp. (small).
- Striarca?
- Anomia cf. A. argentaria Morton.
- Lucina sp.
- Cardium (Trachycardium) sp. (a small species).
- Tellina sp.
- Leptosolen sp.
- Corbula cf. C. subgibbosa Conrad.

From sandy micaceous clay in the SE. ¼ NW. ¼ Sec. 22, T. 10 S., R. 29 W., at crossroads on Brownstown-Lockesburg road, Sevier County, Ark.:

Pelecypoda:
- Leda sp. (large).
- Striarca sp. (aff. S. umbonata Conrad).
- Cardium (Trachycardium) sp.
- Leptosolen aff. L. biplicatus Conrad.
- Corbula cf. C. oxynema Conrad.
- Corbula cf. C. subgibbosa Conrad.
- Trigonarca sp. (large).

Gastropoda:
- Gyrodes sp.
- Anchura sp.

Vertebrata:
- Lamna texana Roemer.

From red ferruginous sand in the SW. ¼ NE. ¼ Sec. 8, T. 10 S., R. 29 W., about a mile south southeast of Gravelly

Point school, on secondary road between Lyons school and Gravelly Point school, Sevier County, Ark.:

Pelecypoda:
- Trigonarca? (large).
- Ostrea plumosa Morton?
- Cardium sp.
- Solyma?
- Leptosolen sp.
- Corbula cf. C. subgibbosa Conrad.
- Corbula cf. C. oxynema Conrad.

Gastropoda:
- Gyrodes?
- Natica?
- Pugnellus sp.

Vertebrata:
- Lamna texana Roemer.

From sandy, micaceous, lignitic clay in the SE. ¼ SE. ¼ Sec. 10, T. 10 S., R. 28 W., Mineral Springs to Kennedy's store road, at ford of Blue Bayou, Howard County, Ark.:

Pelecypoda:
- Leda sp. (large).
- Leda sp. (medium sized).
- Trigonarca sp. (small).
- Gryphaea? (small).
- Cardium (Trachycardium) sp. (small).
- Corbula cf. C. subgibbosa Conrad.
- Corbula sp.

Gastropoda:
- Unidentified internal mold.

Most of these fossils are preserved as small, poor casts in sand and clay. In view of the general aspect of the fauna, and particularly of the occurrence in it of *Inoceramus aff. I. barabini* Morton and the large Trigonarca with a strongly dentate hinge, Stephenson regards these deposits as not older than the Austin chalk. An exhaustive search of the formation might possibly disclose a better preserved and more decisive fauna. The conclusion that this formation is of Austin age is, of course, greatly strengthened by the fact that it occupies the stratigraphic position of the Bonham clay and Blossom sand, in northeastern Texas, which are unquestionably of the age of the Austin chalk.

The lithology of the Tokio in the western part of its outcrop in Sevier County is very similar to that of the Blossom sand. The upper part of the Tokio in western Arkansas is much more sandy than the lower part, and this upper part may be in general the equivalent of the Blossom sand. Both the Blossom sand and the upper part of the Tokio contain much dark slightly sandy and micaceous clay. Clay of

Tokio type, containing fossils and fragments of plants, has been found in southeastern Oklahoma, but it is there largely concealed by the terrace and alluvial deposits of the Red River. The name Tokio formation is applied only to deposits of the type and age described that lie north and east of Red River.

Fossil plants from the Tokio formation have been listed and described by E. W. Berry.[52]

ORIGIN

The Tokio formation was evidently laid down in a sea, near its shores. Its fauna is unquestionably marine, although possibly it includes brackish-water species. Deposition in shallow water is indicated by ripple marks and by lenses of cross-bedded sand deposited at high angles by strong currents. The nearness of the shore is indicated by fragments of lignite and lignitic layers, and by imprints of leaves and plants. Evidence of subaerial exposure has not yet been noted. No mud cracks, rill marks, or rain prints have been seen. Lack of exposure to subaerial oxidation at the time of its deposition is also indicated by the originally gray or white color of the sand. It clearly contained sufficient iron to have been oxidized if subaerially deposited, as shown by the distinctly red color of many of the weathered outcrops.

Transgression of the Tokio sea is shown by the overlap and eastward truncation of the Woodbine and successive members of the Trinity formation by the gravel at the base of the Tokio. This gravel is interpreted as a beach deposit formed by the transgressing sea. It is of little importance that the actual unconformity at the base has not yet been seen, for an irregular surface necessarily occurs at the base of a bed of such physical composition. Some of the cobbles of novaculite in the gravel were probably derived from the novaculite in the Ouachita Mountains, but more were derived from the older Cretaceous gravels in the Trinity formation, and particularly from those in the Woodbine, upon which the basal gravel bed of the Tokio rests for most of its extent. A brief consideration of the distribution of the basal gravel as shown by well records indicates that it is confined to a strip, about 10 miles wide, lying parallel to the outcrop, and that

[52] Berry, E. W., Contributions to the Mesozoic flora of the Atlantic Coastal Plain, XII, Arkansas: Torrey Botanical Club Bull., vol. 44, pp. 167-190, Pl. 7. 1917.

it thins out and disappears toward the south. Its areal distribution as thus determined corresponds nearly with the area underlain by gravels of the Woodbine formation, the transgressing sea apparently depositing a basal gravel where suitable material was available for reworking.

The combination of eastward truncation of lower formations and northeastward thinning along the outcrop suggests northeastward transgression of the sea. This suggestion is supported by the greater thickness of clay in the formation toward the west along the outcrop, which indicates that during most of the sedimentation this area was at a greater distance from the shore. The proportion of clay recorded in well logs apparently increases also toward the south from the eastern sandy portion of the outcrop. The general direction of transgression seems to have been between north and northeast.

The basal gravel of the Tokio probably differs in age from place to place, the youngest part being toward the north and probably somewhat toward the east, but its areal extent is so small that this variation in age is probably not significant.

The shore line of the sea in which the Tokio was deposited undoubtedly varied in position, but the fact that in the eastern part of its outcrop the formation is either sand or gravel of near-shore origin and includes very little clay indicates that the shore was not many miles to the north throughout the period of deposition. The distance to which a transgressive deposit could have extended northward is not limited by the present height of the mountains, for the slope of the land now is less than the slope of the Cretaceous floor. The intertonguing of sand and clay in the formation indicates variation in the conditions of deposition, the clay tongues probably representing periods of farther advance of the shore line, although possibly only a decrease in the rate of supply of sediment.

The uplift and tilting that occurred before the deposition of the Woodbine was repeated or continued before the deposition of the Tokio, and as a result the transgression of the Tokio over the land surface has truncated the Woodbine in areas to the north and east. The log of the Perpetual Oil and Gas Company, near Nashville, shows 350 feet of beds referable to the Woodbine, but about 8 miles northwest of this well, in the vicinity of Center Point, there can be scarcely more than 200 feet of Woodbine on the outcrop, and in areas farther east it is cut out and does not crop out east of Little Missouri River. Part of this variation in thickness is probably variation in the original thickness of the Woodbine, due to the fact that the source of the volcanic material was near Nashville.[53]

PHYSIOGRAPHIC EXPRESSION

Erosion has produced a prominent cuesta on the resistant basal gravel of the Tokio formation. This cuesta has an abrupt scarp and an extensive gentle dip slope in Pike, Hempstead, and Howard counties, where the gravel is thickest. This feature is here named the Highland cuesta, from the village of Highland, in Pike County, where there are very large peach orchards on the gravelly soils of the dip slope. The scarp of this cuesta is clearly evident about a mile south of the village of Centerpoint, but the dip slope in this area, although extensive, has been deeply dissected by southward-flowing streams into long, northward-trending gravel-topped ridges. From about 2 miles southwest of Centerpoint the scarp runs continuously southwestward nearly to Saline River and is conspicuously visible south of the Centerpoint-Rosedale road. A little south of Rosedale the effect of the scarp on geographic names is indicated by the name of Longview school. To the west, across Saline River, in Sevier County, the scarp is not so striking, but it is in places between 50 and 100 feet in height. Gravelly Point school stands on the edge of the scarp.

East of the Little Missouri, where the gravel is not thick, the scarp is not so strong, but it persists, although it is dissected by southward-flowing streams, until it reaches a point where the Tokio transgresses the Trinity and rests on the harder Paleozoic rocks.

The extensive dip slope in Pike, Howard, and Hempstead counties is indicated approximately on the sketch map (Pl. VII, p. 34), showing the areal extent of the outcrop of the basal gravel of the Tokio. The slope is much less extensive

[53] Ross, C. S., Miser, H. D., and Stephenson, L. W., Water-laid volcanic rocks of early Upper Cretaceous age in southwestern Arkansas, southeastern Oklahoma, and northeastern Texas: U. S. Geol. Survey Prof. Paper 154 (in press).

in southeastern Sevier County. The nearly unconsolidated sand of the Tokio above the basal gravel bed produces areas having small hills and rather narrow valleys in which little clear streams flow rapidly in irregular courses. In Hempstead and Howard counties the area of outcrop of the Tokio stands at a lower elevation than the belt of the overlying Brownstown marl, as the soft sand has been cleaned from the dip slope of the basal gravel. In Sevier County the Tokio makes a belt of sandy hill land, which decreases in general elevation toward the south.

BROWNSTOWN MARL (RESTRICTED)

HISTORICAL SUMMARY

The Brownstown marl as here redefined and restricted corresponds to the lower part of the beds included in the Brownstown marl of Veatch, the upper part of which is here named the Ozan formation. The name Brownstown was first applied by Hill[54] to the marl outcropping in the vicinity of Brownstown, Sevier County, Ark., which was then believed to overlie the chalk at White Cliffs. In a later report[55] the term Brownstown was used to include all the beds between the Annona chalk and the "Washington greensand beds" (now included in the Nacatoch sand). Subsequently[56] the term was used to include the beds at Brownstown below the Annona chalk and the marls that overlie the chalk. Veatch correctly restricted the term to "the blue clay marls between the Bingen sand and the Annona chalk."[57] It has now become desirable to divide these marls. The settlement of Brownstown stands on the uppermost part of the outcrop of the lower unit, and accordingly the name Brownstown marl has been retained for these lower beds.

LITHOLOGY AND OUTCROPS

As here restricted the Brownstown marl includes the dark-gray calcareous clay or marl and subordinate sandy marl and fine-grained sand that rest unconformably on the Tokio formation and are overlain by the Ozan formation. The term

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[54] Hill, R. T., The Neozoic geology of southwestern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1888, vol. 2, pp. 86-87, 1888.

[55] Hill, R. T., Geology of parts of Texas, Indian Territory, and Arkansas adjacent to Red River: Geol. Soc. America Bull., vol. 5, p. 302, 1894.

[56] Hill, R. T., Geology of the Black and Grand prairies, Texas: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 7, p. 340, 1901.

[57] Veatch, A. C., Geology and ground waters of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 25, 1906.

unconformity as here used implies only that between two formations thus separated there was an interval of time equal at least to that required for the deposition of a formation. The period of time represented by such a break may have been occupied by erosion, either subaerial or submarine, or it may have been merely a period of cessation of deposition, but it was usually sufficient to allow a perceptible modification of the fauna. Breaks and interruptions in marine sedimentation may cover long or short periods, and many may have been too short and of too little lateral extent to serve as planes for formational separation. Those breaks in sedimentation which are sufficiently distinct and extensive to serve as bounding plans of formations over considerable areas are here termed unconformities. Those that represent periods of time of less than formation value are of the order of the breaks called diastems by Barrell.[58] All the breaks within the Gulf series in this area are of the type classed as disconformities by Grabau,[59] in which the strata on both sides of the plane of separation are parallel or so nearly parallel that the divergence is not locally recognizable.

The relation between the Brownstown marl and the underlying sandy beds, once called the "Bingen sand," was regarded by Veatch[60] as transitional. In the region studied by Miser[61] the Brownstown occupies only a very small area, and its contact with the underlying sand was nowhere exposed, so that he accepted without question the view held by Veatch. The Brownstown, however, clearly lies unconformably on the Tokio, although the contact is exposed at but few places. At a point in Sevier County 0.9 mile north of Ben Lomond, on the road to Lockesburg, although the uppermost Tokio is clay and the contact of the two formations is not exposed, the abrupt change in lithology is evident, the soft, deeply weathered yellow-gray marl of the Brownstown appearing without gradation above the sandy clay of the Tokio. The lithologic break is still more evident at a place about a mile north of Ben Lomond, near the center of Sec. 32, T. 10 S., R. 29 W., where the top of the Tokio is argilla-

[58] Barrell, Joseph, Rhythms and the measurements of geologic time: Geol. Survey America Bull., vol. 28, p. 794, 1917.

[59] Grabau, A. W., Principles of stratigraphy, p. 821-826, 1913.

[60] Veatch, A. C., Geology and underground water of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 25, 1906.

[61] Miser, H. D., and Purdue, A. H., Gravel deposits of De Queen and Caddo Gap quadrangles: U. S. Geol. Survey Bull. 690, p. 25, 1919.

ceous sand containing large lenses of hard calcareous sandstone. The normal soft marl of the Brownstown crops out a few feet above this sand. A similar change in lithology occurs 1.3 miles east of Mineral Springs, on the road to Ben Lomond, where bedded limy Brownstown marl crops out a short distance above Tokio sand and clay. These lithologic changes, although suggestive, are not conclusive, but east of Mine Creek, in eastern Howard County and in Hempstead County, to the Little Missouri River, a similar lithologic break occurs, and the irregular contact is exposed.

On the road from Nashville to Ozan, 2.4 miles south of Nashville, in the ditch at the side of the road, there is exposed white Tokio clay containing poorly preserved fragments of plants. Here, resting on a slightly irregular surface, there is a deposit of dark, calcareous Brownstown clay showing "borings" and irregularities filled with limy, sandy clay that extends down into the Tokio. In the basal clay of the Brownstown are several layers of hard limestone containing rather numerous fossils, particularly the shells of *Inoceramus*.

About a mile east of this locality, 3 miles south of Nashville, on the road to Clow, the following section is exposed:

Partial Section Through Brownstown-Tokio Contact

	Ft.	In.
Top of exposure.		
Brownstown marl:		
Gray marl containing some hard lenses of gray limestone	3	0
Very hard, dense gray limestone containing numerous poorly preserved fossils	0	8
Yellow-gray marl	10	0
Irregular contact, poorly exposed.		
Tokio formation:		
Gray, non-calcareous clay, weathering white	2	0
Purple clay containing carbonaceous fragments	0	6
Principally white clay, but includes interbedded thin ferruginous sandstone	8	0
Yellow-weathering sand, cross-bedded with white clayey sand	3	0
Gray sand, massive and cross-bedded, weathering yellow	30	0
Base of exposure.		

A mile east of Doyle, along the Belton road, the top of the Tokio crops out in the ditch at the side of the road. Here purple clay containing small carbonaceous fragments is succeeded above by 3 feet of white and light-gray, thin-bedded, slightly sandy clay. Resting upon this clay, with the precise contact not exposed, is limy yellow-gray Brownstown marl. In the northwest corner of Sec. 18, T. 9 S., R. 25 W., about 2 miles northwest of Belton, the basal Brownstown makes a slight topographic elevation above the uppermost Tokio and crops out as an outlier about a mile in diameter. Over most of this area are scattered numerous lenses of hard, dense, gray limestone set in soft, deeply weathered marl. The top of the Tokio below consists of interbedded and cross-bedded sand, weathering yellow, and of white sandy clay. Four-tenths of a mile south of the Antoine-Arkadelphia highway, on the road to Okolona, the bedded gray Brownstown marl, which is sandy at the base, rests on coarse, gravelly, red-weathering sand of the Tokio formation.

From the Arkansas-Oklahoma line near the village of Arkinda eastward to Antoine Creek the Brownstown marl is lithologically almost uniform. Typically it is a gray marl nearly free from palpable sand. In nearly all its outcrops it is so deeply weathered that its original color can not be determined. In well samples and in the freshest exposures it appears to be uniformly dark gray. In weathered exposures, when damp, it shows slightly varying shades of light gray-brown and green-brown. When dry it is light gray to white and is hard, but when wet it is darker gray and is soft and plastic. In deeply weathered outcrops and in the subsoil it generally has a distinctly yellow tone. Such outcrops are spotted with numerous small, white, soft calcareous spherules, the product of the leaching and concentration of the carbonate in the marl. These nodules are more rarely yellow and ferruginous. At some places the unweathered marl appears massive, but exposure usually brings out distinct bedding planes and develops numerous irregular joints, so that it usually breaks into small, blocky fragments. It shows from place to place slight variations in its content of sand, and a small part of it is perceptibly sandy, even in the most typical localities. It generally contains thin and broken shells and rarely thin reefs of oyster-shell breccia.

East of Antoine Creek the lithologic character of the formation is more variable; it includes sandy beds of several types. About 5 miles north of Okolona, along the road to the Antoine-Arkadelphia highway, there is an outcrop of sand in its lower part. At the base of this outcrop there are

4 or 5 feet of irregularly bedded, very sandy gray clay. This clay is only slightly calcareous, and the fossils it contains are preserved only as casts and prints having red ferruginous coatings. At the top of the outcrop is a 2-foot bed of very fine-grained, even-grained yellow quartz sand, which weathers red and contains soft, irregular, stem-shaped ferruginous concretions. The base of the Brownstown, as exposed 0.7 of a mile farther north along this road is typical pure marl, weathering olive-brown, but the basal few feet are sandy. At this place the Brownstown rests on the sand of the Tokio formation. A few miles to the east the calcareous marl of the Brownstown rests directly on the Paleozoic rocks without any intervening sand of Tokio type. In the vicinity of Hollywood the lower part of the Brownstown is distinctly sandy. Seven-tenths of a mile east of Hollywood, on the road to Arkadelphia, the cut made for the road leading uphill out of the Terre Noire bottom land exposes at the base a few feet of interbedded fine yellow sand and gray calcareous clay. Above is a 10-foot section of fine-grained yellow argillaceous sand, in places in very thin layers, with some interbedded soft, red ferruginous sand and some sandy bedded clay.

Near Hollywood and east of it the interstream divides that rise gently to the north are mantled with a thin veneer of Cretaceous sand. This sand is somewhat like that of the Tokio, but is usually finer grained, and it usually includes no gravel, although gravelly sand is found at some places. In the absence of fossils it is necessary to determine the stratigraphy here by lithologic features and field relations, and in view of the truncation of the gravel and sand of the Tokio in areas farther east, where typical Brownstown rests directly on the Paleozoic rocks, and the known sandy character of the lower part of the Brownstown in this area, it seems reasonable to regard this thin veneer of clean sand at the base of the Cretaceous as the basal sand of the Brownstown transgression rather than as a remnant of Tokio sand.

At a place 1.6 miles east of Hollywood, on the Arkadelphia road, and at another place a mile south of Hollywood, on the road to Dobyville, beds of different lithologic character are exposed at a higher horizon in the Brownstown. These beds consist of a soft, marly, greenish-weathering, ripple-bedded sand and sandy clay containing some massive, soft, fine-grained green sand. Interbedded are hard beds and lenses of calcareous sandstone, 1 foot thick and 5 to 20 feet long. These lenses contain rounded and polished black, gray, and white pebbles of chert, one-sixteenth of an inch to three-eighths of an inch in diameter. The lenses contain abundant small nondescript calcareous fossils. The beds at this horizon are as much as 15 feet thick.

Higher in the Brownstown and half a mile farther south along this road, where it crosses a small creek near the edge of the Terre Noire bottom, in the SW. ¼ Sec. 34, T. 7 S., R. 21 W., is an outcrop of soft, dark-gray sand that includes hard, calcareous lenses containing numerous phosphatic pebbles. Some of these lenses are richly fossiliferous.

From 1.6 miles to 3.1 miles east of Hollywood, on the Arkadelphia road, new cut banks expose much of the Brownstown formation. It is here a bedded marl, some of it pure but most of it containing varying amounts of sand. The outcrops consist of interlenticular thin beds of fine yellow sand, sandy marl, and pure marl. Here there are lenses and small concretions of hard, dark-gray, very calcareous sandstone and several beds, a foot thick or less, of hard, calcareous, glauconitic marly sand containing numerous pebbles of chert and phosphate ranging from small grains to rounded flat pieces half an inch in diameter.

THICKNESS

The Brownstown marl is about 250 feet thick along a line running roughly through Nashville, Howard County, and Columbus, Hempstead County. Farther west, in Sevier County, between Ben Lomond and Brownstown, it appears to be only about 220 feet thick. Still farther west its thickness probably diminishes slightly. East of Howard County its thickness diminishes steadily, but no estimates of it are available.

FAUNA

The Brownstown marl is abundantly fossiliferous, but its fauna is most strikingly characterized by the large fossil *Exogyra ponderosa* Roemer (see Pl. IX, Fig. 1). This fossil is so plentiful in the formation and the overlying Ozan that they have together been termed the "*Exogyra ponderosa* marl." The large shells of this species are strewn in great

PLATE IX

(All figures natural size)

FIGURE 1. *Exogyra ponderosa* Roemer, a small specimen from the Ashdown-Ben Lomond road, 2 miles north of the bridge over Little River, Sevier County. This species ranges upward to the top of the Marlbrook marl (restricted).

2. *Exogyra ponderosa* Roemer (variety), a species of average size, from the Bingen road, 4.4 miles north of Ozan, Hempstead County. This variety has been found in Arkansas only in the Brownstown marl (restricted).

3. *Scaphites hippocrepsis* (De Kay) near the base of the formation, on the Mineral Springs road a mile east of Ben Lomond, Sevier County.

4. *Lucina* aff. *L. glebula* Conrad from the Brownstown road 1.5 miles southeast of Ben Lomond, Sevier County.

1

4

3

2

FOSSILS FROM THE BROWNSTOWN MARL

numbers over many plowed fields and weathered outcrops of the formation. A common form is *Exogyra ponderosa var. erraticostata* Stephenson,[62] a variety of the species ornamented with irregular costae that become weaker toward the margin. An *Exogyra* that has been found in Arkansas in the Brownstown formation only is regarded as a subtype of *Exogyra ponderosa var. erraticostata* Stephenson. It has a shell that is small and thin in comparison with other members of the genus and a left valve that is marked by numerous fine, narrow, bifurcating costae (see Pl. IX, Fig. 2). These fine costae resemble somewhat those found near the beak of some specimens of *E. ponderosa var. erraticostata.* This finely costate variety of *Exogyra* resembles *E. upatoiensis* Stephenson,[63] but is larger and more coarsely ribbed. According to Stephenson [64] an Exogyra having similar markings but of somewhat narrower and higher form is found in the Blossom sand in Texas.

The following forms have been identified by Dr. Stephenson in collections made from the formation by him, R. D. Mesler, H. D. Miser, W. C. Spooner, A. L. Selig, and the writer:

Echinodermata:
- Hemiaster (?)

Vermes:
- Hamulus major Gabb.
- Hamulus onyx Morton.
- Hamulus squamosus Gabb.

Molluscoidea:
- Lingula sp.

Mollusca:
- Nucula sp.
- Leda, sp.
- Cucullaea sp.
- Nemodon sp.
- Inoceramus sp.
- Ostrea plumosa Morton.
- Ostrea mesenterica Morton.
- Gryphaea vesicularis Lamarck (variety).
- Exogyra ponderosa Roemer.
- Exogyra ponderosa var. erraticostata Stephenson.
- Pecten sp. (small).
- Pecten sp. (large, smooth).
- Anomia argentaria Morton.
- Paranomia scabra (Morton).
- Pholadomya sp.
- Liopistha (Cymella) bella (Conrad)?
- Veniella conradi (Morton).
- Crassatellites ? conradi (Whitfield)?

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[62] Stephenson, L. W., Species of Exogyra from the eastern Gulf region and the Carolinas: U. S. Geol. Survey Prof. Paper 81, pp. 49-50, fig. 4, pl. 16, fig. 12, 1914.

[63] Stephenson, L. W., idem, p. 46, pl. 13. fig. 1-4, 1914.

[64] Stephenson, L. W., personal communication.

Lucina glebula Conrad?
Cardium dumosum (Conrad)?
Cyprimeria depressa Conrad.
Tellina sp.
Cymbophora sp.
Corbula sp. (large).
Dentalium sp.
Cerithium sp.
Turritella quadrilira Johnson.
Natica sp.
Baculites sp.
Placenticeras sp.
Scaphites hippocrepis (De Kay) (identified by J. B. Reeside, Jr.).
Fish scales and bones.
Shark teeth.

ORIGIN

Physical, paleontological, and regional stratigraphic evidence indicates a sedimentary break at the base of the Brownstown marl. The uppermost sediments of the Tokio were unquestionably laid down in shallow water, and at some places in their top few feet they contain lignite and lignitic material. Over this shallow-water sediment, resting on an irregular surface, are abundantly fossiliferous marls and thin lenses of limestone that were unquestionably formed in deeper water. No transitional beds are found. "Borings" filled with basal Brownstown sediment, which extend down into the uppermost Tokio, have perfectly sharp contacts. The Brownstown overlaps the Tokio a short distance east of Antoine Creek, corroborating the belief that there is a sedimentary break at the base. No decisive evidence of angular unconformity or downcutting and truncation of the Tokio is known; on the contrary there is evidence that the Tokio becomes thinner toward the north and east by a diminution of the thickness of the intercalated clay tongues. Physically the uppermost Tokio is much alike from Saline River to the Little Missouri; it consists of a rather persistent white clay and subordinate violet, slightly carbonaceous clay and yellow sand, which crop out below the lowest Brownstown. The variation in type of the top of the Tokio elsewhere can be more easily explained as due to variation in sediments than to downcutting of the Brownstown eastward.

The fauna also indicates a break at the base of the Brownstown. The specimen of the ammonite *Scaphites hippocrepis* De Kay, which was found near the base of the Brownstown marl half a mile northeast of Ben Lomond, is regarded by

Reeside[65] as a species of definitely Taylor age, but the fauna of the Tokio formation below is regarded by Stephenson as of Austin age. There is faunal break between the Austin and Taylor horizons in Texas, and, according to Stephenson[66] a slight angular unconformity can be detected at a few localities.

It is not known whether the break at the base of the Brownstown represents a period of actual surface exposure and subaerial peneplanation, a period of marine planation, or a period of nondeposition due to the completion of the profile of deposition in a static sea. A much less likely supposition is that sedimentation was continuous, but that submarine tilting produced a slight angular truncation and obliterated part of the record. The apparent magnitude of the faunal break, the absence of known angular truncation in this area, and the complete change in the lithologic character of the sediments weigh strongly against this supposition.

The occurrence of fossiliferous limestones of the Brownstown immediately over lignitic clays of the Tokio seems at first to indicate rather rapid submergence. Such submergence, however, by whatever agency produced, would lower the surface of the marine platform below the depth of effective wave erosion. As a result the material first deposited would be over the handling capacity of wave transportation at the depth of the deposition and would be relatively coarse and certainly unassorted at the base, so that the upper formation would have a relatively coarse basal layer.

The flatness of the marine platform and the adjacent land over which the seas transgressed would probably reduce the supply of coarse material and would alone account for the absence of such material above many of the stratigraphic breaks in the Gulf series. It would seem that a rapid transgression of the sea over such formations as the Tokio, Woodbine, and Trinity, no matter how flat may have been the land surface cut by subaerial degradation, would have preserved a layer of reworked coarser material at the base of the Brownstown. If, however, the transgression took place slowly the material originally deposited near the shore would be gradually worked over by waves and currents and reduced

[65] Reeside, John B., Jr., personal communication.
[66] Stephenson, L. W., personal communication.

in size and carried down the marine profile of equilibrium. By this process the coarse material (which was probably relatively small in amount if the land surface transgressed was nearly flat) would have been reduced to much finer material, distributed through a larger mass of originally fine material, and lost to recognition. Gradual submergence would at last have lowered the platform below the reach of effective wave action, first at the external margin of the platform, and the initial deposit of the upper formation would be material laid down in deep water. Continued gradual submergence would result in the shoreward transgression over the older formation of sediment formed at the same depth.

This submergence proceeded so slowly that most of the shallow-water sediments were removed from the platform by waves and deposited in deeper water. In the northeastern part of the outcrop the basal part of the Brownstown is sandy. It seems possible that this part was preserved here because of the relative proximity of the shore line and the fact that the transgression was practically complete. Accordingly some of the material that was originally deposited is preserved in the northeastern part of the outcrop because there had not yet been time for its removal. Had the transgression continued for several miles farther to the north, this coarser material also would have been redistributed by waves and currents. The transgression may have been accompanied by slight tilting and consequent slight truncation of the Tokio eastward.

Goldman[67] and others have considered the relation between glauconite and stratigraphic breaks, and the presence of glauconite at the contacts between several formations in this area makes the absence of glauconite in appreciable amounts at and above this particular contact interesting. The range in depth within which glauconite can be formed is great. Twenhofel[68] reports mud-cracked greensands in the Cambrian of Wisconsin, and the writer has seen similar sun-cracked glauconitic sand from well cores of Cretaceous rock in Louisiana. The opposite extreme is illustrated by glauconite dredged from a depth of 3,512 meters in the Indian

[67] Goldman, M. I., Washington Acad. Sci. Jour., vol. 60, p. 502, 1919. Lithologic subsurface correlation in the "Bend Series": U. S. Geol. Survey Prof. Paper 129, p. 5, 1922. Basal glauconite and phosphate beds. Science, vol. 56, pp. 171-173, 1922.

[68] Twenhofel, W. H., and collaborators, Treatise on sedimentation, p. 339, 1926.

Ocean.[69] According to Twenhofel[70] the environment best suited for its development seems to be a marine bottom on which deposition is extremely slow and on which the sediments deposited are subjected for a long time to the wash of waves and currents and the action of sea water. Mansfield,[71] following Murray and Renard, believes that glauconite forms most abundantly at about the lower limits of wave, tide, and current action in the neighborhood of what may be called the mud line—that is, at depths of about 200 to 300 fathoms. He also points out[72] that clay layers in a formation such as the greensand beds of New Jersey may be transformed into glauconite by reaction with potash-bearing solutions.

Other factors than depth are clearly important in creating a suitable environment for the formation of glauconite, but it may be that the postulated depth of deposition of the basal Brownstown below the base of wave erosion helped to prevent the formation of glauconite above this disconformity. Glauconite was probably forming contemporaneously in the shallow water on the platform, and in fact the sand in the shallow-water Brownstown sediments preserved in the northeastern portion of the outcrop contains glauconitic layers.

PHYSIOGRAPHIC EXPRESSION

The topographic expression of the Brownstown marl is seen in broad, slightly rolling slopes and wide, alluvium-floored valleys, but the topographic form of the area as a whole depends so much on the partly fortuitous position of the principal drainage lines and the degree of removal of the widespread protecting terrace sand and gravel that high ridges and deeply trenched valleys are seen in some areas of Brownstown outcrop, particularly in Sevier County. In general it appears that the Brownstown, contrary to what might be expected, is more resistant to erosion than the sand of the underlying Tokio. The Brownstown in Sevier County stands so much higher than the uppermost Tokio that it makes a distinct escarpment east of Ben Lomond and north of Brownstown. Between Saline River and Mine Creek the Brownstown occupies a low, partly terrace-covered tract, but east

[69] Collet, L. W., Les dépots marin, p. 188, 1908.
[70] Twenhofel, W. H., and collaborators, op. cit.
[71] Mansfield, G. R., Potash in the greensands of New Jersey: U. S. Geol. Survey Bul' 727, p. 138, 1922.
[72] Mansfield, G. R., idem, pp. 134, 135, 140-142.

of Mine Creek it stands higher than the Tokio, and it becomes increasingly higher farther east, so that between the north fork of Ozan Creek and Little Missouri River it makes a perceptible escarpment above the Tokio. Still farther east, south of Delight, between Little Missouri River and Antoine Creek, the Brownstown escarpment is very noticeable.

The form of physiographic expression of the Brownstown marl may be due in part to its position, for the streams flowing south from the Highland cuesta erode more rapidly at their headwaters. The soft, deeply weathered marl may be more resistant to erosion than it appears to be, for, when wet, it may form a somewhat impermeable surface over which the run-off would flow rapidly with slight erosion except on slopes steep enough to start gullies. A more probably cause of its resistance, however, may be the widespread abundant growth of low vegetation which its limy soil affords in contrast with the sparse growth on the unconsolidated sand of the Tokio. This supposition receives some confirmation from the fact that the Tokio has been more completely removed from the basal gravel cuesta in the eastern area, where it consists almost entirely of sand.

OZAN FORMATION

GENERAL CHARACTER

The Ozan formation consists of sandy, micaceous marl and, in its lower part, of glauconitic marl and sand. It is typically exposed along the south side of the bottom land of the middle fork of Ozan Creek, and the town of Ozan, in Hempstead County, stands on its belt of outcrop. These sandy marls were included in the Brownstown marl of Veatch, but because of their somewhat different lithology and the unconformity at their base they are now set apart as a distinct formation.[73].

At the base of the Ozan formation in Sevier, Howard, and Hempstead counties is a sandy marl or marly sand, 3 to 15 feet thick, containing at some places as much as 50 per cent of coarse grains of glauconite. In many outcrops it contains also thin, highly polished pebbles and grains of black chert, phosphatic nodules, locally numerous shells, phosphatic casts, and shark teeth. This basal sand crops out a short

[73] Dane, C. H., Oil-bearing formations of southwestern Arkansas: U. S. Dept. Interior Memo. for the Press 8823, 1926.

distance north of the village of Buckrange, in Howard County, and also a mile northeast of that village, on the road to Nashville. It is therefore named the Buckrange sand lentil of the Ozan formation. This is almost certainly the stratum "100 to 200 feet above the uppermost Bingen sand, yielding a limited supply of hard, bitter water," mentioned by Veatch,[74] although he apparently knew no outcrops of the bed. Outcrops of quartz sand and sandy glauconitic clay within the Brownstown formation as defined by Veatch have already been noted.[75]

LITHOLOGY AND OUTCROPS OF THE BUCKRANGE SAND LENTIL

The Buckrange sand is traceable by intermittent exposures from a point about 2 miles southwest of Brownstown, in Sevier County, near the bottom of Little River, to the North Fork of Ozan Creek, along a line of outcrop trending east-northeast. It merges gradually upward into a micaceous, very sandy, massive marl containing numerous small oyster shells, which at some places occur in coquina-like layers. A second glauconitic sandy marl, which lies about 50 feet higher stratigraphically, is well exposed in Howard County and poorly exposed in Hempstead County. It seems to be represented in Sevier County by a glauconitic chalky marl. In most of the area to the west, in Little River County, there are no outcrops of the Cretaceous formations, but near the Oklahoma line, on the road between Foreman and Arkinda, there are outcrops of glauconitic beds that are apparently equivalent to the two glauconitic beds in Howard and Hempstead counties. East of Hempstead County the Buckrange sand lentil and the higher glauconitic bed are not found and are represented only by thin layers containing glauconite, which are with difficulty separable from the mass of the Ozan formation.

The character and relation of the two glauconitic beds are best shown in Howard County. Along the road that leads west from Tollette and across the bottom lands of Mine Creek, near Schaal, in Howard County, the lower part of the Ozan formation is well exposed. About a mile west of Tollette, near the edge of the bottom land, the Ozan-Brownstown

[74] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 78, 1906.
[75] Ellisor, A. C., Age and correlation of the chalk at White Cliffs, Ark.: Am. Assoc. Petrol. Geologists Bull., vol. 9, No. 8, p. 1158, 1925.

contact is exposed along the road. At the base is 14 feet of poorly exposed Brownstown marl. Where freshly exposed immediately below the Ozan it is a black marl nearly free from sand and containing numerous small, very thin, fragile shells. It is massive to irregularly bedded, and it breaks into angular lumps rather than flat plates. At the top this marl is interbedded for a few inches with lenses of glauconitic sand in a transition layer not more than 6 inches thick. The lenses are from a quarter of an inch to a half an inch thick and range in length from half an inch to 10 inches. The upper surfaces of the marl on which the lenses rest are at many places marked with ripples of an eighth of an inch to a quarter of an inch amplitude and half an inch or more wave length. The number of lenses gradually increases up to the base of the overlying massive sand. From the bottom of the larger sand lenses "borings" half an inch in diameter, filled with glauconitic sand, extend down into the marl for a few inches. The overlying sand is massive, very fine, marly quartz sand, spotted abundantly with grains of glauconite and weathering white. At the base of the sand there are thin lenses of black marl. The sand is harder and more resistant to weathering than the marl and makes a distinct ledge. Although not richly fossiliferous, it contains casts of gastropods and a few shells. Scattered through it are hard, black and brown waterworn and polished pebbles and grains of chert, which range in length from less than a quarter of an inch to a half an inch. The sand grades upward without a break into material that is less sandy and more marly, and the percentage of glauconite decreases concomitantly until the deposit becomes a hard, sandy, micaceous dark-gray to nearly black marl. This marl continues upward, with variations in its content of sand. The more resistant basal sand is about 3 feet thick. The sandy marl above is abundantly fossiliferous, containing numerous shells of *Exogyra ponderosa* and great numbers of small, thin shells, particularly *Ostrea plumosa* and *Ostrea falcata,* which are strewn over weathered surfaces. These oysters form weathered reefs of Coquina-like shell marl, from half an inch to 2 inches thick. The weathering is very deep; tapering joints filled with marly wash penetrate as much as 20 feet down into the rock.

Along the same road, about half a mile west of Tollette, is an outcrop that lies stratigraphically higher. Here 18 feet of sandy fossiliferous marl, weathering white, is exposed in gullies and ditches along the road. The top 6 inches of this deposit is glauconitic, but above this there is a distinct lithologic break where 6 feet of fine-grained glauconitic marly sand containing numerous shells and phosphatic casts of shells rests on a slightly irregular surface. Many of these casts are waterworn, but some are unworn, and a shark tooth with serrated edges shows little sign of wear. There are some small black pebbles and grains of phosphate and chert. The sand merges upward into silghtly sandy fossiliferous marl. Plane-table elevations and locations and a consideration of the regional dip show that the base of this higher glauconitic bed is about 50 feet above the base of the Buckrange sand exposed half a mile farther west.

These two glauconitic beds are exposed also along the Mineral Springs-Saratoga road. About 3.5 miles south of Mineral Springs the Buckrange sand is exposed in the road banks as a bed, 2 to 3 feet thick, of hard glauconitic sand, which contains numerous shells and phosphatic casts. Here the hard sand has formed a low ridge that trends east-northeast. Below the sand lies 20 feet of dark-gray marl containing numerous thin shells and small imprints of shells. The sand merges upward into sandy marl. About 4 miles south of Mineral Springs, on this road, the higher glauconitic bed crops out as a soft, glauconitic sandy marl containing phosphate nodules and casts. Plane-table elevations and locations and consideration of the regional dip shows that the base of the higher bed is here also about 50 feet stratigraphically above the base of the Buckrange sand.

About a mile northeast of Buckrange school, along the Nashville road, in the SW. ¼ NE. ¼ Sec. 26, T. 10 S., R. 27 W., the Buckrange sand crops out in a deep gully at the side of the road as a very glauconitic marly sand 3 feet thick. The contact at the base shows the 6-inch transitional band of interlenticular marl and sand, but at the base of the hard, sandy bed there is a distinctly irregular surface having a relief of nearly 1 foot vertically in 3 feet horizontally.

About half a mile southeast of Buckrange, on a road that stops a mile from the village, there is a small outlier of the higher glauconitic bed in the NW. ¼ NE. ¼ Sec. 35, T. 10 S.,

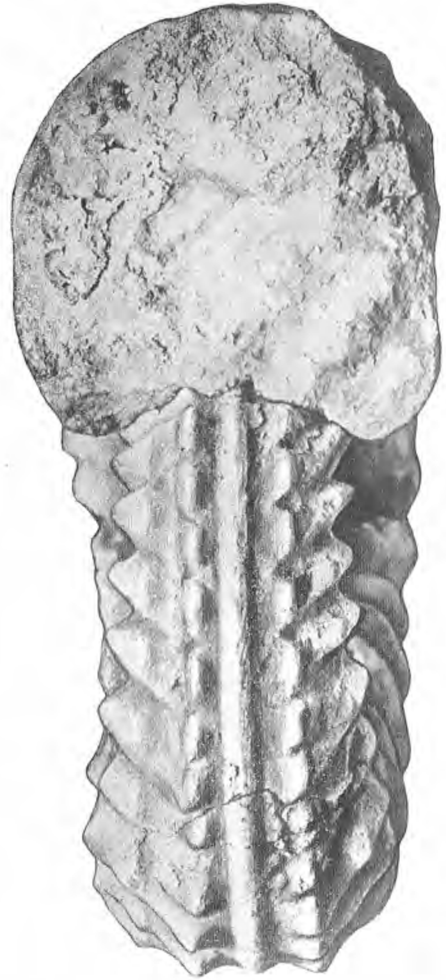
PLATE X

(Figures natural size)

FIGURE 1. *Mortoniceras* aff. *M. delawarenses* (Morton) from bank of branch near the Arkinda road, 5.5 miles northwest of Foreman, Little River County.

2. Front view of the same specimen with the large end removed back to the first conspicuous crack.

1



2

FOSSIL FROM NEAR THE BASE OF THE OZAN FORMATION

R. 27 W. Here there are 3 feet of marly, glauconitic, fine-grained sand containing numerous phosphatic casts of shells. Half a mile farther southeast, across a small gulch, the main line of outcrop of this higher sand is exposed.

The Buckrange sand is exposed 5.9 miles from Nashville post office, on the road from Nashville to Ozan. At this place 4 or 5 feet of white, strongly fossiliferous glauconitic marly sand crops out above weathered brown and gray non-glauconitic and only very slightly sandy Brownstown marl. No higher glauconitic bed has yet been found in this vicinity.

The lower part of the Ozan is well exposed along the road from Ozan to Bingen by way of Zion Church. The Buckrange sand is exposed at a point 4.2 miles from Ozan as a 3-foot bed of glauconitic marly sand containing a few phosphatic nodules and casts.

A few feet below, in the vertical banks of the creek that crosses the road, there are extensive outcrops of non-sandy Brownstown marl. Above the Buckrange sand there is sandy, very fossiliferous marl.

At a point 3.3 miles from Ozan on this road, above good exposures of sandy Ozan marl, there is a glauconitic zone, which is probably equivalent to the glauconitic bed above the Buckrange at its type locality. The exposure at this place shows a 2-foot bed of strongly glauconitic sandy marl containing a few phosphate casts and rather abundant fossils. Above is 20 feet of micaceous sandy marl, and at the top is another 2-foot bed of glauconitic marly sand, in which nearly one-third of the mass is glauconite.

East of these localities surficial sand terraces and alluvium conceal the outcrop of the Ozan formation to and a few miles beyond the Little Missouri, and the greensand beds are not well exposed there. The more easterly part of the Ozan formation is described on pages 67 to 69.

West of Howard County, between Saline and Cossatot rivers, in southern Sevier County, the basal Ozan is well exposed for a distance of about 5 miles.

In the northeast part of the SE. ¼ NW. ¼ Sec. 15, T. 11 S., R. 29 W., on the hill slopes west of Black Branch, is a 2-foot ledge of hard, very glauconitic sand containing numerous rounded, flat pebbles, which are set variously in the sand. The pebble bed has an irregular under surface and rests on glauconitic sandy marl. A few feet below it non-sandy Brownstown marl crops out.

In the NE. ¼ Sec. 22, T. 11 S., R. 29 W., near the bottom of Black Branch, is an outcrop of the Buckrange sand, which was first noted by Taff in 1902.[76] At this place 3 or 4 feet of glauconitic sandy marl crop out below massive gray sandy marl. The material is really a marl containing grains of sand and grit and pebbles of black chert. The pebbles range from an eighth of an inch to a half an inch in diameter and are smoothly rounded and polished. Some are spheroidal, but flat pebbles are strikingly predominant. The glauconite occurs in irregular patches and lenses in the marl, and the typical lens is an inch or so in length and an eighth of an inch in thickness.

At a place 0.3 mile south of Brownstown the following section is exposed:

Section South of Brownstown

	Feet
Top not exposed.	
Chalky glauconitic sandy marl containing numerous phosphatic casts	5
Sandy marl containing numerous fossils (*Ostrea plumosa, Ostrea falcata, Exogyra ponderosa, and Exogyra ponderosa var. erraticostata*)	60
Massive marly sand containing a great quantity of angular and rounded grains of grit and pebbles of quartz and chert. The pebbles are as much as an inch in diameter, have rounded polished surfaces, and are prevailingly flat. Phosphatic casts, calcareous fossils, and shark teeth are abundant. Some of these teeth are unworn; others show much wear. A few have been broken and broken edges worn smooth	6
Glauconitic sandy marl, in which the glauconite is concentrated into small lenticular pockets in less glauconitic marl	12
This lower bed is transitional at its top into the bed above.	
Base not exposed.	

The Buckrange sand near the base of the exposure here is evidently more nearly transitional than at the outcrops already described. The chalky glauconitic bed higher in the section is the only glauconitic outcrop at a higher horizon thus far found in Sevier County.

There is a small outlier of Buckrange sand about 2 miles southeast of Ben Lomond, on the road to Brownstown, near the Gravel Hill School. Almost 30 feet of very sandy marly and some strongly glauconitic beds containing phosphatic nodules are here exposed. Fossils and waterworn shark teeth are abundant. The contact with the marl below is sharp.

[76] Taff, J. A., Chalk of southwestern Arkansas: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 3, p. 707, 1902.

About a mile southeast of the outcrop of Buckrange sand just south of Brownstown there is an outcrop in a small gully in the northeast corner of the SW. ¼ Sec. 13, T. 11 S., R. 29 W. Here a few feet of glauconitic sand containing numerous dark, flat, well-worn chert pebbles and worn shark teeth crops out above non-sandy Brownstown marl. The sand is transitional above into dark-gray, massive sandy marl. Four feet above the top of the sand is a lenticular bed of hard sand, 6 inches in thickness and about 25 feet in length, above which massive sandy marl again outcrops.

Along the highway from Foreman to Arkinda, in Little River County, there are good exposures of the Ozan formation. From 3.5 to 3.8 miles from Foreman there are good outcrops of two beds, each about 3 feet thick, of hard, white, glauconitic marly chalk, separated by 12 feet of chalky, very sandy marl. These glauconitic beds carry abundant calcareous fossils, mainly small, convex shells of Gryphaea and Inoceramus. Below these slightly glauconitic beds there is massive, gray, poorly bedded sandy marl containing numerous fragments of shells, including *Ostrea plumosa, Ostrea falcata, Anomia sp., Paranomia scabra,* and large *Exogyra ponderosa.*

At a distance of 4.75 miles from Foreman along this road there are outcrops of massive, dark-gray sandy marl containing some beds of fine-grained marly sand; at a distance of 5 miles there is an outcrop of sandy, very chalky marl; at 5.5 miles there are good outcrops of poorly sandy marl. At a point 5.65 miles from Foreman the lower glauconitic horizon crops out in the bank of a small creek along the east side of the road. Here the following section was measured:

Partial Section of Ozan Formation 5.65 Miles from Foreman, Along the Road to Arkinda

Top of exposure.	Ft.	In.
Bed of hard, white-weathering earthy chalk containing numerous large prints of *Inoceramus*	1	6
Massive, sandy, micaceous marl containing lenses of hard marly chalk. This bed and the one below it contain large *Placenticeras, Mortoniceras,* and straight ammonites *(Baculites)* more than a foot long	5	0
Gray sandy marl containing abundant scattered coarse glauconitic grains and black, well-rounded chert pebbles and grains, most of them flat, as much as half an inch in diameter	2	0
Glauconitic marly sand in small lenses scattered through nonglauconitic marl	0	6

PLATE XI

(Figures natural size)

Figure 1. *Exogyra ponderosa* Roemer from near the top of the Ozan formation 2.5 miles northeast of White Cliffs, Sevier County.

2. *Gryphaea* sp., a smooth, convex species from the Hollywood road 8.1 miles west of Arkadelphia, Clark County.

2

1

FOSSILS FROM THE OZAN FORMATION

Base of Ozan formation.		
Soft, bedded micaceous, slightly sandy marl	1	0
Concealed by bank slump	4	0
Base of exposure: creek level.		

Carefully taken aneroid elevations and consideration of regional dip show that the base of this glauconitic bed is about 100 feet below the base of the higher glauconitic beds exposed 3.5 miles from Foreman along this road, as compared with 50 feet in the vicinity of Buckrange and about 70 feet in the vicinity of Brownstown.

LITHOLOGY AND OUTCROPS OF THE UPPER PART OF THE OZAN FORMATION

The normal phase of the Ozan formation in Sevier, Hempstead, and Howard counties varies in lithologic composition somewhat between sandy marl and marly sand. In its lower part it is extraordinarily fossiliferous, containing thin reefs of *Ostrea falcata* and *Ostrea plumosa* and numbers of *Ostrea congesta* attached to shells of *Inoceramus* sp. *Exogyra ponderosa* is extremely abundant. In this part there are some thin, hard, light-brown, slightly sandy beds of limestone. In Hempstead and Howard counties, as shown by the section along the South Fork of Ozan Creek and by an outcrop near Yancy, in Hempstead County, and one near Schooley, in Howard County, the upper 75 to 100 feet is only sparingly fossiliferous. This upper zone contains also some very sandy beds, as shown a mile north of Yancy, on the road to Nashville. At this place very sandy marl is interbedded with cross-bedded, fine-grained marly quartz sand and thin beds of hard, cemented, calcareous sandstone In Sevier County the upper part of the Ozan can hardly be separated from the lower part, although the upper part is somewhat less fossiliferous.

In Little River County the Ozan is generally less sandy and includes some beds of chalky marl, particularly in its upper part and between the two glauconitic beds in its lower part.

LITHOLOGY AND OUTCROPS OF THE OZAN FORMATION EAST OF LITTLE MISSOURI RIVER

Sandy marl of the Ozan formation crops out in a small area east of Little Missouri River in the vicinity of Bowenstown, in southern Pike County. Four miles from Delight, on the road from that place to Bowenstown, there is a small outcrop of glauconitic marl containing a few phosphatic casts of gastropods. This outcrop probably represents the base of the Ozan in this area. It rests on poorly exposed, deeply weathered, micaceous, slightly sandy marl. Half a mile from Bowenstown, on the road to Pisgah, glauconitic, very sandy marl crops out along the road and sandy marl crops out along the creek below. Half a mile from Bowenstown, on the road to Antoine, sandy micaceous gray marl and marly sand crop out along the road. The Brownstown differs from the Ozan in lithologic character in this area, but the difference is much less than it is farther west. The Buckrange sand does not appear at the base of the Ozan.

In the area east of Antoine Creek the Ozan is only tentatively separated from the Brownstown marl, although its presence is clearly shown by the abundance of the smooth, convex variety of *Gryphaea vesicularis* Lamarck (see Pl. XI, Fig. 2) and the much higher percentage of sand in the upper part.

Eight-tenths of a mile north of Okolona, on the road to the Antoine-Arkadelphia highway and at many places further along the road, the dark-gray sandy marl containing abundant smooth, convex gryphaeas crops out At a place 2.4 miles north of Okolona, in gullies in the field west of the road, is a bed of sandy marl containing coarse grains of quartz and glauconite, phosphatic grains, and fossil casts. This bed may represent the base of the Ozan formation, for the gullies below expose about 20 feet of much less sandy and better bedded marl. Above the glauconitic layer is sandy marl containing some beds of calcareous sandstone, as much as 4 inches thick, carrying small pebbles of quartz and chert.

A good outcrop of typical Ozan is found along the Okolona-Arkadelphia road, in the NE. ¼ Sec. 3, T. 8 S., R. 21 W. The dark sandy marl here contains numerous specimens of *Exogyra ponderosa* and the smooth, convex variety of gryphaea.

Cuts along the Arkadelphia-Hollywood road expose a fairly good section of the Ozan formation. The most interesting outcrop is that of the top of the formation 8.1 miles from Arkadelphia. The bank of the creek here exposes 30 feet of dark-gray, massive, slightly sandy marl. Above, along the road, is a 5-foot bed of fine-grained, very dark gray sand, slightly argillaceous and calcareous.

This sand carries an abundant fauna containing great numbers of the small, smooth, convex species of *Gryphaea*. Above is a foot or two of hard calcareous sand which contains some grains of grit size, weathers white, and carries a fauna consisting principally of the smooth, convex species of *Gryphaea*. This bed is overlain by the Marlbrook marl.

The base of the Ozan along this section can not be certainly placed, but it may perhaps be at a point 8.8 miles from Arkadelphia, at the base of a 3-foot bed of massive glauconitic marl containing scattered phosphate nodules and casts and some chert pebbles. The marl above this bed is generally more massive and sandy; the marl below it, although it is sandy, show distinct bedding into alternating layers of sandy and pure marl.

The hard marly sand at the top of the Ozan, which carries abundant shells of the smooth, convex gryphaea, is exposed in small creeks and gullies in the SW. ¼ Sec. 16, T. 7 S., R. 20 W., half a mile south of the road from Arkadelphia to Hearn, in Clark County.

An outcrop of sandy micaceous marl that is assigned tentatively to the Ozan may be seen along a secondary road in the NW. ¼ SE. ¼ Sec. 10, T. 7 S., R. 20 W. It contains glauconitic and pebble-bearing beds. Another outcrop that is tentatively placed in the Ozan is found in a small gully in the NE. ¼ Sec. 11, T. 7 S., R. 20 W. The outcrop at this locality is unusual in that it contains some pieces of black, carbonized wood as much as 6 inches long.

THICKNESS

A thickness of 200 feet is assigned to the Ozan formation along the line between Nashville, Howard County, and Columbus, Hempstead County. This estimate of its thickness is based on careful aneroid elevations and consideration of the regional dip. In Sevier County the Ozan is certainly thinner. The hand-levelled sections given by Taff[77] show a thickness of only 115 feet, but the "Gryphaea vesicularis bed" by which his two partial sections were tied together may not have been the same bed, as there are certainly beds containing extremely abundant smooth, convex gryphaeas at several levels in the formation. The well records, the aneroid

[77] Taff, J. A., Chalk of southwestern Arkansas: U. S. Geol. Survey Twenty-second Ann. Rept., 1900-1901, pt. 3, p. 707, 1902.

PLATE XII

(All figures natural size)

FIGURE 1. *Baculites* cf. *B. ovatus* Say, from near the base of the Ozan formation, in bank of small branch near the Arkinda road 5.5 miles northwest of Foreman, Little River County. This is part of an incomplete specimen 12 inches long.

2. View of the broken end of the same specimen.

3. *Gryphaea* sp., a smooth convex species from near the top of the formation a mile northwest of White Cliffs, Little River County.

4. Another view of the same specimen.

FOSSILS FROM THE OZAN FORMATION

elevation, and the regional dip show that the Ozan is here probably about 150 feet thick. In Little River County along the Foreman-Arkinda road, the Ozan is probably about 250 feet thick. East of Antoine Creek, in Clark County, the thickness of the Ozan alone has not been estimated because of the uncertainty of the position of the Ozan-Brownstown contact. The formation diminishes steadily in thickness toward the east, however, and in the vicinity of Arkadelphia the combined thickness of the Brownstown and Ozan is probably only 150 feet.

FAUNA

Until much more extensive collections of fossils have been made and the faunas have been studied critically there will apparently be few significant points of difference between the Brownstown and the Ozan faunas and apparently still less between the fauna of the glauconitic sands of the Ozan and that of the remainder of that formation. Nevertheless, as a starting point for further investigation, the species identified from the Ozan formation have been tabulated below in three lists, one including forms found in the Buckrange sand, a second including those found in the glauconitic sand (which stands 50 to 100 feet higher stratigraphically), and a third including those identified from the Ozan formation at large. It should be noted that this third list includes collections made from the marl between the two sands as well as from the upper part of the formation.

The following species from the Buckrange sand have been identified by Dr. Stephenson from collections made by him, W. C. Spooner, A. L. Selig, H. D. Miser, and the writer. Three cephalopods, as noted, were identified by Dr. J. B. Reeside, Jr.

Coelenterata:
- Cliona (a boring sponge).
- Corals.

Vermes:
- Serpula sp.
- Hamulus onyx Morton.

Mollusca:
- Leda sp.
- Striarca?
- Arca sp.
- Inoceramus (cf. I. barabini Morton).
- Ostrea panda Morton.
- Ostrea falcata Morton.
- Ostrea plumosa Morton.
- Gryphaeaostrea vomer (Morton).

Gryphaea aucella Roemer.
Gryphaea sp. (smooth, convex species).
Exogyra ponderosa Roemer.
Pecten sp
Pecten aff. P. quinquecostatus Sowerby.
Pecten sp.
Anomia argentaria Morton.
Paranomia scabra (Morton).
Pholadomya sp.
Liopistha (Cymella) sp.
Liopistha alternata Weller.
Veniella conradi (Morton).
Veniella (Etea) sp.
Crassatellites sp.
Cardium (Pachycardium) sp.
Clavagella armata Morton.
Gastrochaena (?)

Gastropoda:
Delphinula lapidosa Morton.
Natica sp.
Anchura sp.
Gyrodes sp.
Anisomyon (?)
Turritella sp.
Actaeonina (?)
Actaeon sp.

Cephalopoda:
Baculites asper Morton.
Baculites cf. B. ovatus Say (identified by J. B. Reeside, Jr.).
Baculites cf. B. ovatus var. haresi (identified by J. B. Reeside, Jr.).
Nostoceras (?)
Placenticeras.
Pachydiscus (?)
Mortoniceras aff. M. delawarense (Morton) (identified by J. B. Reeside, Jr.). (See Pl. X.)

Vertebrata:
Shark teeth.
Mososaurus (?)

The following species have been identified by Dr. Stephenson from collections made by him and the writer from the higher glauconitic sand of the Ozan:

Vermes:
Serpula sp.

Pelecypoda:
Cucullaea sp.
Inoceramus aff. I. barabini Morton.
Gryphaea sp. (smooth, convex species).
Trigonia sp.
Pecten aff. quinquecostatus Sowerby.
Crassatellites sp.
Cardium sp.
Pachycardium sp.
Aphrodrina (?)
Clavagella aff. C. armata Morton.

Gastropoda:
Anchura sp.
Actaeon sp.
Anisomyon (?)

Cephalopoda:
- Eutrephoceras sp.
- Scaphites sp.
- Hamites (?)
- Baculites asper Morton.
- Baculites sp.

Crustacea:
- Stenocionops (?) (identified by Mary J. Rathbun of the U. S. National Museum as this genus or near it).

From the marls of the Ozan formation Dr. Stephenson identified the following species from collections made by him, T. W. Vaughan, H. D. Miser, J. A. Taff, D. B. Coulter, Jr., and the writer:

Echinodermata:
- Hemiaster sp.

Vermes:
- Serpula sp.
- Hamulus squamosus Gabb.
- Hamulus onyx Morton.

Molluscoidea:
- Terebratulina (?)

Pelecypoda:
- Ostrea plumosa Morton.
- Ostrea falcata Morton.
- Ostrea panda Morton.
- Gryphaea vesicularis Lamarck, variety.
- Gryphaea sp. (smooth, convex species).
- Gryphaeostrea vomer (Morton).
- Exogyra ponderosa Roemer.
- Exogyra ponderosa var. erraticostata Stephenson.
- Exogyra sp. (var. resembling but smaller than E. costata Say).
- Pecten aff. P. quinquecostatus Sowerby.
- Pecten hilgardi Stephenson.
- Lima aff. L. reticulata Forbes.
- Anomia argentaria Morton.
- Paranomia scabra (Morton).
- Veniella (Etea sp.).
- Crassatellites sp.
- Cardium sp.
- Sauvagesit cf. S. belti Stephenson. (See Pl. XIII.)
- Durania (?) cf. D. austinensis (Roemer).
- Cyprimeria sp.
- Cymbophora (?)
- Gastrochaena americana Gabb (?)

Gastropoda:
- Delphinula cf. D. lapidosa Morton.
- Gyrodes (2 species).
- Natica sp.
- Turritella sp.
- Anchura (2 species).
- Volutilithes (?)
- Volutomorpha sp.
- Volutoderma sp.
- Actaeon sp.

Cephalopoda:
- Baculites asper Morton.
- Baculites sp.

Vertebrata:
- Fish tooth.
- Shark tooth.
- Vertebra.

PLATE XIII

(Figures natural size)

Figure 1. *Sauvagesia* aff. *S. belti* Stephenson, from a point a mile northwest of White Cliffs, Little River County. Interior view.

2. Exterior view of the same specimen.

1

2

FOSSIL FROM THE TOP OF THE OZAN FORMATION

The most striking difference in the larger forms in the faunas of the Ozan and Brownstown formations are seen in the genera *Gryphaea* and *Exogyra*. The *Gryphaea,* usually termed *Gryphaea vesicularis* Lamarck, variety; exhibits a wide range of variation in size and convexity. There is, however, an approach to uniformity in a variety having a smooth surface that is nearly free from growth lines; a convex, nearly hemispherical left valve; and a size ranging from a quarter by a half an inch to 2 by 2½ inches, somewhat smaller than the flatter-valved varieties (see Pl. XII, Figs. 3 and 4). This smooth, convex variety of gryphaea occurs in abundance throughout the Ozan formation, but apparently not in the Brownstown marl, or is rare there, although the large, flat variety is found in the Brownstown as well as in the Ozan.

The variety of *Exogyra ponderosa* having a finely ribbed left valve and showing similarity to *Exogyra upatoiensis* Stephenson, which is found occasionally in the Brownstown marl, has not been found in the Ozan formation. On the other hand, an exogyra that is apparently identical in surface ornamentation with *Exogyra costata* Say, but usually much smaller and from a third to a half the size of a typical specimen of *E. costata,* has been found occasionally in the Buckrange sand and higher in the Ozan formation, but has not been found in the Brownstown marl. A closer study of the great numbers of specimens of *Exogyra ponderosa* that occur in the Brownstown and Ozan formations might show that other varieties also have a definite range. The Brownstown appears to contain a larger number of exogyras of a type that has a more convex left valve, more circular cross section, less tendency to spiral twist, and a longer shell, the surface of which is smooth, marked by fewer lines of growth and less crenulation in the lines (see Pl. IX, Fig. 1). The exogyra in the Ozan, on the contrary, appears generally to have a flatter and more twisted shell, on which the lines of growth are more closely spaced and crenulated (see Pl. XI, Fig. 1).

CORRELATION

The Ozan formation has been tentatively correlated with the lower part of the Annona chalk as exposed in the vicinity of Clarksville, Texas,[78] partly on paleontologic grounds and

[78] Stephenson, L. W., Notes on the stratigraphy of the Upper Cretaceous formations of Texas and Arkansas: Am. Assoc. Petrol. Geologists Bull., vol. 11, No. 1, pl. 1, 1927.

partly by other evidence. The Annona chalk as exposed at Clarksville is unusually thick, measuring possibly about 400 feet, but its thickness in Arkansas is not much more than 100 feet. The combined thickness of the Ozan and the chalk in Little River County is, however, about 350 feet. Although there is some evidence of a break and certainly of an abrupt change of sedimentation at the base of the chalk in the vicinity of White Cliffs and at places further east, the chalk in the area around Rocky Comfort, in Little River County, apparently merges gradually into the Ozan marl below. The change in the character of the glauconitic beds of the Ozan westward from marly sands to marly chalk has been already mentioned, and other beds of marly chalk are found in the sandy marl of the Ozan in the lower part of the formation in Little River County. The upper part of the Ozan in this vicinity is also chalky. Furthermore, the base of the Annona north of Clarksville, Texas, is marked by a bed of glauconitic chalk carrying phosphatic nodules and casts, a bed very similar to that in the zone at the base of the Ozan exposed 5.65 miles north of Foreman, on the road to Arkinda. The lithologic character of the marl below the chalk at Clarksville is practically identical with that of the typical Brownstown marl. All the evidence now available tends to show that by the gradual westward diminution of its content of sand and clay and the concomitant increase in its content of calcareous material the Ozan formation of Arkansas merges into the lower part of the Annona chalk at Clarksville.

ORIGIN

The break at the base of the Ozan formation is interpreted as representing a submarine surface of erosion or non-deposition. Such a submarine surface might result from the completion of the marine profile of equilibrium during a period of stability of sea level. If this were so, the time that elapsed before transgression and submergence were resumed would be unrepresented in the sedimentary record. With a decrease in the supply of sediment after the profile of equilibrium had been established the conditions would probably demand a new and lower profile of equilibrium, so that there would be submarine erosion and removal of the excess sediment. A new transgression or a rejuvenation of sedimentation by climatic or orogenic change would mantle the submarine surface once more. A temporary lowering of the sea level would also lower this profile of equilibrium and would develop a surface of submarine erosion that would be covered by sediments when there was a rise of sea level.

The local details at the base of the Ozan formation where it is best exposed show evidence of transition and nearly continuous, although probably extremely slow, sedimentation. There is usually a zone, a few inches thick, in which small lenses of glauconitic sand alternate with the marl, although several outcrops show considerable irregularity at the base of the pebble-bearing sand, probably due to local erosion by currents. This partly transitional character of the base seems to indicate that the break represents a period of practical cessation of sedimentation, rather than a period of submarine erosion. If this cessation of sedimentation was due to the completion of the profile of marine equilibrium, the pure marls of the uppermost Brownstown show that the profile in this area must have been established at considerable distance from shore or that the land-derived sediments were very sparse. An alternative possibility is that lowering of the water level and regression occurred to the extent of establishing the profile of equilibrium without effecting submarine erosion. The Buckrange sand, at the base of the Ozan, exhibits much internal evidence that it was long worked over by waves and currents. That it lay at a depth within the range of such action is shown by ripple marks and by the striking flatness of the chert pebbles embedded in it. According to Wentworth [79] an abundance of flat pebbles, if composed of originally homogeneous material, may indicate long-continued sliding abrasion produced by waves or currents, or selective sorting, the more rounded pebbles being moved more readily by rolling. These pebbles may have been shaped, in part at least, on a beach not far from the rocks from which they were derived.

By whatever process these pebbles were shaped, the work of shaping them must have consumed a long time. The extremely abundant worn shark teeth found in several outcrops indicate the same long-continued action. The quantity of glauconite in the basal sand of the Ozan confirms this

[79] Wentworth, C. K., The shapes of pebbles: U. S. Geol. Survey Bull. 730, 1922.

conclusion, for deposition on the postulated marine surface was no doubt extremely slow, and the material was subjected for a long time to the action of waves and currents under conditions that are regarded as ideal for the formation of glauconite,[80] although the conditions under which glauconite is formed show a wide range. Goldman[81] has called attenention to the relation between glauconite and disconformity. The large number of phosphatic nodules and casts in it apparently suggests an abundance of decaying organic matter.[82] The Buckrange sand is probably a residue of a much larger deposit from which most of the finer material has been removed by the action of waves.

The disconformity at the base of the Ozan should extend landward into an unconformity indicating actual subaerial exposure, provided the Ozan overlaps the Brownstown. Such an overlap has not been found. Both formations, as traced northeastward, presumably toward a not far distant shore, exhibit increasingly near-shore characteristics. Certainly this statement is particularly true of the Brownstown, but this is slight evidence on which to predicate a progressive overlap of the Ozan.

In order to start sedimentation on this disconformity, the marine profile of equilibrium must have been raised, either by a rise of the sea level and accompanying transgression of the sea or by a higher rate of supply of sediment. The fact that the Ozan is much more sandy and micaceous than the Brownstown indicates that the supply of sediment was more abundant during its deposition, as there is no reason to believe that the Ozan was formed nearer the shore than the Brownstown. The slight evidence of overlap of the Ozan appears to favor the opposite conclusion that sediment supply was less abundant during its deposition, for transgression by rise of sea level would raise the base level of subaerial erosion and diminish the rate of erosion and the supply of sediment unless the climate varied simultaneously.

The higher glauconitic sandy bed of the Ozan may represent a second short period of change in the profile of equi-

[80] Twenhofel, W. H., Treatise on sedimentation, p. 339, 1926.
[81] Goldman, M. I., Lithologic subsurface correlation in the "Bend series" in Texas: U. S. Geol. Survey Prof. Paper 129, pp. 4, 5, 1922.
[82] Murray and Renard, Deep-sea deposits, Challenger Report, 1891, pp. 291-340.

librium, possibly of the rank of a diastem as defined by Barrell.[83]

The practical disappearance of the Buckrange sand and the higher glauconitic sand in the Ozan northeastward is possibly due to the fact that the conditions near the shore were not favorable to their deposition and possibly to the fact that such material as was deposited was completely removed by currents and waves rather than reworked and resorted.

The diminution in the thickness of the Ozan and Brownstown is apparently due not to truncation but to the progressive shoreward thinning of the formations.

PHYSIOGRAPHIC EXPRESSION

The topographic expression of the Ozan formation is similar to that of the Brownstown marl except that the average elevation of the Ozan is usually lower, for the formation is farther down the general dip. The hard bed of Buckrange sand at the base of the Ozan has here and there produced a slight topographic ridge, but more often it has found no appreciable expression. A topographic ridge attributable to the Buckrange may be seen 2 miles southeast of Ben Lomond, on the road to Brownstown, and less certainly 3½ miles south of Mineral Springs, on the road to Saratoga.

ANNONA CHALK

HISTORICAL SUMMARY

The Annona chalk is a hard, white, thick-bedded and massive, slightly fossiliferous chalk. The outcrops in Arkansas can be readily divided into four geographic groups, which are separated by considerable stretches in which the chalk is concealed by alluvium and terrace sand. One group is at Rocky Comfort, in the southwestern part of Little River County; one is at White Cliffs Landing, in eastern Little River County; one is on the south side of Plum Creek, in Howard County; and one is south of Yancy, in Hempstead County.

In his original report Hill[84] assigned the "Rocky Comfort" chalk in the southwestern part of Little River County to a lower horizon than the chalk that crops out at White Cliffs Landing and south of Plum Creek, which he termed

[83] Barrell, Joseph, Rhythms and the measurement of geologic time: Geol. Soc. America Bull., vol. 28, No. 4, p. 794, 1917.

[84] Hill, R. T. Neozoic geology of southwestern Arkansas: Arkansas Geol. Survey Ann. Rept. 1888, vol. 2, p. 89, 1888.

the "White Cliffs Chalk"[85] (see Pl. XIV, A). Later Hill[86] regarded the Annona chalk south of Paris, Texas, and the "White Cliffs" chalk of the Arkansas section as stratigraphic equivalents. The "Rocky Comfort" chalk he regarded as the equivalent of the Austin chalk,[87] and he used the term Annona for the chalk exposed in the vicinity of Clarksville and Annona, Red River County, Texas, and at White Cliffs in Arkansas,[88] because the term "White Cliffs" was preoccupied as a formation name.[89]

Taff recognized the equivalence of the chalk exposed at Rocky Comfort and at White Cliffs and included them in the "White Cliffs formation."[90] He believed that the base of the chalk transgressed upward in the geologic section eastward from Sherman, Texas, but it is not clear that he believed that the chalk in Arkansas as a whole was younger than the chalk in Texas. Veatch adopted the term Annona chalk, [91] used by Hill, but applied it to the beds defined as the "White Cliffs formation" by Taff, including the chalk at Rocky Comfort.[92] The name Annona is rather inappropriate, for the village of Annona is about 2 miles southeast of the nearest outcrop of the chalk, but the term has become so commonly used that it should be retained.

Stephenson regarded the chalk near Clarksville and Annona, Texas, as younger than the type Austin[93] and, accepting Gordon's mapping of the Austin chalk continuously with the chalk near Clarksville,[94] called the chalk in northeastern Texas and southwestern Arkansas the Annona tongue of the Austin chalk. Later work by A. C. Ellisor[95] and L. W. Stephenson[96] has shown that the top of the Annona at Clarks-

[85] Idem, pp. 87, 88.

[86] Hill, R. T., Geology of parts of Texas, Indian Territory and Arkansas adjacent to the Red River: Geol. Soc. America Bull., vol. 5, p. 308, 1894.

[87] Hill, R. T., Geography and geology of the Black and Grand Prairies, Texas: U. S. Geol. Survey, Twenty-first Ann. Rept., pt. 7, p. 331, 1901.

[88] Idem, p. 340.

[89] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains: U. S. Geol. and Geog. Survey Terr., 2d div., pp. 41, 51, 151, 1876.

[90] Taff, J. A., Chalk of southwestern Arkansas: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 3, p. 700, 1902.

[91] Hill's spelling Anona was changed to conform to the spelling used in the Postal Guide.

[92] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 25, 1906.

[93] Stephenson, L. W., A contribution to the geology of northeastern Texas and southern Oklahoma: U. S. Geol. Survey Prof. Paper 120, p. 151, 1918.

[94] Gordon, C. H., Geology and underground waters of northeastern Texas: U. S. Geol. Survey Water Supply Paper 276, 1918.

[95] Ellisor, A. C., The age and correlation of the chalk at White Cliffs, Arkansas: Am. Assoc. Petrol. Geologists Bull., vol. 9, No. 8, p. 1153, 1925.

[96] Stephenson, L. W., Notes on the stratigraphy of the Upper Cretaceous formations of Texas and Arkansas: Am. Assoc. Petrol. Geologists Bull., vol. 11, No. 1, p. 10, 1927.

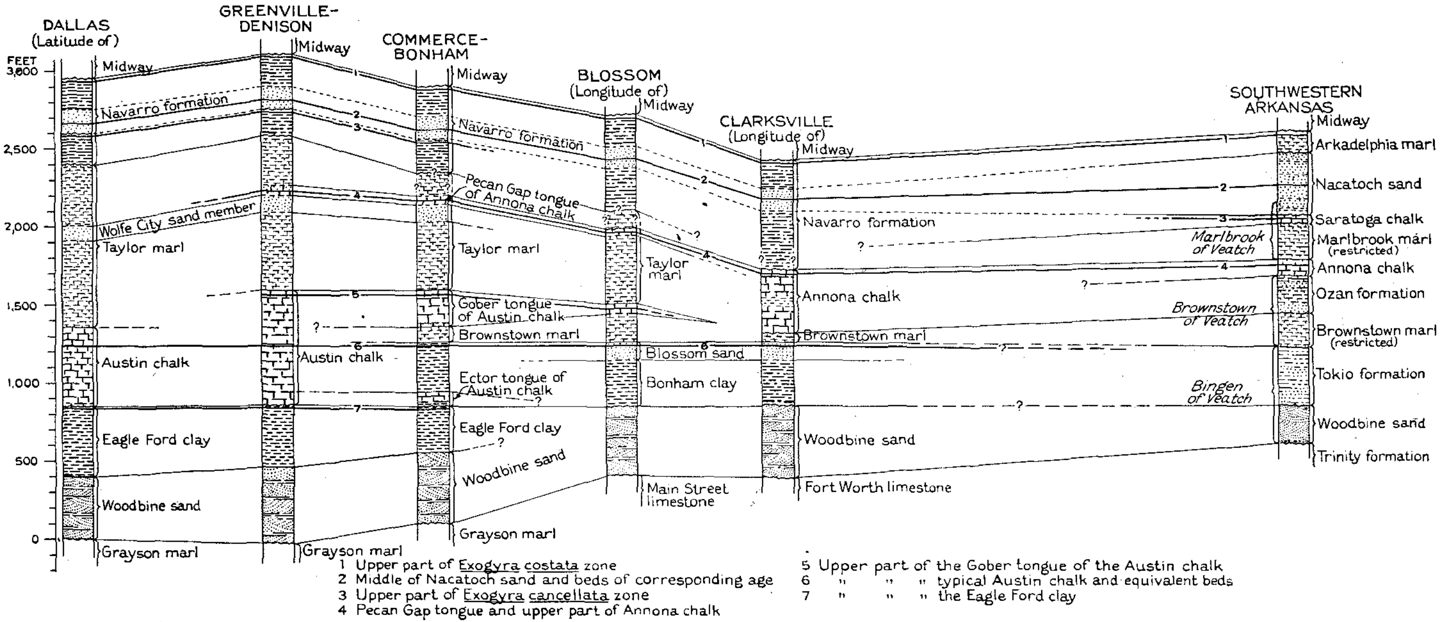


FIGURE 3.—Correlation of the Upper Cretaceous formations (Gulf series) in northeastern Texas and Arkansas as determined by L. W. Stephenson in collaboration with C. H. Dane.

ville, Texas, is lithologically continuous with and of the same age as the Pecan Gap chalk, at the top of the Taylor marl. The continuity and the age equivalence of the chalk in Arkansas with the upper part of the chalk in northeastern Texas is unquestioned, and the name Annona chalk will be retained for it. The stratigraphic relation of these chalks in Texas and Arkansas as now interpreted by Stephenson[97] is shown in Figure 3.

LITHOLOGY AND OUTCROPS

The Rocky Comfort area is a rudely rectangular block about 2 miles long from northeast to southwest and 1 mile wide. Old Rocky Comfort is about 1.7 miles southwest of Foreman, along the road to Laynesport, about in the middle or the northeast end of the rectangle. In general the northeastern edge of the rectangle is overlapped and concealed by Quaternary terrace sand and gravel and the southwestern edge (mostly concealed) abuts against the alluvial bottom of Walnut Bayou, which is continuous with the bottom of Red River. The northwestern edge represents the line of contact with the underlying Ozan formation, the irregular southeastern edge represents the contact with the overlying Marlbrook marl, but it is in part concealed by terrace sand and in part adjoins the alluvial bottom land.

At Rocky Comfort about 50 feet of massive and bedded blue-gray chalk is exposed in a gullied slope (Pl. XIV, B). The chalk weathers light yellow-gray, brown-gray, and white. The beds are from 1 to 2 feet thick. Some are weathered into conchoidal angular plates and fragments; others are still rather massive. The more easily weathered beds are the more fossiliferous, carrying a sparse fauna of echinoids, inoceramuses, *Gryphaea sp.* of the small, smooth, convex kind, and pectens. Of particular correlative value is the large echinoid *Echinocorys* cf. *E. texana* (Cragin) (see Pl. XV, p. 86). The chalk is sufficiently friable to soil the fingers, and eventually weathers into chalky dust. In this exposure it is broken by small fractures and faults and has irregular dips, some as high as 12°.

The chalk crops out at many places along the road from Rocky Comfort to Laynesport and very extensively at White

[97] Stephenson, L. W., idem.

A. THE ANNONA ("WHITE CLIFFS") CHALK AT WHITE CLIFFS, ON LITTLE RIVER, SEVIER COUNTY

Showing the contact between the Annona chalk and the underlying Ozan formation at the base of the overhanging ledge near the middle of the cliff.

Photograph by J. A. Taff

B. EXPOSURE OF THE ANNONA CHALK AT ROCKY COMFORT, 17 MILES SOUTHWEST OF FOREMAN, LITTLE RIVER COUNTY

Hill (or Bayou Hill), about 2.5 miles southwest of Rocky Comfort, where the area of chalk abuts against the bottom land of Walnut Bayou. A little over 25 feet of massive marly chalk, showing conchoidal weathering, is here exposed, containing some half-inch beds of chalky marl. The base of this outcrop is probably about 25 feet above the top of the chalk exposed at Rocky Comfort. Here several specimens of *Echinocorys cf. E. texana* (Cragin) have been collected. The overlying Marlbrook is not exposed here. The foraminiferal fauna collected at this place was regarded as that of the Saratoga chalk by Miss Ellisor,[98] but the stratigraphic position, lithology, and macrofossils show so clearly that this outcrop is upper Annona that the microfaunas of the two chalks must contain many species in common. The contact of the Annona and Marlbrook is exposed[99] in the SE. 1/4 NW. 1/4 Sec. 33, T. 12 S., R. 32 W.

The base of the chalk in this area is exposed in the SE. 1/4 SW. 1/4 Sec. 29, T. 12 S., R. 32 W., where the chalk apparently merges into the Ozan formation below. The lower part of the chalk is rather marly and the upper part of the Ozan is a non-sandy, chalky marl, which grades downward into very slightly sandy marl. The chalk in this area is about 100 feet thick.

The White Cliffs area has been described in detail in the excellent report of Taff. The chalk crops out in a bluff 130 feet high, rising above Little River, and in a roughly circular area about a mile in diameter north of the bluff. The following section is abstracted in incomplete form from Taff's report:[1]

Section at White Cliffs Landing

	Feet
Top of cliff.	
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	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 (see Pl. XIV, A). Analysis shows that this chalk contains nearly twice as much silica as the chalk above	25

[98] Ellisor, A. C., The age and correlation of the chalk at White Cliffs, Arkansas: Am. Assoc. Petrol. Geologists Bull., vol. 9, No. 8, p. 1157, 1925.

[99] Taff, J. A., Chalk deposits of southwestern Arkansas: U. S. Geol. Survey Twenty-second Ann. Rept., 1900-1901, pt. 3, p. 704, 1902.

[1] Taff, J. A., idem, p. 706.

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 chalk is quite friable and weathers in recesses beneath the siliceous chalk	8
4. Bluish, sandy, chalky marl containing great numbers of the fossil shell *Gryphaea vesicularis* Lamarck variety. Except for the abundant fossils this bed would be classed with 3, though it is probably slightly more sandy	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 *Gryphaea vesicularis* Lamarck variety, but they are not so abundant 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

A few notes can be added to Taff's excellent section and description. Beds 1 and 2 include the exposed thickness of the Annona chalk; beds 3, 4 and 5 are the upper part of the Ozan formation. The upper, purer chalk (bed 1) is well bedded and the beds persist with even thickness for long horizontal distances. Its fracture is conchoidal, but it breaks on weathering into numerous irregular, angular chips. It contains scattered nodules of marcasite 1/16-inch to 2 inches in diameter. It is sparingly fossiliferous and contains, among other species, the large echinoid *Echinocorys* cf. *E. texana* (Cragin).

The massive siliceous chalk of bed 2 is not very hard and contains no megascopically visible quartz sand, but it makes an overhanging ledge above the more easily eroded marl below. This chalk breaks with a distinctly granular fracture, probably due to its abundant content of foraminifera, and it contains some specimens of the small, smooth, convex gryphaea. Owing to the recesses in the cliffs below the base of this chalk (see Pl. XIV, A) the stratigraphic relations are not well exposed, but the break between bed 2 and bed 3 seems to be sharp, and a few tubular "borings" a foot long extend downward from the base of bed 2 into the chalk-marl. This break is the contact between the Annona chalk and the Ozan formation below.

The line between chalk and marl can not be easily drawn on dry, fresh surfaces. Short exposure to weathering and moisture leaves the chalk unchanged or at some places appears to harden it slightly, an effect that may be due to redeposition after slight solution. The marl, on the contrary, is soft and plastic when wet, and its weathered surfaces are covered with soft, loose, crumbly débris. Long weathering of either produces deep, calcareous, richly organic soil, the fertile "black land." North of White Cliffs post office, along the road in the NW. ¼ Sec. 25, T. 11 S., R. 29 W., the base of this bed is exposed, and here also several chalk-filled "borings" extend from the base of the chalk into the marl below. Here evidently is the contact between the Annona chalk and the Ozan below, a distinct sharp line of demarcation between the two.

The marl in the gryphaea-bearing bed (No. 4) in the section appears to be lithologically nearly identical with the marl above and below. The base of the bed is very uneven, its irregularity being due to the patchy occurrence of the accumulations of the shells. The total exposed thickness assignable to the Annona here is 85 feet, but the beds at the top of the section are not exposed.

About 4½ miles east of White Cliffs the Annona chalk is exposed at Saline Landing and thence 6 miles east by north along the south side of the bottom land of Plum Creek. The colluvial soil and the alluvial soil of the bottom land has been derived almost entirely from the chalk and the chalk marl and can hardly be distinguished from the residual soil of the chalk, but most of the area has been cleared for cultivation, and the consequent gullying of the gentle slopes toward the bottom lands has laid bare many outcrops of hard, white chalk.

The bluff at Saline Landing is 20 feet high and about 300 feet long and consists of white, massive chalk having no distinct bedding planes. In the north part of Sec. 30, T. 11 S., R. 27 W., there are extensive outcrops of white, bedded, pure chalk, which extend eastward to the Mineral Springs-Saratoga road. In the upper part of these outcrops there are thin shaly layers, and at the top the chalk merges into the Marlbrook, but the change from chalk to marl is nearly everywhere abrupt. Just south of the bottom land on this road about 35 feet of creamy white, pure chalk are exposed. A few thin beds are chalky marl. Here fossils are rare; inoceramus, echinoids, and a few small ostreas are the most abundant.

There are many outcrops of the chalk along the edge of the bottom land on the south side of Plum Creek, but its base is nowhere exposed, and on the north side of the creek Ozan

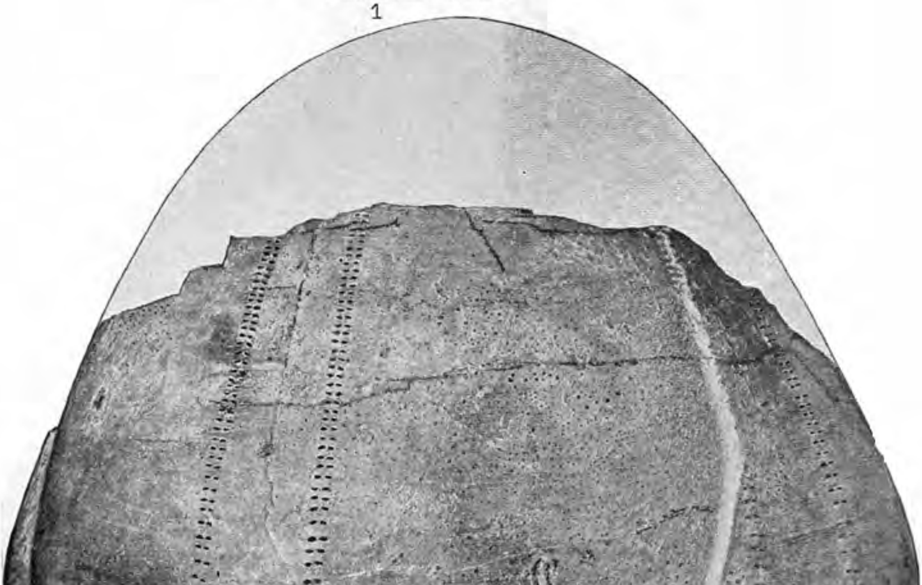
PLATE XV

(Figures natural size)

FIGURE 1. *Echinocorys* cf. *E. texana* (Cragin) from the topmost layer of the Annona chalk, from a branch of Kiekapoo Creek 6.5 miles east of Clarksville, Red River County, Texas. Similar specimens, most of them less perfectly preserved, have been found in the Annona chalk at White Cliffs, Arkansas, and at Old Rocky Comfort, southwest of Foreman, Little River County, Arkansas.

2. Basal view of the same specimen.

1



2

FOSSIL FROM THE ANNONA CHALK

marl crops out. The lower part of the chalk bed (bed 2 of the section at White Cliffs) is exposed in the ditch in the SW. ¼ NW. ¼ Sec. 22, T. 11 S., R. 27 W. This is massive, slightly sandy chalk having a granular fracture and carrying a few broken fossils. The upper, purer chalk is well exposed in the hill near the northeast corner of Sec. 22, T. 11 S., R. 27 W. The easternment exposure of the chalk south of Plum Creek is in the SE. ¼ Sec. 14, T. 11 S., R. 27 W., on the road from Mineral Springs to Columbus. Here a gullied and eroded area shows the upper edge of the chalk and about 40 feet of overlying chalky marl. This pure, massive, white marl, which contains few fossils, is believed to be equivalent to the upper part of the Annona farther west and shows the gradual transition of the upper Annona into marl eastward.

In the vicinity of Yancy the thin eastern edge of the Annona crops out. About 500 feet west of the Yancy-Columbus road, at a point 1.75 miles south of Yancy, the Annona chalk, there about 2 feet thick, crops out in a thin ledge and above it in a bench about 50 feet wide. The Ozan marl crops out below the ledge and the Marlbrook marl crops out at the top of the gently sloping bench. The creamy white chalk is bedded, slightly sandy, and very fossiliferous, presenting a strong contract to the Annona chalk farther west. It rests on a slightly irregular surface of the Ozan, and borings or irregular chalk-filled tubes extend from the chalk into the underlying sandy marl. Phosphatic casts and nodules are abundant in the chalk. It is transected by numerous veins, half an inch to 1½ inches wide, of ferruginous material and by veinlets of barite. The Marlbrook marl rests on the chalk, and there is, as usual, an intervening thin transitional zone. This outcrop extends almost without interruption half a mile a little south of west into the bottom lands of Plum Creek. The thin layer of Annona chalk extends eastward across the Yancy-Columbus road and thence northeastward about half a mile to a point where it disappears under the surficial sand. It has not been found east of this area. A small outlier of the thin chalk rests on the Ozan at a point nearly a mile south of Yancy on the Yancy-Columbus road, and another smaller outlier crops out about 1.25 miles from Yancy.

PLATE XVI

(All figures natural size)

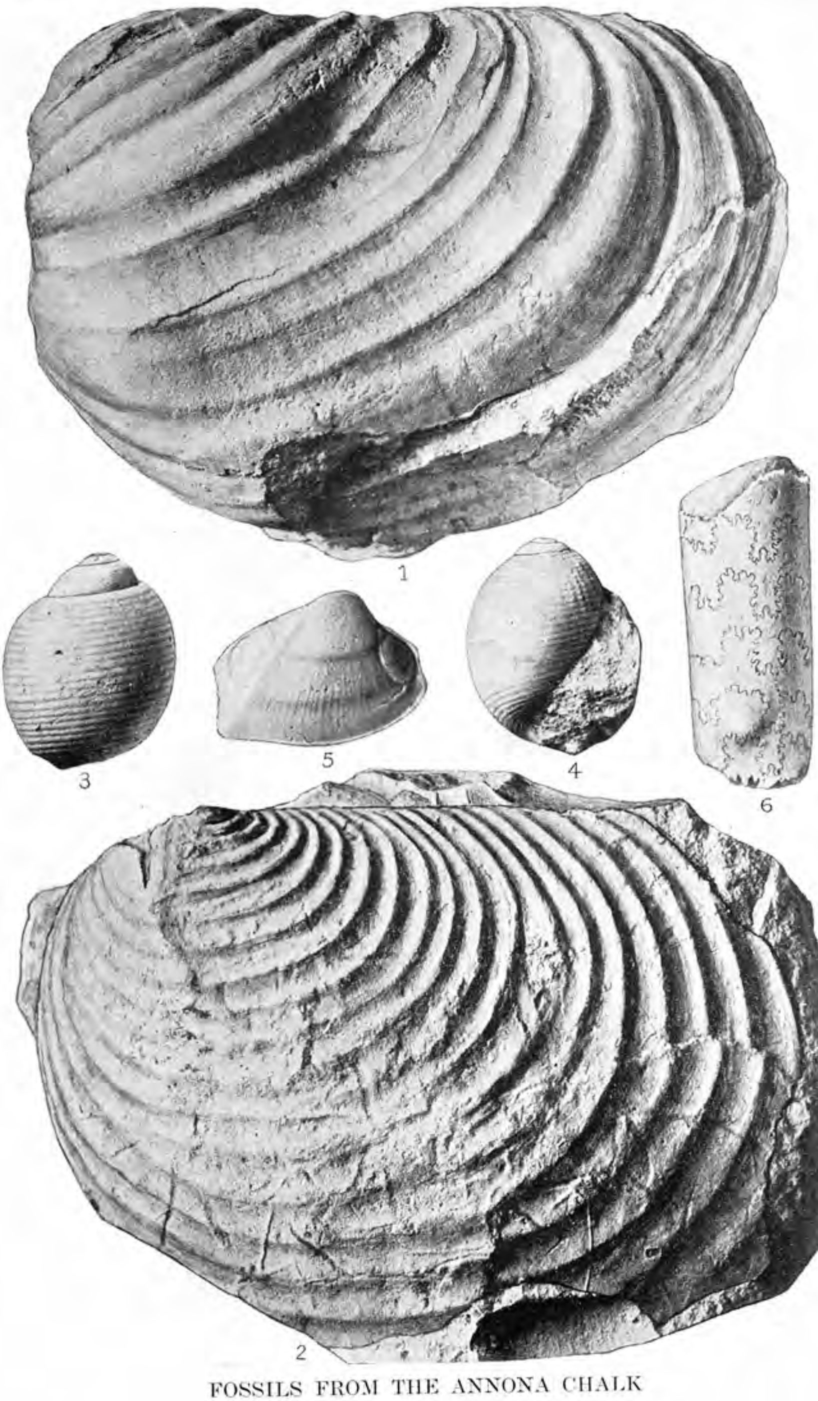
FIGURE 1. *Inoceramus* sp. from exposures at Old Rocky Comfort, southwest of Foreman, Little River County.

2. *Inoceramus* sp. from the quarry at White Cliffs, Little River County.

3, 4. Actaeon sp. from Columbus road 0.9 mile southwest of Yancy, Hempstead County.

5. *Veniella (Etea)* sp. from Columbus road 1.75 miles south of Yancy, Hempstead County.

6. *Baculites asper* Morton from Columbus road 0.9 mile southwest of Yancy, Hempstead County.



FOSSILS FROM THE ANNONA CHALK

FAUNA

The megascopic fauna of the Annona chalk of Arkansas is sparse in the outcrops that have long been known. By far the greatest number of forms in the subjoined list were recently collected from the fossiliferous thin eastern edge of the chalk in the vicinity of Yancy. A few of these are shown in Plate XVI. Dr. Stephenson has identified the following forms from collections made by him, T. W. Vaughan, and the writer:

Coelenterata:
  Coral.
Echinodermata:
  Hemiaster (?)
  Echinocorys cf. E. texana (Cragin).
  Echinoid of family Spatangidae, section Adetes (?).
  Cidaris (?)
Vermes:
  Serpula sp.
  Hamulus onyx Morton.
  Hamulus squamosus Gabb.
Pelecypoda:
  Inoceramus aff. I. barabini Morton.
  Ostrea plumosa Morton.
  Ostrea falcata Morton.
  Ostrea panda Morton.
  Gryphaeostrea vomer (Morton).
  Gryphaea sp. (smooth, convex species).
  Trigonia sp.
  Pecten sp.
  Lima sp.
  Paranomia sp.
  Spondylus sp.
  Rudistid fragments.
  Veniella (Etea) sp.
Cardium sp.
  Solyma (?)
  Legumen sp.
Gastropoda:
  Gyrodes sp.
  Monodonta sp.
  Anchura sp. (large).
  Anchura sp. (small).
  Tudicla sp.
  Turritella sp.
  Volutoderma sp.
  Morea cancellaria Conrad.
  Actaeon sp.
Cephalopoda:
  Eutrephoceras sp.
  Nostoceras sp.
  Pachydiscus sp.
  Baculites asper Morton.
  Baculites sp.
  Hamites (?)
Vertebrata:
  Corax falcatus Agassiz.
  A vertebra.

CORRELATION

In the description of the Ozan formation reasons are given for believing that the Ozan is equivalent to the lower part of the Annona chalk as exposed at Clarksville, Texas. Therefore, although the name Annona has been retained for the chalk in Arkansas it is evidently equivalent to only the upper part of the Annona chalk at the type locality.

The lithology and the fauna of the Annona chalk is much like that of the overlying Marlbrook marl. This similarity and the apparent continuity of sedimentation from the Annona into the Marlbrook indicate that the two formations should be considered a sedimentary unit. The possible changes in conditions of sedimentation between the time of the deposition of the Ozan formation and that of the deposition of the overlying beds will accordingly be considered after the Marlbrook marl has been described.

MARLBROOK MARL (RESTRICTED)

HISTORICAL SUMMARY

In his original report Hill[2] placed the Marlbrook or the "*Gryphaea vesicularis* chalk marls" above the Brownstown or "*Exogyra ponderosa* marls" and below the "Washington greensand" and "High Bluff blue sands" (which now form parts of the Nacatoch sand) and the "Big Deciper calcareous sands" (now placed in the upper part of the Saratoga chalk). At that time the "White Cliffs" chalk was supposed to underlie the marl exposed near Brownstown.

Under the subhead "Marlbrook-Columbus" or "*Gryphaea vesicularis* chalk marls" Hill[3] included in his Marlbrook marls parts of the Saratoga chalk, Nacatoch sand, and Arkadelphia marl, as these formations are now defined. In a later paper[4] he placed the "*Gryphaea vesicularis* chalk marls" in the Brownstown, which then included all the beds between the "White Cliffs" chalk and the "Washington greensand." Still later,[5] although he realized that the marls exposed at Brownstown lay below the chalk at White Cliffs, he used the term Brownstown marl, apparently, to include the "Marl-

[2] Hill, R. T., Neozoic geology of southwestern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1888, vol. 2, p. 188, 1888.

[3] Hill, R. T., idem, pp. 84-86.

[4] Hill, R. T., Geology of parts of Texas, Indian Territory, and Arkansas adjacent to Red River: Geol. Soc. America Bull., vol. 5, p. 302, 1894.

[5] Hill, R. T., Geography and geology of the Black and Grand Prairies, Texas: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 7, p. 340, 1901.

brook-Columbus chalk marls'' as well as the marl below the chalk.

Taff interpreted the section in this area correctly, but he applied no name to the marl above the Annona chalk. Veatch applied the term Marlbrook formation to the marls above the Annona chalk, including the Saratoga chalk and the lower part of the Nacatoch sand as now defined, a consistent usage, but one which does not accord with the present interpretation of the stratigraphy.

LITHOLOGY AND OUTCROPS

The name Marlbrook marl is here restricted to the marl that lies above the Annona chalk or the Ozan formation and below the Saratoga chalk. It is a strikingly uniform chalky marl, which when freshly exposed and moist is dark blue but when weathered deeply is nearly white, a color it exhibits best when it is dry. It merges at its base into the Annona chalk, in the upper part of which are shaly layers. Nevertheless the change from chalk to marl is usually rather abrupt. Where the Annona is absent and the Marlbrook rests directly on the Ozan formation there is a sharp contact and evidence of a break in sedimentation.

In Little River County the Marlbrook is exposed above the Annona chalk in the vicinity of Rocky Comfort and about 4 miles to the southeast, along the low breaks that rise above the bottom lands of Red River.

In Howard and Hempstead counties the Marlbrook is well exposed between the bottom lands of Saline and Little Missouri rivers as a narrow strip lying south of Plum Creek and on both sides of the south fork of Ozan Creek, extending generally northeastward. On the northward-sloping sides of the valley south of these creeks the marl is abundantly exposed by gullies that have removed the deeply weathered soil (Pl. XVII, A). Much of this gullying is due to deforestation for cultivation. On the broad, nearly level divide between the headwaters of Plum Creek and the south fork of Ozan Creek the soft, deeply weathered, rich, limy soil has been less removed by gullying and the exposures are fewer.

The Marlbrook is most extensively exposed on the hill slopes below the Saratoga chalk from the area near Saratoga northeastward to the area north of Columbus. The striking ridge known as the Devil's Backbone, about a mile northwest of Saratoga, is composed of Marlbrook marl. The marl is only sparingly fossiliferous in its lower part, but is moderately fossiliferous in its upper part, in which large exogyras and the large, flat variety of *Gryphaea vesicularis* Lamarck are abundant (see Pl. XVIII, Fig. 1). When unweathered it may be nearly massive in appearance, although it usually shows thick bedding without lamination. When dry it looks almost chalky, but when wet it is highly plastic, because of its large content of clay.

The upper part of the Marlbrook is well exposed from a point 3.3 miles north of Washington to the south fork of Ozan Creek along the road from Washington to Ozan in the SW. ¼ Sec. 19, and the NE. ¼ Sec. 30, in T. 10 S., R. 24 W., on the west side of Marlbrook Creek. A few small outcrops can be found in the vicinity of Blevins. East of this locality for about 14 miles the Marlbrook is concealed beneath the alluvium and terrace sand of Little Missouri River. It again outcrops in a strip about 1 mile wide and 8 miles long below the Saratoga chalk, extending generally northeastward between the bottom lands of Little Missouri River and Antoine Creek. The marl here is similar to that found farther west, but is possibly slightly more sandy. In its upper part there are a few beds, each about half an inch thick, of hard, sandy, calcite-cemented coquina containing abundant foraminifera and Inoceramus prisms and some shark teeth. The Marlbrook is transitional into the Annona chalk below. East of Yancy the Annona is not found in the section, but the contact of the Marlbrook and the Ozan formation is not exposed in Hempstead County. Eight-tenths of a mile north of Okolona, along the road to Antoine, the Marlbrook marl is exposed, without transition beds, immediately above typical sandy Ozan marl containing numerous small convex gryphaeas. Glauconite and black, probably phosphatic, grains are seen in the basal part of the Marlbrook.

East of the Antoine Creek bottom the Marlbrook is unchanged in lithologic character and it crops out almost continuously to a point in the SW. ¼ Sec. 12, T. 7 S., R. 20 W., beyond which it does not appear in the section. The base of the Marlbrook is exposed 7.8 miles west of Arkadelphia, on

A. GULLIES IN THE MARLBROOK MARL ON THE OLD MARLBROOK PLANTATION, HEMPSTEAD COUNTY

Photograph by L. W. Stephenson

B. EXPOSURE OF THE SARATOGA CHALK IN THE SE. ¼ SEC. 12, T. 8 S., R. 21 W., NEAR THE BOTTOM OF TERRE NOIRE CREEK, CLARK COUNTY

The smooth slopes in the lower left corner and in the foreground are Marlbrook marl.

the road to Hollywood, where the basal foot is gritty, containing quartz grains and spattered coarse glauconite, and rests directly on the Ozan below without beds of transition.

THICKNESS

The most accurate section of the Marlbrook marl measured is found along the Mineral Springs-Saratoga road, south of Plum Creek. A traverse run along this road and consideration of the dip as determined instrumentally show that the marl is here between 210 and 220 feet thick. Aneroid elevations and consideration of the regional dip show that the Marlbrook is about 210 feet thick between Yancy and Columbus. The same method shows a thickness of about 160 feet along the line between Ozan and Washington. Just northwest of Okolona the marl is about 80 feet thick, and farther east, in Sec. 30, T. 7 S., R. 20 W., there is only 50 feet of the formation, with typical Saratoga above and Ozan below.

FAUNA

The following pelecypods have been identified from the Marlbrook marl by Dr. Stephenson:

Ostrea plumosa Morton.
Ostrea falcata Morton.
Ostrea panda Morton.
Ostrea tecticosta Gabb.
Gryphaea vesicularis Lamarck, var.
Gryphaeostrea vomer (Morton).
Exogyra ponderosa Roemer.
Exogyra ponderosa Roemer (variety showing the beginnings of cancellation).
Exogyra cancellata Stephenson.
Anomia argentaria Morton.
Paranomia scabra (Morton).

The brevity of the list suggests the paucity of fossils in the Marlbrook as compared with the formations above and below, but the expenditure of more time in careful collecting would no doubt yield a much more extensive fauna, though the Marlbrook would afford meager returns in comparison with the more fossiliferous formations, particularly in its lower part, many outcrops of which contain no fossils. An examination of this lower part with a hand lens failed to show any foraminifera.

The upper part of the formation is more fossiliferous. The occurrence in it of thin cemented reefs of coquina has already been mentioned and it contains numerous shells of

PLATE XVIII

(Figures natural size)

FIGURE 1. *Gryphaea vesicularis* Lamarck (a large flattish variety) from the Columbus road a mile east of Saratoga, Howard County, Arkansas. (Slightly reduced.)

2. *Exogyra cancellata* Stephenson (variety) from the same locality. (Slightly reduced.)

1

2

FOSSILS FROM THE UPPER PART OF THE MARLBROOK MARL the large, flat variety of *Gryphaea vesicularis* Lamarck. Foraminifera are found in some layers, and shells of the genus *Exogyra* are numerous in certain beds. The foregoing list shows that these shells represent both *Exogyra ponderosa* Roemer and *Exogyra cancellata* Stephenson. Inasmuch as these two species have been regarded as having a sharply separated range, the recognition of a zone in southwestern Arkansas in which they overlap is important. As already stated, *Exogyra ponderosa* shows a rather wide range in form, and the forms found in the Ozan formation show a tendency toward a less convex left valve and more closely spaced growth lines. In the Annona chalk exogyras are scarce, but those found resemble those in the Ozan formation. Exogyras of this type are also found in the Marlbrook marl up to its very top, just below the Saratoga chalk. The specimens show varying degrees of smoothness, and some bear numerous concentric lines of growth, due to thin overlapping lamellae. On some specimens the edges of these lamallae are crenulated. The apex of the shell in some of the exogyras of this type is marked by costate ornamentation, which disappears outward a short distance from the beak. This costate ornamentation of the beak is more common in the exogyras of the Marlbrook. In the upper part of the Marlbrook there are many specimens of a varietal form of *Exogyra ponderosa* Roemer that exhibit, near the beak, the beginnings of cancellated ornamentation. Associated with these are specimens that are so typically cancellated that it seems necessary to refer them to *Exogyra cancellata* Stephenson (see Pl. XVIII, Fig. 2). The variety of *E. ponderosa* that shows incomplete cancellation is regarded as ancestral to the typical *E. cancellata*. *Exogyra costata* is not found in the Marlbrook except possibly as an exotic variant. The assemblage of exogyras from this upper part of the Marlbrook is clearly distinctive and has not been found in northeastern Texas, where the Navarro formation overlies the Annona chalk. A similar assemblage, however, has been found in central Texas, in Williamson and Travis counties, in the upper part of the Taylor marl.[6]

The occurrence in the upper part of the Marlbrook of

[6] Dane, C. H., and Stephenson, L. W., Notes on the Taylor and Navarro formations in east central Texas: Am. Assoc. Petrol. Geologist Bull., vol. 12, No. 1, pp. 57, 58, 1928.

the species *E. cancellata* Stephenson seems, therefore, to indicate evolutionary development toward the more strongly cancellated representatives of the species in the basal Saratoga and shows that the time break in Arkansas between beds of the age of typical Taylor and the typical Navarro is considerably less than in northeastern Texas. The transition between the Annona and Marlbrook in Arkansas and the absence of *E. cancellata* in the lower part of the Marlbrook suggests that this lower part may be represented by chalk in the upper part of the thick section of Annona chalk near Clarksville.

Reptilian vertebrae are found here and there in all the calcareous Cretaceous formations of this area, but they are especially abundant in the upper part of the Marlbrook, particularly in the vicinity of Columbus. Individual vertebrae are locally used as door stops, and apparently several large vertebral columns have been broken up by curiosity seekers. A particularly promising exposed vertebral column (Pl. VI, p. 28) in the SE. ¼ Sec. 17, T. 11 S., R. 26 W., on the farm of Mr. C. Stewart, was brought to the writer's attention by Dr. H. H. Darnall of Columbus, and the exposed skeletal parts were removed. Many bones that were embedded in the marl below were obtained by excavating to a depth of 3 feet over an area about 80 square feet. Most of the bones found were hard and well preserved and were easily freed from the soft marl. Dr. C. W. Gilmore, of the U. S. National Museum, reports that the bones consist of 38 vertebral centra, numerous ribs, a complete pelvic arch, and many fragments. The specimen is one of the Mosasauria, but generic and specific identifications have not yet been made.

PHYSIOGRAPHIC EXPRESSION

The Marlbrook is one of the least resistant of the Cretaceous formations, and it accordingly underlies a belt of low country along its outcrop, but it rises somewhat toward the south and forms part of the escarpment made by the more resistant overlying formations. The valley of the south fork of Ozan Creek has been formed altogether within the belt of Marlbrook.

ORIGIN OF THE ANNONA CHALK AND MARLBROOK MARL

The change in sediments from the sandy marl and marly sand of the Ozan formation to the pure chalky marl and chalk of the Annona and Marlbrook formations indicates an abrupt diminution in the quantity of sandy and silty land waste reaching the site of its ultimate deposition, as there seems little reason to postulate a sudden and great increase in the rate of organic or inorganic precipitation of lime carbonate. This change may have been due to a rise of the sea level and a consequent seaward increase in the distance of this area from the shore, with less deposition of sediment. Unless a longer period of time elapsed than that indicated by the similarity of the faunas, it would seem that under this hypothesis the base of the deposit should be not abruptly marked, but transitional. Simple diminution in the rate of supply of sediment would reduce the level of the marine profile of equilibrium and allow the deposition of a more purely calcareous sediment. Under this hypothesis the base of the new formation would probably be abruptly marked or would show some other evidence of an interruption of sedimentation. The observed nature of the contact on the whole favors the latter hypothesis.

The decrease in the thickness of the Annona chalk from over 100 feet at a point near the Arkansas-Oklahoma line to a few feet in the vicinity of Yancy, about 35 miles to the east, and its ultimate disappearance eastward, is obviously due not to truncation by an unconformity at the base of the overlying Marlbrook, but partly to the mergence of the chalk eastward into the lower part of the Marlbrook and partly to conformable overlap of the Marlbrook eastward over the Annona. The deposit probably became thinner toward shallower water, as the Annona may have been laid down in slightly deeper water than the more argillaceous Marlbrook, although fossils occur in sufficient abundance in both to show that they are by no means abyssal. If this hypothesis is acceptable, the areal distribution of the attenuated edge of the Annona chalk should give some indication of the direction of the shore line, but not its position. A little trustworthy information is available. Accepting the outcrops of the Annona near Yancy as the edge of the chalk there, the absence of the Annona in the well of the Hope Water Company (see Appendix A, p. 182) shows that the edge has a strong southeastward trend in this part of its extent. An examination of the records of deep wells in Nevada County and western Ouachita County shows that the Annona is not recognizable north of a line trending 5° south of east from Hope. Without more detailed information than records of rotary wells it is not possible to extend this line farther east. As far as the edge of the chalk has been traced it indicates that the direction of the shore line during this period was a little south of east, a conclusion in conformity with the evidence of uplift in the area generally northeast of Hope during parts of Lower Cretaceous and Woodbine time.

The thinning of the Annona eastward is particularly significant in showing that the thinning of the overlying Marlbrook may be due in large part to similar causes, although it is overlain unconformably by a possibly truncating formation.

SARATOGA CHALK

HISTORICAL SUMMARY

The Saratoga chalk, which rests unconformably on the Marlbrook marl, is a very fossiliferous, hard, sandy, somewhat glauconitic chalk including some beds of marly chalk and chalky sand. It ranges in thickness from 20 to 60 feet. It was originally included in the "Marlbrook, Columbus or *Gryphaea vesicularis* chalk marls."[7]

This formation was first called the Saratoga chalk by J. C. Branner[8] in 1897, and it was later described in detail by Taff[9] as the Saratoga formation. Somewhat later the Saratoga was regarded as a chalky layer in the upper part of the Marlbrook marl.[10] The town of Saratoga itself stands on the basal part of the Nacatoch sand, but the chalk crops out a short distance north, east, and west of town, so the name is sufficiently appropriate and has been confirmed by priority and long usage.

LITHOLOGY AND OUTCROPS

The Saratoga chalk is separated from the underlying marl by a well-exposed and persistent lithologic and faunal

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[7] Hill, R. T., The Neozoic geology of southwestern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1888, vol. 2, pp. 84-85, 1888.

[8] Branner, J. C., The cement materials of southwest Arkansas: Trans. Am. Inst. Min. Eng., vol. 27, p. 53, 1898.

[9] Taff, J. A., Chalk of southwestern Arkansas: U. S. Geol. Survey Twenty-second Ann. Report. 1901, pt. 3, p. 714, 1902.

[10] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 26, 1906.

break and from the overlying Nacatoch sand at most places by an erosional and lithologic break. It is clearly a lithologic unit of formation value. Outcrops of it have not been found in Little River County and it has not been identified in Texas. It is exposed almost continuously in a strip ranging in width from a few feet to a mile and extending from the bluff along Bairds Lake, 3 miles southwest of Saratoga, to Blevins, in Hempstead County, a distance of 20 miles. It is concealed for more than 10 miles by the terrace sand and alluvium of the Little Missouri River, but reappears in the southwest corner of Sec. 15, T. 9 S., R. 22 W., and extends for 8 miles through Okolona to Dobyville. After a short concealed interval of 3 miles in the bottom land of Antoine Creek it reappears in the NE. ¼ Sec. 13, T. 9 S., R. 21 W., and extends 7 miles to Little Deciper Creek. It disappears eastward from the section on the surface, but small outcrops occur beneath the Nacatoch sand just north of Arkadelphia.

The base of the Saratoga chalk is the best exposed formation contact in the region, and the character of the contact and of the basal few feet of the chalk are remarkably similar at each outcrop. The excellence of the exposure is due in part to the position of the Saratoga on the steep northward-facing escarpment of the hilly ridge made by the outcrop of the Nacatoch sand above and in part to the softness of the Marlbrook marl below. As a result of these conditions erosion has laid bare gullied patches of the chalk and marl, the base of the chalk forming small ledges in the gullies above the vertical banks of marl (Pl. XVII, B, p. 92).

The base is almost invariably marked by a few inches of glauconitic chalky sand containing abundant irregular phosphatic nodules and fossil casts. Borings having elliptical or circular cross sections a third of an inch to a half an inch in diameter, filled with material like the basal Saratoga, extend a few inches to 2 feet down into the gray non-sandy marl below. The basal sandy marl or chalky sand makes a sharp contact with the marl and usually rests on an irregular lower surface. At many places small lenses of glauconitic chalk, which are completely separated from any of the borings, occur in the upper foot of the pure marl of the Marlbrook. The lowest few feet of Saratoga above the basal few inches is a persistent shell conglomerate—a sandy, marly chalk containing numerous phosphate nodules and sparingly spattered with glauconite grains. Through it are scattered innumerable shells and phosphatic casts, and especially the large, flat valves of *Gryphaea vesicularis* Lamarck, variety, set at all angles with the bedding planes. Large valves of *Exogyra* are also very abundant (Pl. XIX, A).

The variation in the Saratoga from place to place can be brought out most clearly by descriptions of a number of sections and a few other typical exposures.

About a mile southwest of Saratoga, on the road to Baird's Lake Bridge, in the SW. 1/4 Sec. 5, T. 12 S., R. 27 W., the base of the chalk is well exposed (Pl. XIX, B). The hard, somewhat sandy basal shell conglomerate is 3 feet thick, and the chalk-filled borings into the uppermost Marlbrook are well shown. At the top of the chalk there is about 5 feet of marl below the Nacatoch sand. Southward along the bluff adjoining the Saline River bottom and along Baird's Lake the chalk crops out at several places, extending as far south as Newman's fishing camp, on Baird's Lake.

A complete section of the chalk is exposed just north of Saratoga, along the road to Mineral Springs. Here it is only 23.5 feet thick. The somewhat harder sandy basal bed containing numerous shells of the large variety of *Gryphaea vesicularis* is well exposed, and borings filled with sandy chalk extend into the top of the Marlbrook. The chalk at the base merges gradually upward into a soft, clayey sand containing a few imprints of shells. In the intermediate sandy, marly chalk, about half way up from the base of the section, there are numerous imprints of *Inoceramus* and gastropods. At the top of the Saratoga there is somewhat less than a foot of slightly sandy light-gray clay. The Nacatoch sand rests on an irregular surface cut in this clay.

In the valley of Yellow Creek, about half a mile east of Saratoga, on the road to Columbus, the Saratoga makes a bench and ledge along the road. Below this bench the Marlbrook is exposed. A little farther on the road crosses a small outlier of the chalk east of the center of Sec. 34, T. 11 S., R. 27 W. The basal harder bed here is about 2 feet thick, is speckled with glauconite, and contains numerous shells of *Gryphaea vesicularis,* variety, and other forms. The usual chalk-filled borings, the longest a foot in length,

A. SHELL BED AT THE BASE OF THE SARATOGA CHALK 3.3 MILES NORTH OF WASHINGTON, ON THE ROAD TO OZAN

Marlbrook marl shown in lower left part of view.

B. SHELL BED AT THE BASE OF THE SARATOGA CHALK IN THE SW. ¼ SEC. 5, T. 12 S., R. 27 W., HEMPSTEAD COUNTY, ABOUT A MILE SOUTHWEST OF SARATOGA ON THE ROAD TO BAIRD'S LAKE BRIDGE

The base of the Saratoga is shown in the lower right corner. The surface back of the ledge made by the shell bed is strewn with large specimens of Exogyra and Gryphaea.

extend curvingly down into the marl. Near the center of Sec. 35, T. 11 S., R. 27 W., the road going up out of the valley of Yellow Creek crosses a poorly exposed Saratoga-Marlbrook contact. Along this road chalk is exposed up to a place a short distance west of Columbus, at which place the Nacatoch is exposed. North and northeast of Columbus the chalk is concealed beneath its own residual soil. From Columbus eastward for some miles the chalk crops out near the headwaters of the southward-flowing streams of the Bois d'Arc drainage and along the divide between the westward-flowing drainage of Plum Creek and the eastward-flowing drainage of the south fork of Ozan Creek. Accordingly, very little of the residual soil has been removed and the exposures are poor.

On the road from Washington to Ozan, 3.3 miles north of Washington, a complete section of the chalk is exposed.

Section of the Saratoga Chalk North of Washington

	Feet
Nacatoch sand:	
Light-brown argillaceous, calcareous, micaceous sand, slightly indurated; weathers white.	
Contact not exposed:	
Saratoga chalk:	
Chalky marl; poorly exposed in upper part	20
Sandy white chalk, heavy bedded, abundantly fossiliferous; some beds marly	26
Shell conglomerate containing *Gryphaea vesicularis*, variety, *Exogyra costata*, and *Exogyra cancellata*, embedded in hard, sandy, slightly glauconitic chalk	2
Hard, glauconitic sandy chalk, with a granular texture due to abundant foraminifera. Contains numerous irregularly shaped phosphatic nodules. This bed rests on a sharp, irregular surface	1
Marlbrook marl:	
Dark-gray, well-bedded, pure marl, soft and plastic when moist.	

About a mile east of this locality, along the Missouri Pacific branch railroad from Hope to Nashville, in the central part of Sec. 9, T. 11 S., R. 25 W., there are good outcrops of the chalk, although its base is not exposed. At this place there is an incomplete section of 40 feet of the chalk. A little farther north the soft, blue-gray Marlbrook is exposed. A thick section of the chalk is exposed west of Marlbrook Creek, in the western half of Sec. 29, T. 10 S., R. 24 W., and about 2 miles southwest of Blevins. At this place there is at least 60 feet of hard, white, abundantly fossiliferous slightly sandy chalk. The contact is not exposed, but in the NE. ¼ Sec. 30, T. 10 S., R. 24 W., soft, dark-gray plastic marl crops out a little below the chalk and the weathered surfaces are thickly strewn with a large flat variety of *Gryphaea vesicularis* and phosphatic nodules.

The Saratoga chalk is exposed in the vicinity of Okolona as a dip slope, 2 miles in breadth, having a dispersed covering of surficial sand weathered from the overlying Nacatoch. The north end of this dip slope forms a topographic ridge that stands 50 to 150 feet above the lower tracts to the west and north. The head of the south fork of Terre Rouge Creek has cut through this wide Saratoga surface and separated the chalk outcrops into two areas by a narrow strip of the underlying Marlbrook marl, along which runs a branch line of the Missouri Pacific Railroad. The town of Okolona stands on the chalk east of the railroad. The public road from Okolona to the highway bridge over the Little Missouri at Nacatoch Bluff, after crossing the head of the valley of the south fork of Ozan Creek, runs southward for over 2 miles on the partly concealed dip slope of the chalk. At a point 1.3 miles from Okolona, a short distance west of the road, the basal 8 feet of the chalk crops out. The contact with the marl below is sharp and well exposed, and the basal chalk carries abundantly the usual irregular phosphatic nodules and casts. As much as 30 feet of the chalk is seen in some outcrops, and its total thickness is probably about 50 feet. Beneath a scattered covering of surficial sand the chalk crops out at several places near the crest of the ridge east of Okolona, on the road to Arkadelphia. At a point 3.3 miles along this road the basal 15 feet of the chalk is exposed, resting on a sharp, irregular contact with the Marlbrook below.

An excellent section of the chalk is exposed in gullied northward-facing hill slopes in the SE. 1/4 NE. 1/4, Sec. 29, T. 8 S., R. 21 W., north of the vicinity of Dobyville.

Section of the Saratoga Chalk North of Dobyville

Nacatoch sand: Poorly exposed sandy marl and clay.	
Contact not exposed.	
Saratoga chalk:	Feet
Dark sandy, chalky marl and fine-grained marly sand containing *Exogyra costata* and numerous casts of bivalves and gastropods	25
White-weathering, irregularly bedded dark-gray chalk and chalky marl containing *E. costata* and *E. cancellata* and, in the lower part, numerous large *G. vesicularis*, variety	30

Hard, slightly glauconitic, very sandy chalk containing scattered phosphatic nodules.......... 3
Very sandy marl containing abundant glauconite and numerous phosphatic nodules and casts. Generally rests sharply on the marl below, although in places there is interlensing of quarter-inch beds of glauconitic sandy marl and the pure marl below.......... 1–1½
Irregular contact having a relief of a few inches.
Marlbrook marl.
Pure, dark-gray bedded marl.

According to Taff,[11] "the next known occurrence of the Saratoga chalk marl east of Okolona is on 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 creeks." At present there are about 6 miles of only slightly interrupted outcrop of the chalk west of the Deciper Creek outcrops and east of the bottom of Terre Noire Creek. As the work done by Taff elsewhere on the chalk was very careful, it seems not unlikely that this strip of outcrops was in large part concealed by surficial sand and soil when he performed his work and has in the ensuing 25 years been exposed by the gullying and erosion started by the widespread removal of the forest cover from areas now under cultivation.

In the SE. ¼ Sec. 12, T. 8 S., R. 21 W., near the Terre Noire bottom, there are extensive outcrops of gullied Saratoga chalk and the Saratoga-Marlbrook contact is exposed at many places (Pl. XVII, B). The basal part of the Saratoga here is a heavy-bedded white chalk, at most places not glauconitic except in the inch or two above the Marlbrook, and there only slightly. A thickness of about 45 feet is exposed. The Saratoga outcrop rises to the northeast for about a mile and then runs northward along the edge of a clearly defined escarpment. A good section is exposed in the SE. ¼ Sec. 30, T. 7 S., R. 20 W. This section extends along the road from Arkadelphia to Okolona to a point 7.8 miles from Arkadelphia.

Section of the Saratoga Chalk in SE. ¼ Sec. 30, T. 7 S., R. 20 W.

Top of section.
Saratoga chalk: Feet
Soft marly sand, carrying numerous black, macerated fragments of plants, and hard, dark-gray calcareous marl lenses

[11] Taff, J. A., Chalk of southwestern Arkansas: U. S. Geol. Survey Twenty-second Ann. Rept., 1901, pt. 3, pp. 723-724, 1902.

which contain numerous large fossil casts *(Trigonia, Scaphites, Isocardium, Cyprimeria)*. Some layers contain great numbers of the large flat variety of *Gryphaea vesicularis*. By a decrease in the percentage of sand this bed merges into the one below	10
Alternating chalky marl and sandy chalk in irregular beds, 1 to 2 feet thick, containing numerous small echinoids *(Hemiaster* sp.) and *Exogyra costata*. *Exogyra cancellata* is found in the lower part	11
Irregularly bedded, slightly sandy, chalky marl	12
Glauconitic sandy chalk and marl contains *Exogyra costata* and *Gryphaea vesicularis*, variety, in abundance and *Exogyra cancellata* sparingly, and dark-brown phosphatic nodules and casts of other fossils. Tubules filled with glauconitic sandy chalk extend for a foot or more into the top of the Marlbrook	5
Slightly irregular contact.	
Marlbrook marl:	
Dark-gray, massive and thick-bedded pure marl containing in its upper foot small pockets or lenses of glauconitic sandy marl that is lithologically like the basal Saratoga.	

The base of the chalk is exposed a little farther north, along the escarpment near the Arkadelphia-Hollywood road, at a point 7.4 miles from Arkadelphia. It is glauconitic and sandy, as usual, and shows borings of elliptical and subcircular cross section, filled with the chalk, which extends down into the marl below.

About half a mile east of this place the road toward Arkadelphia crosses the head of Mill Creek near the center of Sec. 29, T. 7 S., R. 20 W. The upper part of the Saratoga is exposed in bare patches just north of the road, and about a mile to the north, up the creek, the base of the Saratoga makes a small escarpment, at the base of which the Marlbrook is exposed.

Where the Arkadelphia-Hollywood and Arkadelphia-Okolona road crosses Big Deciper Creek and goes up the hill on the west side of the creek the road cuts expose only surficial sand wash. North of the road, however, in the north half of Sec. 28, T. 7 S., R. 20 W., the Saratoga chalk is exposed above the Marlbrook marl in gullied slopes. The following section of the lower part of the chalk was measured by Taff[12] "on the Bozeman place, one-third of a mile northeast of the house."

Partial Section of Saratoga Chalk in Sec. 28, T. 7 S., R. 20 W.

	Feet
Overwashed sandy soil.	
Saratoga chalk:	
Chalky marl, more sandy than that below	10–15
Even-textured blue chalk marl	15

[12] Taff, J. A., Chalk of southwestern Arkansas: U. S. Geol. Survey Twenty-second Ann. Rept., 1901, pt. 3, p. 724, 1902.

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.

Gryphaea vesicularis shell-bearing marl..................................1 to 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 layer of shells indurated by a calcareous matrix.

Marlbrook marl:

The blue marl from the *Gryphaea vesicularis* bed downward.. 15

About a mile south of the Arkadelphia-Hollywood road crossing, the upper road from Arkadelphia to Gurdon crosses Big Deciper Creek 5.4 miles from Arkadelphia. In the road cuts up the hill on the west side of the creek, and in the creek bluff near by, the upper part of the Saratoga and the basal part of the Nacatoch are exposed. The contact relations here are described on page 129. About 25 feet of the Saratoga is exposed. It is a massive or irregularly bedded dark-gray, very sandy marl, chalky in some beds, and contains hard calcareous lenses. Its upper part is very fossiliferous, containing large casts of *Cucullaea, Inoceramus, Isocardia, Cardium* and *Cyprimeria* sp. *Exogyra cancellata* is found sparingly to a horizon within 10 feet of the Saratoga-Nacatoch contact, and *Exogyra costata* is found throughout the deposit. Hemiasters half an inch to an inch in diameter are rather numerous and larger echinoids are not uncommon.

Four miles from Arkadelphia the road to Okolona crosses Little Deciper Creek, and the road cut up the hill on the west side of the creek exposes the most easterly complete section of the Saratoga. The base of the Saratoga is exposed in the bottom of the creek gully south of the road.

Section of the Saratoga Chalk at the Arkadelphia-Okolona Crossing of Little Deciper Creek

Nacatoch sand:

Interbedded sand and sandy clay.

Contact concealed by wash.

Saratoga chalk:	Feet
Chalky sand containing numerous black, carbonaceous fragments; poorly exposed	16
Very sandy chalk and chalky sand, partly massive, mostly bedded irregularly, containing numerous black, carbonaceous fragments and impressions, some doubtful impressions of leaves and large plants, a few *Exogyra costata*, a few small echinoids, and, in the more chalky beds, fairly numerous fossil prints and shells	16
Sandy chalk without fragments of plants. Fossils occur as prints and shells, but not abundantly	10
Glauconitic sandy chalk containing phosphatic nodules and grains	6

Contact sharp. Poorly exposed.

Marlbrook marl. Dark gray pure marl.

Outcrops of the lower part of the Saratoga chalk extend northward about half a mile along the east side of the valley of Little Deciper Creek. On the north and east the Saratoga is cut from the section by the erosional unconformity at the base of the Nacatoch sand. The Saratoga reappears from beneath the Nacatoch in a few small outcrops near Arkadelphia. In the SW. 1/4 NE. 1/4 Sec. 18, T. 7 S., R. 19 W., about a mile northwest of the center of Arkadelphia, a small outcrop exposes about 5 feet of gray marly and chalky sand showing clay laminations and containing some thin hard, dark-gray slabby beds of limestone. Small black, macerated carbonaceous fragments of plants are scattered through the beds. A few unidentifiable oysters and possibly some worm tubes are the only fossils. Lithologically this is much like the top of the Saratoga in the outcrops along Deciper Creek. This locality is just north of a small creek that flows eastward into Ouachita River. Half a mile east of this place, north of the same creek and 1.2 miles north of Arkadelphia, on the road to Hot Springs, the same chalky material and beds of thin, slabby limestone crop out in a small mound west of the road, on the golf course. No fossils were found here. Nacatoch sand overlies this Saratoga chalky sand.

A definite Saratoga outcrop lies along the deep gulch of a small creek that flows northeastward from the Free Tourist Camp Ground in Arkadelphia. In the upper part of this gulch Nacatoch sand is exposed, but where it comes out onto the bottom land of Ouachita River the creek has exposed 3 feet of chalky sandy marl, which weathers creamy yellow but is light gray on fresh fracture. It carries numerous dark, carbonaceous fragments of plants and some fossils, among them *Exogyra cancellata* of the type found in Arkansas only in the Saratoga chalk. The relation of the outcrop to the overlying Nacatoch is concealed by surficial sand.

FAUNA

The Saratoga chalk is abundantly fossiliferous almost throughout, particularly in its lower few feet. Many of the species are not found lower than the base of the Saratoga; others that have a more extensive range are found in greatest abundance in this formation. The type of *Exogyra cancellata* Stephenson characterized by strongly developed but cancellated costae occurs typically and in greatest abundance in the Saratoga chalk (see Pl. XX, Fig. 1), but a few specimens approaching the typical form occur also in the upper part of the underlying Marlbrook marl. In most of the outcrops examined the species does not extend to the top of the chalk.

In the prominent outcrops 3.3 miles north from Washington, along the Washington-Ozan road, specimens referable to *Exogyra cancellata* are not found above the lower 24 feet of the chalk, although *Exogyra costata* is abundant in the upper part (see Pl. XX, Fig. 2). At least 20 feet in the upper part of the chalk in the vicinity of Okolona carries only *Exogyra costata* abundantly without *Exogyra cancellata,* and north of Dobyville *Exogyra cancellata* is confined to the lower 32 feet of the chalk.

In the outcrop 5.4 miles southwest of Arkadelphia, in the bank of Big Deciper Creek, described on page 105, types clearly referable to *Exogyra cancellata* occur up to a horizon within 10 feet of the Nacatoch contact, although there is no thinning to indicate that the upper part of the Saratoga has been cut out, and indeed this upper part seems to form a lithologic unit that is traceable eastward from Dobyville, where it does not carry *Exogyra cancellata.* In the outcrop found in the gully just north of Arkadelphia, described on page 106, *Exogyra cancellata* was found just below the Nacatoch, but at this place it is likely that at least the upper few feet of the Saratoga has been removed by erosion. The upper limit of *Exogyra cancellata* apparently varies from place to place, ranging from about the middle of the Saratoga chalk nearly to its top. The lower limit of strongly costate types of *Exogyra cancellata* is the base of the Saratoga, although specimens properly referable to that genus are found in the upper part of the Marlbrook, but probably not below its uppermost 50 feet.

A species of *Hemiaster* ranging in diameter from one-half to three-fourths of an inch is very abundant in the chalk, particularly in its middle part, beginning 20 to 25 feet above its base. The fauna of the upper part of the chalk, particularly from Dobyville eastward, differs somewhat from that of the lower part and is characterized by numerous casts of large mollusks, such as *Inoceramus,*

PLATE XX

FIGURE 1. *Exogyra cancellata* Stephenson from the Saratoga road 3½ miles west of Columbus, Howard County. (Slightly reduced.)

2. *Exogyra costata* Say from the Ozan road 3.3 miles north of Washington, Hempstead County. (Slightly reduced.)

1

2

FOSSILS FROM THE SARATOGA CHALK

Cyprimeria, Isocardia, Cardium, and *Trigonia* (see Pl. XXI, Figs. 4, 5, 6), rather than by calcite shells of *Ostrea, Gryphaea,* and *Exogyra,* although these forms as well are found in the upper part. The data available is not sufficient to make possible the separation of the faunas into two lists, and such separation may not be desirable, as it seems most likely that the difference is due to variation in environment rather than to a limitation of range of species within the Saratoga.

The following list includes species identified by Dr. Stephenson from collections made from the Saratoga chalk by him, H. D. Miser, C. H. Gordon, and the writer:

Porifera:
- Cliona sp. (a boring sponge).
- Unidentified sponges.

Vermes:
- Serpula sp.

Echinodermata:
- Micraster sp.
- Hemiaster sp.

Molluscoidea:
- Bryozoa.

Pelecypoda:
- Cucullaea aff. C. antrosa Morton.
- Inoceramus sp. (large, with radiating sculpture).
- Glycymeris sp.
- Cuspidaria sp. (large).
- Gryphaea vesicularis Lamarck (variety).
- Exogyra costata Say.
- Exogyra cancellata Stephenson.
- Trigonia sp. (large).
- Pecten (2 species).
- Anatimya antiradiata Conrad.
- Paranomia scabra (Morton).
- Liopistha protexta Conrad.
- Veniella conradi (Morton).
- Veniella (Etea) sp.
- Trapezium sp.
- Crassatellites sp.
- Panope sp.
- Sauvagesia (?)
- Epitonium sp.
- Isocardia sp.
- Cardium sp. (large).
- Cardium (Pachycardium) spillmani Conrad.
- Cyprimeria densata Conrad.

Gastropoda:
- Gyrodes cf. G. altispira (Gabb).
- Capulus (?)
- Turritella trilira Conrad.
- Anchura sp.
- Ornopsis (?)
- Sargana sp.
- Volutoderma sp.

Cephalopoda:
- Scaphites sp.
- Baculites sp.
- Eutrephoceras sp.

PLATE XXI

(All figures natural size)

FIGURE 1. An unidentified sponge from gullies near the Columbus road a mile east of Saratoga, Howard County.

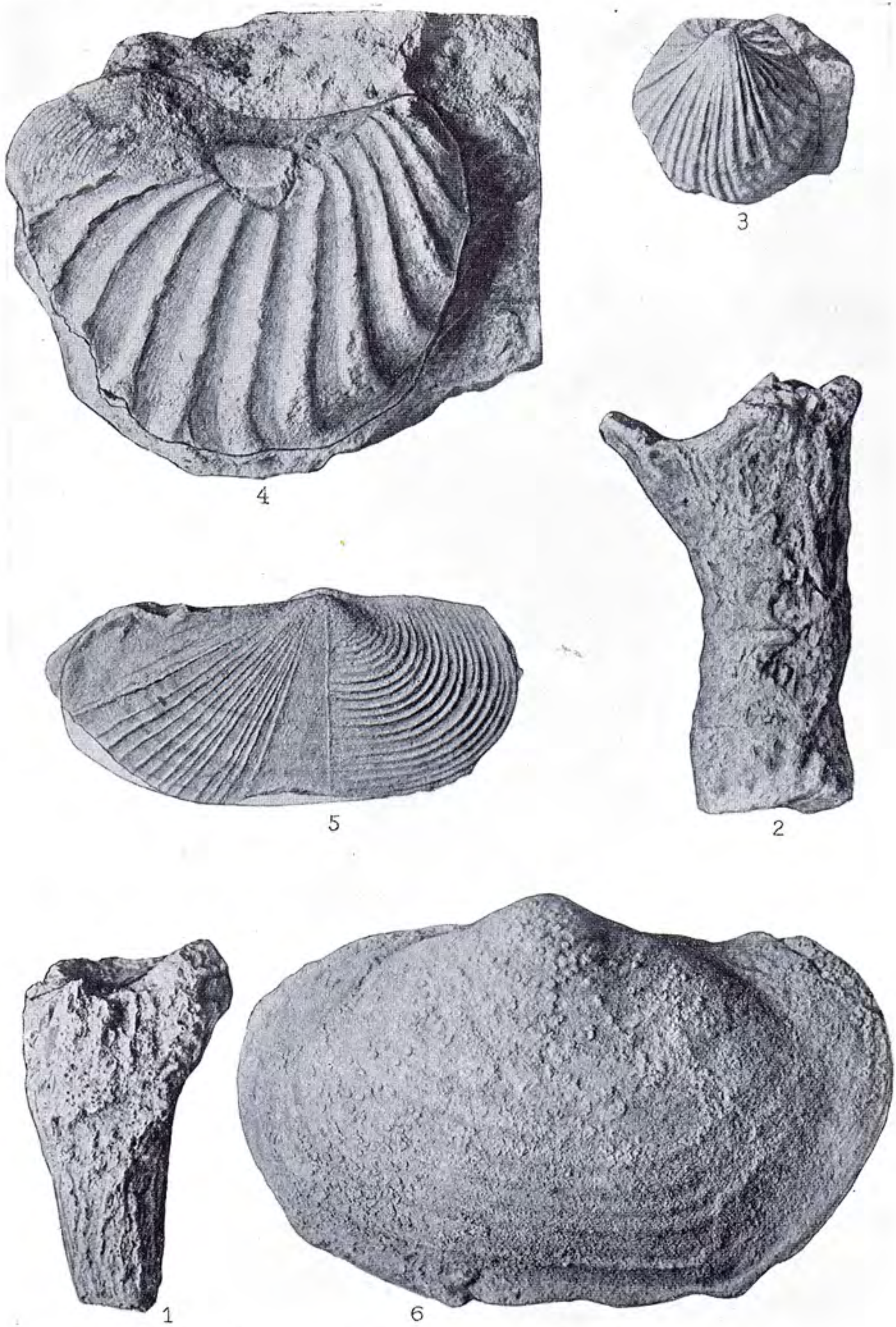
2. An unidentified sponge from the Columbus road one-fourth mile east of Saratoga, Howard County.

3. *Capulus* sp. from the Ozan road 3.1 miles north of Washington, Hempstead County.

4. *Trigonia* cf. *T. thoracica Morton* from near the Gurdon road at the crossing of Big Deciper Creek, 5.4 miles southwest of Arkadelphia, Clark County.

5. *Anatimya* aff *A. antiradiata* Conrad from the same locality.

6. *Panope* sp. from near the Okolona road 7.4 miles southwest of Arkadelphia, Clark County.



FOSSILS FROM THE SARATOGA CHALK

Nostoceras helicinum (Shumard) (?)
Pachydiscus sp.
Belemnitella americana (Morton).
Crustacea:
Scalpellum sp.
Vertebrata:
Fish teeth.

CORRELATION

The base of the Saratoga chalk clearly marks the base of the beds of Navarro age in Arkansas and the base of the *Exogyra costata* zone, the importance of which in correlation has been pointed out by Stephenson.[13] The thinner *Exogyra cancellata* subzone includes the lower part of the Saratoga and extends downward stratigraphically a short distance into the uppermost Marlbrook. *Exogyra cancellata* of the type found in the Saratoga has been found at several places in the lower part of the Navarro in northeastern Texas, showing that the Saratoga is of lower Navarro age.[14] The chalk does not extend on the outcrop into northeast Texas, however, the lower part of the Navarro consisting of dark-gray calcareous shaly clay or marl.

ORIGIN

That a considerable break in sedimentation occurred before the deposition of the Saratoga chalk is shown by the great change in the character of the fauna. A part of this change is due to the evolution of forms that were in existence before the time that is now unrepresented by sediments, but most of it is probably due to the appearance of a different set of forms under a different environment or to the migration of forms from other places into this area. If the evolutionary change in the genus *Exogyra* could be taken as even a rude measure of the time that elapsed, the break between the Marlbrook and the Saratoga might represent as much time as was required for the deposition of the Brownstown, Ozan, Annona, and Marlbrook. The establishment of the costate tendency shown in the uppermost Marlbrook probably required more time than that required for its progression to completion, and presumably also the evolution was accelerated in the lost interval by changing

[13] Stephenson, L. W., Cretaceous deposits of the eastern Gulf region and species of Exogyra from the eastern Gulf region and the Carolinas: U. S. Geol. Survey Prof. Paper 81, p. 23, 1914.

[14] Stephenson, L. W., A contribution to the geology of northeastern Texas and southern Oklahoma: U. S. Geol. Survey Prof. Paper 120, p. 157, 1918.

conditions, so the lost interval probably represents less time than would at first be thought. However, it appears that from Hunt to Falls County, in east-central Texas, there is about 200 feet of the *Exogyra cancellata* zone, most of which is certainly later than the top of the Marlbrook; yet above this zone in Texas there is probably an unconformity at the base of the *Exogyra costata* zone.[15] The time importance of the Saratoga-Marlbrook unconformity is therefore greater than the 200 feet of the *Exogyra cancellata* zone in east-central Texas.

In addition to the faunal change, a marked lithologic change takes place at the base of the Saratoga. The beds at the base were evidently deposited in shallower water than the marl below, although the absence of land waste during Annona and Marlbrook time and its abundance during Saratoga time probably contributed somewhat to the difference. Although quiet, clear water of no great depth, containing abundant carbonate-secreting organisms is favorable to the deposition of calcareous sediment, it is difficult to avoid the conclusion that a deposit of 300 feet of pure chalk and marl like the Annona and Marlbrook must have been laid down in water that was quiet and clear because of its depth below the reach of waves and currents. Slightly deeper water is probably also indicated by the much less abundant fauna. Wade[16] has brought out the fact that sparsity of fauna at some places is due to conditions that were unfavorable to the preservation of the organisms, and particularly to the absent of detrital sediment that would rapidly bury them. There is, however, a marked diminution in the number of the Ostreidae in the Marlbrook and Annona as compared with the Ozan, and the shells of this family are hard and resistant to corrosion by minute organisms.

Although the Saratoga is correctly termed a chalk, most of it contains beds of sand, sandy marl, and chalky sand. It is abundantly fossiliferous almost throughout, a fact indicating the agitation of the water and the presence of light for the photosynthesis of abundant plants for food. At its

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[15] Dane, C. H., and Stephenson, L. W., Notes on the Taylor and Navarro formations in east-central Texas: Amer. Assoc. Petrol. Geol. Bull., vol. 12, No. 1, pp. 46-47, 55-57, 1928.

[16] Wade, Bruce, Fauna of the Ripley formation on Coon Creek, Tennessee: U. S. Geol. Survey Prof. Paper 137, p. 7, 1926.

base in many places is a 3-foot bed of shell conglomerate, in which the shells have been shifted, broken, and mixed by the action of water. Glauconite is found in much of the chalk and is abundant at its base, together with phosphatic nodules and casts of fossils. The glauconite and phosphate also suggest depth within the zone of wave action. Much of the upper part of the Saratoga in the eastern area of its outcrop consists of chalky sand containing extremely abundant, small, black carbonaceous fragments of plants, a strong indication of its deposition near the shore in shallow water.

The base of the Saratoga resembles in many ways the base of the Ozan. The contact at the base is sharp and at many places shows a minor irregularity amounting to a few inches. On a larger scale there is an irregularity of several feet in several hundred feet horizontally, but no marked scour or channeling. Glauconite is abundant at the base, and tubular borings filled with the glauconitic overlying chalk extend down into the marl below. A phenomenon difficult to explain is the occurrence in the top foot of the Marlbrook of small lenses of glauconitic, sandy chalk and glauconitic marl of the same lithologic character as the basal part of the overlying Saratoga. Such glauconitic lenses are not found elsewhere in the Marlbrook. The hypothesis that the upper part of the Marlbrook was reworked will not clearly explain the existence of these isolated lenses. The evidence of unconformity and lapse of time is hardly to be challenged; yet the appearance of these lenses here and there suggests continuity of sedimentation. This apparently contradicts the definite evidence of a time break, but in lieu of a more credible hypothesis it is suggested that the unconformity at the base of the Saratoga, instead of being a single sharp plane, is actually the uppermost foot of material in the uppermost Marlbrook, which represents sediment that has been subjected to long exposure to very slight submarine agitation.

The break in the deposition of the Marlbrook and the following deposition of the Saratoga were apparently not due to an uplift of the area above sea level and a subsequent depression, involving a transgression of the sea. Some uplift was probably necessary to bring the sediments up to the level of the marine profile of equilibrium, but this uplift may have occurred gradually during the deposition of the Annona and Marlbrook rather than toward the end of that deposition. The more fossiliferous character of the upper part of the Marlbrook is possibly an indication of a slightly shallower sea. There is little evidence of submarine erosion, so that the time during which the marine profile of equilibrium was maintained was probably a period of non-deposition or of very slow deposition, during which the material deposited was removed by currents before much of it had accumulated. To initiate the deposition of the Saratoga it was necessary that the surface of the sedimentary deposit be lowered beneath the profile of equilibrium, either by actual depression of the floor or by elevation of the profile of equilibrium due to increase in the supply of sediment. During the time of non-deposition there was probably some regression of the shore line, and a subsidence of the floor might allow the preservation of the near-shore sediments. The character of the Saratoga and the overlying Nacatoch, however, suggests that there was at this time a considerable increase in the rate of supply of sediment, and probably this operated jointly with depression to allow permanent deposition.

The Saratoga rests with approximate parallelism on the Marlbrook. The eastward thinning of the marl may be due to a slight angular unconformity at the base of the Saratoga, caused by tilting and subsequent bevelling, but there are no beds in the Marlbrook by which such truncation could be detected. The eastward tapering of the Annona to a thin edge below the unconformable Marlbrook tends to confirm the conclusion that similar shoreward thinning was repeated in the later formation, as the two are closely related.

NACATOCH SAND

HISTORICAL SUMMARY AND GENERAL CHARACTER

The Nacatoch sand, which overlies the Saratoga chalk is a complex unit made up of cross-bedded yellowish and gray fine-grained unconsolidated quartz sand; hard, crystalline, fossiliferous sandy limestone; coarse, richly glauconitic sand; fine-grained, argillaceous blue-black sand; and pure light-gray clay and marl. It rests on an irregular surface having the physical aspect of an unconformity. For some distance east of Little Deciper Creek this irregularity cuts out the Saratoga chalk and the Nacatoch rests directly on the Marlbrook marl and still further east on the Ozan formation. The Nacatoch sand was defined by Veatch as a series of sandy beds above the Marlbrook marl.

The formation was named from Nacatoch Bluff, on the east bank of Little Missouri River, in the SW. ¼ Sec. 36, T. 9 S., R. 22 W., in Clark County, a few hundred feet northwest of the Hope-Arkadelphia highway bridge over the river. This bluff expcses about 50 feet of beds in the upper part of the formation. According to Veatch[17] "the outcrop of this bed (the Nacatoch sand) produces the belt of sandy land which begins on Yellow Creek south of Saratoga and extends, with interruptions of greater or less importance, along the main drainage channels, through Washington, De Ann, Garlandville, Nacatoch Bluff and Keyton, and finally reaches Ouachita River at High Bluff, above Arkadelphia."

Veatch further says:[18] "The beds described by Hill in 1888 as the 'Washington greensand' or the 'Washington or High Bluff greensand'[19] are doubtless very nearly equivalent to the Nacatoch sand as used in this report and this older name would have been adopted here but it was found to be preoccupied by the name 'Washington County group,' used by Stevenson in 1876.[20] The term 'Washington greensand' has never been very closely defined, but the writer is inclined to believe that it includes a portion of the greensand marls which in the present classification are included in the Marlbrook formation, the term 'Nacatoch' being restricted to the sandy beds."

An examination of Hill's report leaves no doubt that most of the beds included by him in the "Washington or High Bluff greensand beds," as well as the underlying "Blue sands of High Bluff and of Pate's Creek," were included by Veatch in the upper part of his Marlbrook formation. An examination of the map accompanying Hill's report simi-

[17] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 27, 1906.

[18] Veatch, A. C., idem, p. 27.

[19] Hill, R. T., Neozoic geology of southwestern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1888, vol. 2, pp. 72-75, 1888.

[20] Stevenson, J. J., Report of progress in the Greene and Washington district of the bituminous coal fields of western Pennsylvania: Second Geological Survey Pennsylvania, 1875. Report K, pp. 44-56. 1876.

larly leaves no doubt that the quartz sands and calcareous sandstone to which Veatch restricted the term Nacatoch sand were regarded by Hill as Tertiary sand and "Plateau gravel."

The present examination has emphasized the complexity of this group of sandy beds but has shown that the logical base of the unit lies at the top of the Saratoga chalk throughout the area. The difficulty of distinguishing these beds from the surficial sands that mantle the region has been stated by previous writers and verified by the author's experience. In addition the various sandy types become indistinguishable after they have been deeply weathered and slightly reworked.

The criteria that can be relied upon as definitely proving Cretaceous sand are the presence of marine fossils, either as shells or as casts in soft sand, of irregular calcareous concretionary lenses, and of the nubbly-surfaced clay casts of the possible fossil seaweed *Halymenites major* Lesquereux. This last criterion is a most useful one. Regularity of bedding planes and presence of clay partings, presence of grains of glauconite, absence of carbonaceous or lignitic lenses, absence of pebbles and of gravel lenses, and presence of distinct beds of gray clay, either singly or in combination, show in many places that the sand is really Cretaceous. In small outcrops all these kinds of evidence may fail, and even the intangible criteria gained by field acquaintance with the appearance of the formation are not sufficient to enable one to distinguish it from surficial sand.

From a point west of Washington, in Hempstead County, eastward to Dobyville, in Clark County, the Nacatoch is divisible into three lithologic units. These three units grade into one another. The lowest unit consists of bedded gray clay, sandy clay, and marl; dark clayey, very fine grained sand; and harder, irregular concretionary beds, and contains lenses of calcareous, fossiliferous, slightly glauconitic sand. The middle unit consists of a dark-greenish sand, which contains from 20 to 80 per cent of coarse grains of glauconite and weathers to lighter shades of green. It is generally fossiliferous where it is strongly glauconitic. This unit also contains hard, irregular concretionary beds cemented with calcite and subordinate beds of dark blue-gray, argillaceous, massive, fine-grained sand. The upper unit is composed of unconsolidated gray, fine-grained quartz sand, which weathers yellowish and reddish. Cross bedding is common in this sand, but is obscure except where it is revealed by the differential weathering of thin clay partings. Locally the sand is massive and structureless and contains a few hard lenses and beds of fossiliferous sandstone, cemented by crystalline calcite, and also beds of gray and white clay.

The middle unit, the glauconitic sand, which is exposed most extensively in the vicinity of Washington, serves as a key horizon with reference to which the other phases of the formation may be most conveniently studied and discussed. Accordingly it will be described first.

LITHOLOGY AND OUTCROPS OF THE GREENSAND MEMBER

A road cut less than a quarter of a mile east of the railroad station at Washington, in Hempstead County, exposes about 30 feet of the greensand unit. The following section differs somewhat in detail but not in essentials from the one measured by William Taylor, of the Bureau of Soils, given in Ashley's[21] report on the greensand deposits of the eastern United States. The difference between the two measured sections show the variability of the beds and the lack of sharp divisions between them.

Partial Section of Nacatoch Sand East of Washington Railroad Station

	Ft.	In.
Top of section covered by terrace sand and gravel.		
Greenish-gray soft, massive sand containing at its base about 30 per cent of glauconite, which diminishes to a very small amount at the top. Fossiliferous in the lower 2 feet. Weathers brown and reddish and shows bands of iron-stained sand	15	0
Zone of nearly black glauconitic sand, weathering brown, containing numerous hard lenses of calcareous cemented sands. These lenses weather out as lumps and give a distinctly bedded appearance to the zone	2	6
Soft glauconitic sand containing some shells and a few hard fossiliferous beds. Nearly black on fresh fracture. At the top it contains about 80 per cent of glauconite, but the percentage decreases downward	8	6
Hard, glauconitic, calcareous-cemented sand containing numerous fossils	0	6
	to 1	6
Soft glauconitic sand containing abundant small shells, particularly *Ostrea falcata*	3	0
Base not exposed.		

[21] Ashley, G. H., Greensand deposits of the eastern United States: U. S. Geol. Survey Bull. 660, p. 47, 1918.

West of the railroad, in road cuts extending uphill to the center of Washington, the fine-grained, massive, non-glauconitic sand of the upper part of the formation is exposed.

The road running from Washington northward to Ozan crosses the bevelled edge of the greensand member from 1.3 miles to 2.1 miles from Washington. The lower part is exposed farthest north. The glauconitic beds here are 50 or 60 feet thick. The lower 35 feet includes slightly glauconitic beds of fine-grained quartz sand, beds of somewhat indurated calcareous glauconitic sand one-fourth-inch to 2 inches thick, and beds of glauconitic marl, all slightly fossiliferous, but principally so in the harder calcareous beds and lenses. At a point 1.6 miles north of Washington, a 3-foot bed of dark-green sand containing about 50 per cent of glauconite in grains crops out along the road. This bed carries extremely abundant embedded shells of *Ostrea falcata* and other fossils, particularly *Exogyra costata, Gryphaea vesicularis,* variety (see Pl. XXIII), and *Inoceramus* sp. This bed is very much like the fossiliferous glauconitic sand exposed at the base of the section east of the Washington railroad station and is probably the same bed. Above it crops out massive and irregularly bedded soft, glauconitic sands, about 20 feet thick, containing some hard, calcareous, fossiliferous beds.

The greensand member crops out at several places along the Washington-Columbus road at points from 1.2 miles to 4.2 miles from Washington. At a point 2.85 miles from Washington along this road there is exposed a 10-foot section of dark-green, very glauconitic sand containing *Ostrea falcata, Exogyra costata, Gryphaea vesicularis,* variety, and other fossils. Here there are large, hard, concretionary lenses of calcareous greensand. This material grades upward into less glauconitic and only slightly fossiliferous sand. The greensand at the base of this section resembles the richly glauconitic bed at the base of the section just east of the Washington railroad station and is probably the same bed.

Outcrops of the greensand member have not been discovered west of this road. Along the Columbus-Hope road from Macedonia Church to Griffin's store the surface is almost completely covered by surficial sand. Farther west, along the Columbus-Fulton and Saratoga-Fulton roads, which cross the Nacatoch, the greensand member does not crop out. In this area the underlying rocks are concealed and much ground has not been covered in detail, so there may be some westward extension of the greensand. However, its disappearance eastward along the strike, where exposures are more common, leads to the belief that it diminishes in thickness and disappears westward in the same way and that it is not present in the section west of Sandy Bois d'Arc Creek.

About 3 miles northeast of Washington, the old military road running toward Jakajones goes down a steep hill into the valley of one of the heads of the Flat Branch of Terre Rouge Creek. The road cuts and a deep gully here expose about 60 feet of beds, the upper part of which are in the greensand member. The following section was measured:

Partial Section of Nacatoch Sand in NE. 1/4 Sec. 14, T. 11 S., R. 25 W.

	Feet
Surficial sand at the top of the hill	15
Massive and poorly bedded, slightly glauconitic sand	2
Soft, dark olive-green sand; about 50 per cent of glauconite at the top, decreasing downward	10
Sandstone, light brown, bedded and cross-bedded; lenses of somewhat harder glauconitic sand	9
Concealed	2
Soft brownish-green sand with "fucoid" growths	3
Argillaceous glauconitic sand, poorly exposed	5
Sandstone, hard, gray-green, glauconitic, calcareous, fossiliferous, lenticularly bedded; weathers brown	1
Light-brown, somewhat indurated sand, partly massive, partly bedded and cross bedded at angles of 5° to 15°, slightly glauconitic toward the top	8
Hard calcareous sandstone, containing many fossils; almost a shell bed	1
Dark, argillaceous sand, massive at the top; contains isolated hard, calcareous, fossiliferous lenses	6
Hard, calcareous, fossiliferous sandstone	1
In part sandy clay, in part argillaceous sand; medium gray on fresh fracture but weathers nearly black; contains small, thin fossil shells throughout	12
Base not exposed.	

Road cuts on the opposite side of the creek expose the lower part of the same section but do not show close correspondence of the hard, calcareous beds. The top of this section is probably stratigraphically below the base of the section just east of the Washington railroad station.

At a point 3.5 miles from Washington, toward Jakajones, the road cuts expose the following section in the upper part of the greensand member:

Partial Section of the Nacatoch Sand in the SE. ¼ Sec. 11, T. 11 S., R. 25 W.

	Feet
Surficial sand to top of hill	8
Glauconitic sand (less glauconitic toward the top) containing hard, calcareous concretions from 2 inches to 18 inches long	15
Hard, calcareous sandstone	1
Strongly glauconitic sand containing extremely abundant *Ostrea falcata*	5
Hard, calcareous sandstone	1
Yellow, slightly glauconitic sand	4
Base not exposed.	

The glauconitic sands crop out just east of Holt's store, about 4.2 miles from Washington, and east of Rike's Chapel, about 4.7 miles from Washington, along this same road.

East of these localities the greensand member is practically concealed for many miles by the surficial terrace sand that borders the alluvial bottom of Little Missouri River. Poor outcrops of slightly glauconitic sand indicate that it continues eastward across the Little Missouri to the abundantly glauconitic sand exposed at about the same stratigraphic horizon east of the river.

Nearly 3 miles south of Okolona, on the road to the bridge across the Little Missouri on the Hope-Arkadelphia highway, road cuts and deep gullies on both sides of the road expose the lower part of the Nacatoch. The following section was measured:

Partial Section of Nacatoch Sand 2.9 Miles South of Okolona, on Prescott Road

	Feet
Nacatoch sand.	
Soft, massive, yellow to dark-green, coarsely glauconitic sand; contains up to 40 per cent of glauconite	10
Partly indurated, calcareous, glauconitic sand containing casts of *Inoceramus* and gastropods	1
Poorly bedded argillaceous sand containing poorly preserved shell prints	5
Glauconitic argillaceous sand containing lenses of more richly glauconitic sand	1
Poorly bedded sandy gray clay, grading downward into less sandy clay and becoming increasingly calcareous	18
Grayish, slightly sandy clay, gray clay and marls	30
Contact not exposed.	
Saratoga chalk.	

The upper part of the greensand member is exposed 4 miles a little east of south of Okolona, in the northeast corner of Sec. 26, T. 9 S., R. 22 W., nearly 2 miles north of Nacatoch Bluff, on the edge of the bottom of a small creek flowing into the Little Missouri. This place is accessible by a road from Okolona, which turns westward from the road running southward to the highway bridge at a point 2.9 miles from Okolona and rejoins it about 2 miles farther south. The following section is exposed in road cuts:

Partial Section of Nacatoch Sand in NE. ¼ Sec. 26, T. 9 S., R. 22 W.

	Feet
Top concealed by surficial sand.	
Hard, calcareous, light-gray sandstone, slightly glauconitic and very fossiliferous	1
Fine-grained, very glauconitic sand, containing as much as 50 per cent of glauconite	5
Alternating slightly glauconitic and moderately glauconitic dark-gray sand, very fossiliferous, containing gastropod casts, thin shells, and *Exogyra costata*	15
Very dark gray, fine-grained marly sand, massive and poorly bedded	10
Base of exposure.	

Weathered outcrops of the glauconitic sand are exposed in road cuts in the vicinity of Dobyville, in the SE. ¼ Sec. 29, T. 8 S., R. 21 W., and the SE. ¼ Sec. 28, T. 8 S., R. 21 W.

East of the bottom of Terre Noire Creek no outcrops of the greensand member have been found. In a cut bank of Mill Creek, in the middle of the NW. ¼ Sec. 16, T. 8 S., R. 20 W., north of the upper Arkadelphia-Gurdon road crossing, there is an exposure of dark, fine-grained, marly sand containing beds and lenses of hard, calcareous, fossiliferous sandstone. This bed is approximately in the stratigraphic position of the greensand and may be its eastern termination, because a fairly well exposed section across the Nacatoch, in the bluff on the west bank of Big Deciper Creek, about 2 miles northeast of this locality, does not disclose any of the glauconitic member.

LITHOLOGY AND OUTCROPS OF THE LOWER ARGILLACEOUS MEMBER

The lower member of the Nacatoch in the area where a three-fold division of it can be made has already been partly described. The road from Washington to Columbus crosses the strike of the beds at a small angle and exposures on it accordingly give little idea of the thickness and relations of the beds, but these are the westernmost exposures in which the tripartite division can be recognized. At a point 4.3 miles from Washington outcrops at the roadside expose about 5 feet of very fine grained, slightly argillaceous sand containing numerous casts and prints of small shells. Fine grains of glauconite are scattered through the sand. Below is a zone, 2 feet thick, of argillaceous sand in which there are lenses of hard, gray calcareous sandstone containing numerous gastropod casts composed of crystalline calcite. Below this lie 10 feet of very fine grained, slightly glauconitic sand. A quarter of a mile farther along and stratigraphically below this outcrop bedded gray, very sandy clay is exposed. This clay also carries numerous prints of shells. At a point 6.2 miles from Washington there are outcrops of thin-bedded sandy clay containing similar fossil casts and prints. This clay is slightly calcareous. At a point 6.6 miles from Washington a ditch exposes 15 feet of only slightly sandy, gray, calcareous clay containing numerous very small prints and fragments of shells. Here there are lenses of purplish, argillaceous sand. This outcrop is probably stratigraphically the lowest exposure of Nacatoch along this road. At a point 7.7 miles from Washington, 1 mile east of Columbus, 35 feet of thin-bedded sandy clay and fine-grained sand are exposed. West and south of Columbus this lower argillaceous member is almost entirely replaced in the section by fine-grained sand.

The road from Washington to Ozan crosses the lower unit of the Nacatoch in a stretch ranging from 2.1 to 2.8 miles north of Washington. It is estimated to be nearly 100 feet thick and consists of alternating sandy clay and fine-grained sand and, here and there, some harder calcareous, fossiliferous beds. It becomes more argillaceous and calcareous toward the base. The best exposure, 2.4 miles north of Washington, along the road, show 20 feet of bedded gray argillaceous sand containing some layers of sandy clay, a little of which is slightly calcareous. There are some beds, 6 to 8 inches thick, of harder, slightly calcareous glauconitic sand containing casts of *Inoceramus*. Near the top of the exposure is a bed, a foot thick, of hard, calcareous sandstone carrying numerous casts of gastropods and bivalve fossils. These casts are composed of crystalline calcite.

The lower part of the Nacatoch is exposed at several places north of the Washington station, along the railroad to Ozan and Nashville. The outcrops begin at a point a little over a mile north of the station, and the beds vary from bedded sandy clay to bedded fine-grained quartz sand. They may contain some small grains of glauconite. The cut just north of Conway's crossing, about 1.65 miles north of the Washington station, exposes nearly 25 feet of the same beds of light-gray and dark-gray bedded sandy clay and argillaceous sand. The beds contain some poor imprints of fossils, but are not perceptibly calcareous. A little over 2 miles north of the station the upper part of the Saratoga chalk crops out.

East of these railroad cuts the bedded argillaceous sand of the lower part of the Nacatoch is largely concealed by surficial sand along the steep north slope of the topographic ridge made by the formation. Its character just below the greensand is shown by the section on page 119, and the argillaceous sand is also exposed, though poorly, in the NW. ¼ Sec. 32, T. 10 S., R. 24 W., above the Saratoga chalk exposed west of Marlbrook Creek. East of this area the terrace sand and gravel of Little Missouri River effectually conceal the underlying formations, but a small outcrop of bedded sandy non-calcareous clay in the SW. ¼ Sec. 13, T. 10 S., R. 24 W., 3.2 miles east of Blevins, on the road to Prescott, indicates that the lower unit continues across this area without much change.

The section on page 120 shows that the lower unit in the vicinity of Okolona is nearly all gray clay, somewhat calcareous at the base and somewhat sandy toward the top, and only 50 to 60 feet thick. The lower Nacatoch above the Saratoga at Dobyville is mostly concealed by surficial sand, but is believed to be argillaceous sand and sandy clay. East of the Terre Noire bottom the lower argillaceous unit is replaced in the section by bedded quartz sand.

LITHOLOGY AND OUTCROPS OF THE UPPER PART OF THE NACATOCH SAND

The upper quartz sand above the greensand is exposed in the road cuts along the hill leading down to the railroad station east of Washington. At this lower level the section of greensand described on page 117 crops out. At about the same level 1.2 miles west of Washington the upper part of the greensand again crops out along the road toward Columbus. At a point 1.5 miles west of Washington the road forks and on the branch running southward to Fulton, at a point 2.2 miles from the Washington post office, the following section of sand of the upper Nacatoch is exposed:

Partial Section of Nacatoch Sand in the Center of Sec. 32, T. 11 S., R. 25 W.

	Ft.	In.
Pleistocene (?) terrace sand, with gravel and ligniferous clay	30	0
Nacatoch sand:		
Soft, yellow and white sand and indurated concretionary calcareous masses of sand, 6 to 18 inches in length	5	10
Massive, soft sand containing *Halymenites major*. At the top is a bed, 2 inches thick, of hard ferruginous sand	7	0
Sand, slightly glauconitic and somewhat indurated at the base	28	0
Base of exposure.		

At a point 2.6 miles from Washington along this road 20 feet of massive, light-yellow quartz sand, weathering red, crops out. Here there are numerous *Halymenites* and some thin beds showing partings of gray clay. Similar beds of sand crop out 4.2, 5 and 5.4 miles from Washington, along the road.

The quartz sand phase of the Nacatoch contains nearly everywhere the nubbly-surfaced, occasionally branching marine alga called *Halymenites major*. These fossils are long tubes of light-gray clay, which are oriented variably in the sand. They have studded outer surfaces, and where well exposed they seem to be made up of clay pellets, irregularly spheroidal, about a quarter of an inch in diameter. The pellets are nearly uniform in size. The inner surfaces of the tubes are smooth. The tubes are filled with sand like that of the mass of the deposit. In cross sections they are circular or irregularly elliptical. In general they are found in groups, and in some outcrops they are interlaced in great abundance, but isolated specimens are found at some places. These studded tubes occur in abundance only in the Nacatoch sand, but some are found in the sandy beds of the Tokio formation. They are not seen in the surficial sands. Thin-walled hollow cylinders of clay having vague outlines are found in the Nacatoch and surficial sand alike.

At a place 2.8 miles south of Washington, on the road toward Hope, roadside cuts expose 8 feet of sand near the top of the Nacatoch. This is a massive, soft, light-yellow quartz sand. The grains are subrounded to rounded, fine, and of uniform size. There are a few dark olive-green grains of glauconite. The sand has a matrix of gray clay in some poorly defined layers and clay partings. *Halymenites major* is abundant.

The road from Washington to Reed's store exposes the greensand member about a mile from the Washington post office. At a point 1.3 miles from Washington 15 feet af massive, soft quartz sand, weathering reddish, crops out. The sand carries *Halymenites* in large numbers. At a point 3.0 miles from Washington there is an outcrop of bedded gray sandy clay. Material of this kind crops out at only a few places but is probably more common in the upper part of the Nacatoch than the outcrops indicate.

Along the Jakajones-Hope road, from Atkins' store to Reed's store, the road cuts expose the best section of the upper part of the Nacatoch. Along this road at points 2.9 and 4 miles south of Jakajones there are large exposures of the soft white and light-yellow sand, weathering reddish and containing *Halymenites*. At a point 5 miles from Jakajones, just south of the bottom of the Flat Branch of Terre Rouge Creek, road cuts expose the following section:

Partial Section of Arkadelphia Marl and Nacatoch Sand North of Reed's Store

	Feet
Top of exposure concealed by surficial sand.	
Arkadelphia marl:	
Mostly concealed; indications of underlying calcareous material throughout; top 6 feet very slightly sandy fossiliferous marl	13
Sandy, thin-bedded, soft, gray clay. Contains a few phosphatic casts of *Cucullaea sp.* and other fossils	9
Hard, calcareous gray sandstone and sandy gray limestone with fossil shells	½-1
Nacatoch sand:	
Not exposed. Indications are that the concealed material is like the bed below, but includes more clay partings	3
Fine-grained, soft yellow sand carrying *Halymenites major*. Contains a small amount of glauconite, and some irregular slightly indurated masses	6
Fine-grained, light, soft quartz sand containing a very little glauconite. Massive and poorly bedded	11
Concealed	6
Lenses of hard crystalline limestone containing numerous fossil shells. These lenses, which are found 500 feet east of the road near the creek bottom, are sandy, weathered cavernously, and as much as 2 feet in length. The material in which they were originally imbedded is completely concealed by wash	½-1
Base of exposure.	

Quartz sand of the upper part of the Nacatoch is exposed in many isolated outcrops, notably in the vicinity of De Ann and Arcadia, in Hempstead County, and Iron Springs, in Nevada County.

At Nacatoch Bluff, on Little Missouri River, in the SW. 1/4 Sec. 36, T. 9 S., R. 22 W., the following section in the Nacatoch is exposed just above the greensand unit:

Partial Section of the Nacatoch Sand at Nacatoch Bluff

	Feet
Concealed to the top of the bluff	15
Very hard, gray sandstone containing round, medium-sized grains of quartz set in a dense matrix of white calcite. Fossiliferous. Rests on a wavy, irregular under surface. Persistent for 150 feet and probably more	2
Soft, nearly white, fine-grained quartz containing imprints of small fossil shells and *Halymenites*	10
Chiefly soft, fine-grained quartz sand, packed but not cemented. Includes at some places as much as 10 per cent of glauconite in grains. Includes irregular beds and lenses, 2 feet thick, of hard, gray, calcareous sandstone containing numerous coarsely crystallized calcite shells. In general the percentage of glauconite decreases upward	27
Concealed	10
Level of Little Missouri bottom.	

In the NW. 1/4 Sec. 15, T. 9 S., R. 21 W., 6.9 miles from Okolona, on the road to Gurdon, the top of the Nacatoch is exposed in road cuts up the hill on the south side of the south fork of Terre Noire Creek. Here the following section was measured:

Partial Section of Nacatoch Sand in the NW. 1/4 Sec. 15, T. 9 S., R. 21 W.

	Feet
Arkadelphia marl:	
Deeply weathered, poorly exposed interbedded calcareous sandy clay and clayey sands containing a few fragments of shells and an *Exogyra costata* (Arkadelphia type)	4
Very calcareous light-gray sandstone, weathering white, and dense gray limestone, in irregular beds, and lenses half an inch to 2 inches thick. These are interbedded with gray calcareous clay, and the whole bed rests on a slightly irregular surface	1
Nacatoch sand:	
Soft brown and black fine-grained, massive carbonaceous sand, cross-bedded and interbedded with gray clay	3
Mostly fine, white, soft, massive sand, in beds averaging 2 feet in thickness and including some interbedded gray clay. Toward the top cross-bedded on a large scale at small angles	30
Fine, soft sand in beds 6 inches to 2 feet thick, alternating with layers of interbedded sand and gray clay and with beds of gray clay	16
Concealed by valley wash	22
Level of bottom of south fork of Terre Noire Creek.	

About a mile northeast of this place, approximately along the strike, an outcrop in the NW. ¼ Sec. 11, T. 9 S., R. 21 W., in the bank of the south fork of Terre Noire Creek, adds a little to the lower part of the section just given. At the time of the writer's visit high water nearly concealed inaccessible black laminated clay in the bank, but Veatch[22] reports 12 feet of this black laminated clay containing partings of white sand above the level of low water. Above the black clay is about 30 feet of bedded white sand containing beds and pebbles of gray clay. This 30 feet probably represents at least part of the 22 that is concealed at the base of the section just given. Veatch erroneously assigned this outcrop to a horizon near the base of the Nacatoch.

LITHOLOGY AND OUTCROPS IN WESTERN HEMPSTEAD COUNTY

West of the area in which the Nacatoch can be subdivided lithologically the formation is in part exposed near Saratoga and Columbus and along the Saratoga-Fulton and Columbus-Fulton roads. Just north of Saratoga, on the road to Mineral Springs, the base of the Nacatoch is exposed. At the base a few inches of coarse quartz sand containing clay pellets and lenses rests on a slightly irregular surface. This sand is indurated by ferruginous cement in thin bands and nodules. Above this is 15 to 20 feet of fine-grained light-gray or white cross-bedded quartz sand containing thin beds and partings of clay. The outcrop weathers red. *Halymenites* is present sparingly. Similar sand crops out at several places south of Saratoga.

The base of the Nacatoch is exposed also 1.2 miles south of Columbus, on the road to Fulton. Here the top few feet of the Saratoga crops out near the bottom of a small hill. On an irregular surface rests a foot of gray clay filled with dark, carbonaceous, macerated fragments of plants and merging upward into a fine grained, light-yellow, bedded soft quartz sand, containing a few dark grains and weathering red. The sand is cross bedded and contains clay pebbles, the largest half an inch in diameter, which are usually flattened but are oriented at random with the bedding. *Halymenites major* is abundant. About 20 feet above the

[22] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 27, 1906.

base a bed of white, non-plastic, non-calcareous clay, 2½ feet thick, crops out.

In the SE. ¼ Sec. 2, T. 12 S., R. 27 W., and the SW. ¼ Sec. 1, T. 12 S, R.. 27 W., east of Yellow Creek church, light greenish yellow argillaceous sand containing some hard lenses crop out. These lenses carry some small imprints of shells. At a point 4.4 miles south of Columbus, on the road to Fulton, at the west side of the road, in steep gullies, there is a small outcrop of calcareous, fossiliferous gray sandstone containing a few small calcite shells. This sandstone lies beneath surficial sand. The beds in these outcrops are probably equivalent to the fossiliferous parts of the Nacatoch farther east.

At a point 3.5 miles south of Saratoga, on the road to Fulton, just south of the bottom of Yellow Creek, road cuts up a hillside expose cross-bedded *Halymenites*-bearing quartz sand. Smaller outcrops of this type of material are exposed between this place and McNab.

Half a mile west of McNab, in the cut of the Frisco railroad and in gullies below the railroad level the upper part of the Nacatoch is exposed. It consists of about 50 feet of massive, fine-grained, light-yellow and white quartz sand (Pl. XXII, A). There are a few harder calcareous, concretionary masses, which weather out as knobs on the surface, and a few dark-gray shale partings, but the sand is strikingly uniform. *Halymenites major* is found, but it is not common.

Near the top of the section is a very hard, calcareous fossiliferous sandstone containing abundant but broken large oyster shells, some of which have been identified as *Ostrea owenana* Shumard. This hard sandstone rests on a scalloped surface of the soft sand and presents the appearance of a series of lenses, 3 to 4 feet long, which have coalesced at the ends to form a continuous mass. The relief of the scalloped under surface is more than 6 inches. To the east the lenses are isolated in the sand. Lying upon this hard sandstone and grading into the soil above is a soft, darker yellow sand, which grades into the soft sand below where the hard lenses are absent. The exact relation of the Arkadelphia and Nacatoch in this area is not known, but the top of this outcrop must be practically at the top of the Nacatoch, as the Arkadelphia marl crops out a short distance south of McNab.

LITHOLOGY AND OUTCROPS IN THE DECIPER CREEK AREA

East of the area in which the tripartite division of the Nacatoch is recognizable and across the bottom land of Terre Noire Creek the exposures are not good. A few miles farther east, however, the bluff along the west bank of Big Deciper Creek exposes the Nacatoch fairly well.

At a point 5.4 miles from Arkadelphia, where the upper road from Arkadelphia to Gurdon crosses Big Deciper Creek, the west bank of the creek and the road cuts above it expose the basal Nacatoch, which rests on a slightly irregular surface cut in the Saratoga chalk. The basal 2 feet is a coarse, subangular quartz sand containing some pebbles of black and gray chert and light-gray quartz, the largest half an inch in diameter. This basal sand is glauconitic. Above this are 8 feet of slightly glauconitic quartz sand containing scattered small pebbles of chert and quartz and interbedded layers of gray clay and dark-gray carbonaceous clay containing fragments of plants. Above this crop out 15 feet of fine-grained cross-bedded quartz sand containing interbedded gray clay. About 1,000 feet southward along the creek the basal few feet of the Nacatoch is mostly dark, carbonaceous, bedded clay containing a few fragments of plants. Above the base it is principally fine white sand.

Southward along the west bank of Big Deciper Creek there is a nearly continuous small bluff in which there are numerous exposures. The Nacatoch here consists uniformly of yellowish quartz sand interbedded with gray sandy clay, some of which merges into dark, clayey fine sand. No outcrops of hard, calcareous lenses have been observed. Pebbles, lumps, and angular blocks of gray clay 3 or 4 inches through, occur in the sand. About half a mile west of Gum Springs there are small outcrops of irregularly bedded grayish sandy clay near the top of Nacatoch and at least two half-inch sandy beds containing numerous rounded, polished pebbles. Nacatoch sand crops out near the Poor Farm, a short distance south of the center of Sec. 1, T. 8 S., R. 20 W.

The lower part of the Nacatoch crops out above the

Saratoga chalk in cuts along the Arkadelphia-Okolona road on the hillside just west of the crossing of Little Deciper Creek, 4 miles west of Arkadelphia, although the contact is not exposed. The basal part of the Nacatoch is here cross-bedded, unfossiliferous, yellowish quartz sand showing partings of gray clay.

East of this locality the basal part of the Nacatoch sand gradually changes in character. In the NW. ¼ SE. ¼ Sec. 14, T. 7 S., R. 20 W., in a gully south of the road from Arkadelphia to Hearn, the basal Nacatoch is a poorly stratified argillaceous, very slightly glauconitic soft quartz sand containing numerous impressions of small pelecypods and gastropods. On the property of Mr. James Richardson, in the SW. ¼ Sec. 11, T. 7 S., R. 20 W., a well has been dug through the basal Nacatoch. The material excavated from this well is a soft, marly, greenish-gray fine-grained sand containing abundant small flakes of muscovite and numerous black, angular carbonaceous fragments. The sand contains imprints of small pelecypods.

LITHOLOGY AND OUTCROPS IN THE VICINITY OF ARKADELPHIA

About a mile and a half northeast of this well, in the NW. ¼ Sec. 12, T. 7 S., R. 20 W., the lower part of the Nacatoch is clearly exposed in road cuts and in the bank of a creek. The base is not exposed, but extending for about 500 feet horizontally near the bottom of the exposure there is a dark-gray, very slightly glauconitic, soft, argillaceous sand containing hard, irregular calcareous lenses carrying *Inoceramus sp., Crenella serica,* and *Pecten sp.,* some poor imprints of shells, and fragments of plants. The lowest exposures here are perhaps 25 feet lower topographically than the Nacatoch-Marlbrook contact half a mile to the southeast, and this difference may be due to a northwest-striking fault having a downthrow of about 50 feet to the east, but there is no apparent disturbance of the beds, and the known irregularity at the base of the Nacatoch both to the east and the west makes it more probable that the difference in elevation is due to northward downcutting of the base of the Nacatoch.

In the SW. ¼ NE. ¼ Sec. 18, T. 7 S., R. 19 W., the base of the Nacatoch consists of yellowish, medium-grained sand containing considerable glauconite but no hard calcareous lenses. Half a mile farther east, 1.2 miles north of Arkadelphia, along the Hot Springs road, the base of the Nacatoch crops out in road ditches on the north side of a small creek, but the contact is not exposed. The material here is fine-grained, greenish-gray, soft sand containing some small grains of glauconite. The bedding is not distinct. The sand contains lenses, the largest 2 feet long and a foot thick, of hard, dark-gray crystalline calcite-cemented sandstone containing some glauconite. Some of these lenses are sparingly fossiliferous; others contain numerous fossils. The bed contains pebbles of black chert, the largest half an inch in length, most of them well rounded, though some are subangular, and pebbles of grayish-white quartz which are usually smaller. There are fragments of wood, some brown, others black, soft, and carbonized, and a few imprints of slender leaves, numerous small shark teeth, and fragments of limbs of crustaceans, probably crabs. There is perhaps 50 feet of this material below the yellowish, cross-bedded, unfossiliferous quartz sand, showing partings of gray clay, which crops out south of the small creek along the road.

High Bluff, 1.5 miles north of Arkadelphia, exposes nearly 100 feet of the lower part of the Nacatoch. This conspicuous bluff, which is cut by a wide-sweeping meander of Ouachita River, is the eastern termination of the topographic ridge made by the Nacatoch. The following section is partly hand-levelled and partly estimated:

Partial Section of Nacatoch Sand at High Bluff

	Feet.
Top of bluff.	
Unconsolidated yellowish gravel and sand, probably Quaternary	5
Nacatoch sand:	
Massive, yellowish, slightly glauconitic sand, somewhat coarser than that below	15
Massive, dark gray, fine-grained argillaceous sand containing some thin, harder calcareous beds, lenses and irregular concretions. The beds may be 6 inches thick, have irregular under surfaces, and may extend for as much as 50 feet. Some of the hard calcareous lenses are not fossiliferous, but contain abundant interlaced "fucoid" tubes; others contain numerous *Inoceramus* (see Pl. XXV), *Baculites, Belemnitella, Ostrea*, and crustacean remains. Carbonized fragments of wood, pebbles of black chert and gray quartz and shark teeth are also found in these lenses. Small echinoids, *Exogyra costata, Gryphaea vesicularis*, variety, and *Anomia argentaria* weather out here and there	60
Concealed by slump and talus	15

Very dark gray argillaceous, fine-grained sand containing some small grains of glauconite and broken small shells. Hard, calcareous sandy lenses are interbedded with the soft sand.... 10
Level of Ouachita River at the time.

Similar sand crops out above the Saratoga chalk in a small gully that runs about N. 25° E. from the Free Tourist Camp Ground in Arkadelphia. The outcrop of Saratoga chalk along this gully at the level of the bottom of Ouachita River has been described on page 106. The normal dip would carry the Saratoga chalk from this point well up into the outcrop at High Bluff, a mile north, but it is not found there, probably because of its northward truncation by the base of the Nacatoch.

The upper part of the Nacatoch here consists of yellowish quartz sand, cross bedded and containing partings of gray clay. This part of the Nacatoch crops out west of the center of Arkadelphia and in the vicinity of the Arkadelphia railroad station (Pl. XXII, B).

THICKNESS

The thickness of the Nacatoch has been estimated from the elevation of its upper and its lower contact approximately along its dip and from the breadth of the outcrop. These estimates check rather well with the thicknesses inferred from the best well records available. Along the line through Saratoga and McNab the formation is about 400 feet thick; along the line through Washington and Hope it is about 350 feet thick; southeast of Okolona it is about 250 feet thick; along Big Deciper Creek it is about 200 feet thick; and in the vicinity of Arkadelphia it is probably not much over 150 feet thick.

FAUNA

The following list includes all the forms identified by Dr. Stephenson from collections made at different times from all the phases of the sand by him and the writer:

Coelenterata:
  Coral.
Echinodermata:
  Hemiaster sp.
  Linthia cf. L. variabilis Slocum.
  Cassidulus (?)
Molluscoidea:
  Bryozoa.

Vermes:
- Serpula sp.
- Hamulus onyx Morton.

Pelecypoda:
- Nucula sp.
- Cucullaea sp.
- Glycymeris sp.
- Pteria sp.
- Inoceramus aff. I. barabini Morton.
- Inoceramus sp.
- Ostrea tecticosta Gabb.
- Ostrea plumosa Morton.
- Ostrea falcata Morton.
- Ostrea mesenterica Morton (?)
- Ostrea owenana Shumard.
- Gryphaea vesicularis Lamarck, variety.
- Gryphaea sp. (small).
- Exogyra costata Say.
- Trigonia aff. T. eufalensis Gabb.
- Trigonia sp.
- Pecten simplicius Conrad.
- Pecten mississippiensis Conrad.
- Lima reticulata Forbes.
- Lima acutilineata Conrad.
- Lima sp.
- Anomia argentaria Morton.
- Paranomia scabra (Morton).
- Spondylus sp.
- Crenella serica Conrad.
- Pulvinites argentea Morton.
- Liopistha protexta Conrad.
- Liopistha (Cymella) bella (Conrad) var. (?)
- Veniella conradi (Morton).
- Trapezium (?)
- Crassatellites sp.
- Lunatia sp.
- Epitonium sp.
- Cardium (Criocardium) dumosum (Conrad) (?)
- Cardium (Criocardium) kummeli Weller (?)
- Cardium (Criocardium) tippanum Conrad.
- Cardium (Criocardium) sp.
- Cardium (Pachycardium) spillmani Conrad (?)
- Tenea pinguis (Conrad) (?)
- Legumen sp.
- Aphrodina (?)
- Corbula crassiplica Gabb.
- Corbula sp.

Scaphopoda:
- Dentalium sp.

Gastropoda:
- Pleurotomaria (?)
- Gyrodes cf. G. altispira (Gabb).
- Turritella trilira Conrad.
- Turritella vertebroides Morton.
- Turritella sp.
- Anchura (?)
- Capulus (?)
- Anisomyon (?)
- Solidula riddilli Shumard.
- Liopeplum canalis (Conrad).
- Volutomorpha sp.

Cepholopoda:
- Nautilus sp.
- Pachydiscus sp.

PLATE XXIII

FIGURES 1 AND 2. *Gryphaea vesicularis* Lamarck (variety). Right and left valves of the same individual from the old military road, one-eighth mile northeast of the railroad station at Washington, Hempstead County. (Slightly reduced.)

Baculites sp.
Scaphites sp.
Nostoceras sp.
Belemnitella americana (Morton).
Arthropoda:
Crustacean claws (crab?)
Vertebrata:
Shark teeth.

The fauna of the Nacatoch shows little change from that of the upper part of the Saratoga. The shells of the genus *Exogyra* are apparently identical in the upper part of the Saratoga and in the Nacatoch (see Pl. XX, Fig. 2, and Pl. XXVI, Fig. 1), although this form is distinctly different above and below this zone and the genus was susceptible to variation and to ready response to external conditions, as is shown by its variability in the Brownstown and Ozan formations. Similarly *Liopistha protexta* Conrad, a form which occupies a restricted zone in the eastern Gulf region, has been collected in Arkansas only from the Saratoga and the Nacatoch. A considerable number of other forms are common to the two formations. Although the resemblances between the faunas are striking, a considerable number of new faunal elements first appear in the Nacatoch, and further collecting and critical study will probably increase the number of reliable index fossils. *Ostrea owenana, Crenella serica* (see Pl. XXIV, Figs. 1, 2 and 7), and several other Nacatoch species have not been reported from the Saratoga. Similarly *Micraster, Anatimya antiradiata,* and a few other Saratoga species have not been reported from the Nacatoch, although *Anatimya antiradiata* is found in the Owl creek tongue of the upper part of the Ripley formation in northern Mississippi.[23]

CORRELATION

The Nacatoch sand extends from a point a short distance above the base of the *Exogyra costata* zone to or above its middle part; the Arkadelphia marl, which carries the varietal form of *Exogyra costata* Say having narrow costae, makes up the upper part of the zone. In Texas the age equivalent of the Nacatoch sand is included in the Navarro formation, which has not yet been subdivided. There is within this formation for many miles in northeastern Texas a zone of somewhat glauconitic gray sand and sandy clay

[23] Stephenson, L. W., Cretaceous deposits of the eastern Gulf region: U. S. Geol. Survey Prof. Paper 81, p. 24, 1916.

PLATE XXIV

(Figures natural size unless otherwise marked)

FIGURES 1, 2. *Ostrea owenana* Shumard from the upper part of the formation in a cut of the Frisco railroad just west of McNab station, Hempstead County.

3, 4. *Capulus sp.* from the old military road 2⅛ miles northeast of Washington, Hempstead County.

5. *Belemnitella americana* (Morton) from the old military road 2 miles northeast of Washington, Hempstead County.

6. *Belemnitella americana* (Morton) from the Peedee formation at Burches Ferry, Florence County, South Carolina. Introduced for comparison with figure 5.

7. *Crenella serica* from a bluff on a small branch near a bridge on a public road in the NW. ¼ NW. ¼ Sec. 12, T. 7 S., R. 20 W., Clark County (× 4).

containing calcareous and fossiliferous lenses which corresponds lithologically and faunally to at least a part of the Nacatoch.[24]

The Nacatoch has a greater areal extent on its outcrop in Arkansas than the underlying formations and has been recognized in northeastern Arkansas as a thin strip bordering the western edge of the Mississippi embayment, resting unconformably on Paleozoic rocks and overlain by the Midway formation.[25] The *Exogyra costata* zone in western Tennessee includes most of the Ripley formation and all of the Ripley and the upper part of the Selma chalk in northern Mississippi.[26]

ORIGIN

The base of the Nacatoch presents considerable physical evidence of unconformity in the area east of Terre Noire Creek. In the vicinity of Washington, Marlbrook Creek and Okolona no contacts are exposed, but the change in lithologic character from the upper part of Saratoga through the lower part of the Nacatoch, already described, would give the impression of continuous transitional sedimentation if sharp contacts at the base of the Nacatoch were not exposed both to the west and to the east.

The base of the Nacatoch north of Saratoga, described on page 127, is a sharp and slightly irregular contact, but there is some indication of a gradual change in the conditions of sedimentation in the upper part of the Saratoga. The chalk at the base merges gradually upward into a sandy, marly chalk, then into a soft, argillaceous sand; and at the top there is a foot of slightly sandy gray clay. On this clay rests the quartz sand of the Nacatoch. The unusual thinness of the Saratoga at this locality might be due to the irregularity at the base of the Nacatoch, but the apparent transition to less chalky material upward, corresponding to a similar change in areas farther east, although on a smaller scale, leads to the belief that the entire thickness of the Saratoga is represented here and that the thinning is depositional rather than due to an unconformity cutting

[24] Stephenson, L. W., A contribution to the geology of northeastern Texas and southern Oklahoma: U. S. Geol. Survey Prof. Paper 120, p. 157, 1918.

[25] Stephenson, L. W., and Crider, A. F., Geology and ground waters of northeastern Arkansas: U. S. Geol. Survey Water Supply Paper 399, p. 36, 1916.

[26] Stephenson, L. W., Cretaceous deposits of the eastern Gulf region: U. S. Geol. Survey Prof. Paper 81, pp. 17-19, 1914.

PLATE XXV

(All figures natural size)

FIGURE 1. *Inoceramus* sp. from High Bluff on Ouachita River 1.5 miles north of Arkadelphia, Clark County.

2. *Inoceramus* sp. from a point 3 miles northeast of Washington, Hempstead County.

3, 4. *Ostrea falcata* Morton (variety) from the old military road 2.5 miles northeast of Washington, Hempstead County. Views of the left and right valves of the same individual.

5, 6. *Nostoceras* sp. from the old military road 2 miles northeast of Washington, Hempstead County.

down into the chalk. A more abrupt change in conditions is indicated in the contact exposed south of Columbus described on page 127. Here the top of the Saratoga is typical sandy chalk, and on its irregular surface rests a foot of gray clay, full of carbonaceous fragments and abruptly merging into typical Nacatoch sand. From this locality eastward the Saratoga is perceptibly less chalky in its upper part, which is usually a chalky, sandy marl, but in places a marly sand. This change is particularly evident at the outcrop 7.8 miles west of Arkadelphia, on the road to Okolona, where the upper part of the Saratoga, although clearly transitional into the chalk below, is a soft marly sand containing harder, fossiliferous, calcareous lenses. East of this locality the Nacatoch cuts out the Saratoga and Marlbrook, and the base of the Nacatoch is gravelly and rests on an irregular surface at Big Deciper Creek.

The physical evidence is inconclusive as to whether there has been surface exposure of the Saratoga accompanied by erosion and followed by depression to allow the deposition of the overlying sand or whether such erosional irregularity as occurs at the base of the Nacatoch is due to submarine scour. The numerous places at which the Saratoga shows lithologic transition upward to beds more nearly of Nacatoch type suggests that there was a continuous sequence of events without an intervening time break. The sediments of both formations show that they were deposited in shallow water near shore, where scour of the magnitude of the demonstrated irregularity would not be unlikely. This is particularly true of the lower part of the Nacatoch near Arkadelphia, in which imprints of leaves, fragments of wood, pebbles of chert and quartz, and abundant remains of crustaceans, probably crabs, are intermingled. Such scour would be local rather than general. The initiation of the deposition of the Saratoga chalk has already been attributed in part to an increased supply of sediment and the resulting rise of the marine profile of equilibrium. Shoaling was probably contemporaneous with the first deposition of the sandy chalk and later shoaling is shown by the change in the lithologic character of the upper part of the Saratoga.

According to this hypothesis the change of conditions from upper Saratoga sedimentation to Nacatoch sedimenta-

PLATE XXVI

FIGURE 1. *Exogyra costata* Say from the Nacatoch sand on the old military road, ⅛ mile northeast of the railroad station at Washington, Hempstead County. (Slightly reduced.)

2. *Exogyra costata* Say (variety) from the Arkadelphia marl on the Washington road 5.1 miles northwest of Hope, Hempstead County. (Slightly reduced.)

tion would be interpreted as gradual and in a general way as transitional, but, as the water was shallow, irregularities of current have in places developed submarine scour and abrupt changes in type of deposition. The comparative thinness of the underlying chalk would account for the fact that this postulated scour has completely removed the chalk at some places and produced a true unconformity at the base of the Nacatoch, although elsewhere the Nacatoch merges into the Saratoga.

Such faunal differences as exist between the Saratoga and Nacatoch tend to indicate a time break and offer the principal basis for an alternative hypothesis that there is actually an unconformity at the base of the Nacatoch. Under this hypothesis the clear evidence of erosional irregularity at the base of the Nacatoch in the vicinity of Arkadelphia would probably be interpreted to indicate subaerial exposure in that area, passing into a break of slight importance toward the southwest, where the Saratoga was not exposed to subaerial erosion. It is of course possible that the appearance of the new faunal elements in the Nacatoch is due to the slightly changed environment shown by the change in lithology from the Saratoga to the Nacatoch, or that sufficient time for the migration of faunas was allowed by the time involved in the sedimentation of the Saratoga and the lower Nacatoch. If there is an unconformity at the base of the Nacatoch the time that elapsed was unquestionably short.

The complexity of the lithology of the sediments making up the Nacatoch is a natural result of the rapidly changing conditions that characterize a near-shore, shallow water site of deposition. Without a more thorough knowledge of the shape and extent of the lithologic units of the Nacatoch down the dip as well as along the outcrop it is hardly possible to speculate with any confidence on the local reasons for the variation.

It is evident that the argillaceous lower phase of the Nacatoch was receiving a larger proportion of clay than of the coarser sediments that were being deposited at the same time in the same stratigraphic position both east and west. This difference must have been due to the position of the source of supply, and a possible hypothesis is that rivers flowed into the sea from the northwest on each side of the argillaceous unit. No reasonable hypothesis has been conceived as to why the subsequent greensand member should appear on the outcrop only above the lower argillaceous unit. The dark argillaceous sand of High Bluff may represent an environment somewhat similar to that of the lower argillaceous unit, although it is strange that it should be in the region of deepest scour. Shallow water persisted to the top of the Nacatoch in places, as is indicated by the cross-bedding, although some of the sand is massive. The great numbers of *Halymenites major* show that the bottom was in places covered with abundant aquatic vegetation. The occasional fossiliferous limestone lenses testify that local areas of quiet, clear water were present for short periods.

PHYSIOGRAPHIC EXPRESSION

The sandy beds of the Nacatoch are more resistant to erosion than the underlying and overlying soft marls, and accordingly the belt of outcrop coincides approximately with a topographic ridge extending from Saratoga eastward to the vicinity of Arkadelphia. This topographic ridge Veatch[27] called the Saratoga wold. In accordance with modern usage it is here called a cuesta. It is unfortunate that the appropriate name chosen by Veatch should coincide with the name now given to a formation that is at least only in part a cause of the physiographic feature. The name of the formation that was principally its cause, the Nacatoch sand, might be assigned to it were it not for the fact that the Nacatoch sand extends into northeastern Arkansas, where there is no corresponding topographic ridge. It is possible also that the term Nacatoch may be extended in the future into Texas to include partly equivalent sand in the Navarro formation, and the physiographic feature is not found there at some places and is imperfectly represented at others. Other names might be assigned to the cuesta, but the village of Saratoga is so situated that the name is appropriate, and it has been retained. At some places the ridge shows the typical cuesta form, having a steep front slope (nearly an escarpment) and a long back slope coinciding in inclination with the strata. The highest

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

parts of the cuesta are near the northern edge of it, some distance back from the steeper part of the front slope. The high part nowhere reaches as great an elevation as the crests of the Centerpoint and Highland cuestas, farther north, but maintains a height of 400 to 450 feet except where the ridge is interrupted by the wide alluvial bottoms of the principal streams. The northward-facing escarpment is most conspicuous between the bottoms of Little River and Little Missouri River. It is nearly 200 feet high north of Saratoga and about as high north of Jakajones. The escarpment is lower east of the Little Missouri River, but is still conspicuous. The Saratoga chalk crops out along the steep front slope, usually near the top, and at some places, as at Saratoga and Okolona, the chalk itself forms the crest of the cuesta and the overlying sand has been stripped back for some distance from the front, leaving outliers and dip surfaces of the chalk exposed. In the production of topographic ridges by erosion, the relative resistance of the formations rather than their absolute hardness is of importance. A good example is afforded by the Tokio and Nacatoch formations, especially where the Tokio consists almost entirely of sand, as they are nearly alike in lithologic character. Owing to the superior resistance of the gravel at the base, the sand of the Tokio has been largely stripped back, whereas the sand of the Nacatoch, which is harder than the marl below, forms in places the crest of the ridge. The hard, sandy chalk of the Saratoga has undoubtedly contributed to the development of the cuesta and so, in a lesser degree, has the greensand, calcareous part of the Nacatoch. The irregularity of the topography is as characteristic of the Nacatoch as its greater general elevation and is more appreciable to one going northward, up the dip of the formations. The dissected rolling sand hills form a striking contrast to the smooth, scarcely irregular prairies and broad slopes of the overlying Arkadelphia marl. Between Little River and Little Missouri River the cuesta drainage is typically developed. On the back slope numerous small streams flow down the dip. At their heads these streams are ramified into small tributaries. North of the front escarpment two streams, Plum Creek and the south fork of Ozan Creek, follow the strike of the beds west and east, respectively. From these creeks short, steep streams cut southward into the front of the cuesta. East of the Little Missouri the drainage is less typically developed but shows the same tendencies.

ARKADELPHIA MARL

HISTORICAL SUMMARY

The name Arkadelphia shales was applied by Hill[28] to "blue clays and yellow sands, consisting of alternating bands of these materials, varying from one-eighth of an inch to one foot in thickness," exposed in the vicinity of Arkadelphia, Clark County. These sands and clays Hill regarded as of Tertiary age, and cited other outcrops in southern Hempstead County, on the County Poor Farm, about half way between Fulton and Washington, and along Mine Creek near Nashville. The outcrops near Arkadelphia are now known to be the upper part of the Nacatoch, which is unusually well stratified and in this vicinity consists of alternating clay and sand. The outcrops along Mine Creek are part of the clay phase of the Tokio formation. The exact location of the outcrops cited in southern Hempstead County is not known to the writer, but a locality about half way between Fulton and Washington might be either in the uppermost Nacatoch or, possibly, in the lowest part of the marl now defined as Arkadelphia.

A few years later Harris[29] demonstrated by fossils that the Arkadelphia shales of Hill were of Cretaceous age in the vicinity of Arkadelphia and Nashville and in Hempstead County. Veatch[30] applied the name Arkadelphia clay to "the dark, laminated clays which overlie the Nacatoch sand" These "dark, laminated clays," which, according to Veatch, are "well developed on Yellow Creek 3 to 4 miles northwest of Fulton, 5 to 6 miles north of Hope, north and northeast of Emmet," are not the "blue clay and yellow sand" that crop out near Arkadelphia, to which Hill first applied the name Arkadelphia, and a new name for them would have been desirable. The name, however, has now become well established in geologic literature and common usage,

[28] Hill, R. T., Neozoic geology of southwestern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1888, vol. 2, p. 53, 1888.

[29] Harris, G. D., The Tertiary geology of southern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1892, vol. 2, p. 15, 1894.

[30] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 28, 1926.

although it has been somewhat modified in meaning, and it now seems best to retain it, although with the clear understanding that the formation typically crops out 2 or 3 miles northwest of Fulton and at many places 5 to 7 miles north and northwest of Hope. As stated on page 147, it is possible that the basal few feet of the formation crops out, though not typically, at Arkadelphia, and this is an additional reason for the retention of the formation name. The lithologic name has been changed from clay to marl, for marl indicates more accurately the material composing most of the formation.

LITHOLOGY AND OUTCROPS

The Arkadelphia marl is chiefly a dark-gray and black marl and marly clay, weathering light gray and containing some beds of hard calcareous gray sandstone, gray sandy clay, sandy limestone, dense, concretionary limestone, and white, impure chalk. The marl is prevailingly free from palpable sand. When perfectly fresh it appears laminated or bedded. It is usually more or less weathered and appears poorly bedded, or massive. The cleavage is usually hackly and irregular; at some places markedly conchoidal. The Arkadelphia overlies the Nacatoch sand unconformably, resting upon an irregular surface of slight relief, which probably represents only a brief time break. It is the uppermost formation of the Gulf series, of Upper Cretaceous age, and is overlain by Eocene beds.

Good outcrops of the Arkadelphia marl are rare, for it is soft and weathers readily to a porous, crumbly, yellow-toned marly soil except where it is covered by the wide-spread terrace sand. Besides, its smooth surface is not favorable to the exposure of large outcrops. Twenty feet of abundantly fossiliferous gray, slightly sandy marl is exposed near the base of the Arkadelphia on the road from Washington to Reed's store, in gullies north of the road, 4.55 miles east of Washington. Other easily accessible small outcrops in Hempstead County are at points 2.7 miles from Fulton, on the road toward McNab; 4.0 miles northeast of Fulton, along the Washington road; and in gullies 300 feet east of the Hope-Washington road, 5.1 miles northwest of Hope. In Nevada County there is a good outcrop of Arkadelphia in a road ditch in the SE. 1/4 Sec. 12, T. 11 S., R. 23 W., about 3 miles west of Prescott. Small outcrops of Arkadelphia, rather difficult to locate, are exposed in the banks of small streams in Secs. 4 and 9, T. 9 S., R. 20 W., southwest of Terre Noire bottom. The easternmost exposure of typical Arkadelphia marl is found where the Hope-Arkadelphia road goes down the hill in the SE. 1/4 Sec. 6, T. 8 S., R. 19 W., over the break to the Deciper Creek bottom. The road ditches here expose a section, 50 feet thick, of calcareous bedded clay, which weathers olive brown and contains small prints of shells. Near the base there is a layer, about 6 inches thick, of massive marly limestone. This outcrop is only sparingly fossiliferous, but an outcrop of Arkadelphia marl about a quarter of a mile west of this and half a mile east of Gum Springs contains numerous Cretaceous fossils.

The stratigraphic relations of the Arkadelphia and Nacatoch below have not yet been considered nor have outcrops of the contact been cited. The best exposure of the contact is that shown in the section on page 126, where it is irregular and there is no evidence of transition, although the top of the Nacatoch is unusually carbonaceous. The contact relations are poorly exposed in the section north of Reed's store, described on page 125, but there is no indication of transition. A possible outcrop of the contact in the SW. 1/4 of Sec. 10, T. 12 S., R. 25 W., in the bank of Black Bois d'Arc Creek, shows 3 feet of greenish-brown probably Arkadelphia clay resting on a thin, sandy fossiliferous limestone, which rests on dark, massive sand. Farther north along the creek massive yellow and brown sand is exposed. The precise contact relations at McNab are not known, but as has already been stated, the heavy lenticular sandy limestone at the top of the section must be practically at the top of the Nacatoch and may possibly be the basal bed of the Arkadelphia.

At the top of the section exposed in the vicinity of Arkadelphia in a bed of very dark clay, at the base of which there is a concretionary formation containing fossils (Pl. XXII, B). This bed was first described by Harris,[31] and the following fossils obtained from it were identified by T. W. Stanton:

[31] Harris, G. D., The Tertiary geology of southern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1892, vol. 2, p. 17, 1894.

Leda pinnaformis Gabb.
Exogyra costata Say.
Veniella conradi Morton.
Crassatellites vadosa Morton.
Cyprimeria alta Conrad.
Chemnitzia (?) interrupta Conrad (?)

The following section is exposed in the cut on Fifth Street, Arkadelphia, near the Missouri Pacific railroad station:

Partial Section of Arkadelphia Marl (?) and Nacatoch Sand at Arkadelphia

	Ft.	In.
Terrace sand and gravel.		
Arkadelphia marl (?):		
Bedded dark purplish-gray clay, weathers black, and contains imprints of Leda, possible crab claws, and *Cristellaria*	5	0
Soft, medium-grained argillaceous sand containing large concretions of dense, gray carbonate, in which there are septarian cracks of coarsely crystalline calcite. This is undoubtedly the horizon from which Harris obtained his fossils, but the concretionary lenses examined by the writer were not fossiliferous, or they contained only poorly preserved *Exogyra* and *Crassatellites*. The concretions are 1 to 2 feet thick, 1 to 2 feet long, and are flattened parallel to the bedding	2	0
Marly, pebbly sand. Contains grains of greenish quartz $\frac{1}{32}$ to ¼-inch in diameter, pebbles of gray clay half an inch in diameter, bits of thinly laminated ferruginous sandstone up to ¼-inch in diameter, and pebbles of gray quartz up to half an inch in diameter. Contains no organic remains other than fish teeth	0	1
Slightly irregular contact with relief of 1 to 2 inches vertically in 1 foot horizontally.		
Nacatoch sand:		
Interbedded dark-gray clay and medium-grained and fine-grained yellow quartz. The beds are from $\frac{1}{16}$ to 2 inches thick. The clay contains a few small carbonaceous fragments	10	0
Base concealed.		

This dark Cretaceous clay may represent a layer within the Nacatoch sand, which is fossiliferous in places, but similarity between the contact relations at the base of the concretionary bed and those observed at the Arkadelphia-Nacatoch contact elsewhere suggest that this dark clay and gray limestone is the base of the Arkadelphia, which is here slightly different in lithologic character from the beds found farther west. The scanty evidence afforded by fossils is inconclusive.

THICKNESS

In determining the thickness of the Arkadelphia marl the methods that were used for calculating the thickness of the other formations were supplanted by the use of well records.

The Nacatoch sand is water-bearing, and a large number of artesian wells have been sunk to it along the line of outcrop of the top of the Arkadelphia. In these wells the top of the Nacatoch is easily recognizable by the drillers, both because of the abrupt change from marl to sand and because the Nacatoch carries water. Many of these well records were tabulated by Veatch.[32] Careful examination of these records shows that the thickness of the Arkadelphia north of Fulton is about 150 feet. Records between the Black Bois d'Arc Creek and the Flat Branch of Terre Rouge, in Hempstead County, show that the thickness of the Arkadelphia is very close to 160 feet. Farther east it appears to be a little less—about 130 feet north of Emmett and about 120 feet north of Prescott, in Nevada County. From Little Missouri River eastward to Big Deciper Creek, in Clark County, the records indicate a thickness of 120 to 130 feet.

FAUNA

The Arkadelphia carries fragments of shells and foraminifera, and in some outcrops it yields an abundant fauna, though at certain places it contains no fossils.

The meager fauna listed below has been identified by Dr. Stephenson from collections from the Arkadelphia marl made by him and by the writer. The shortness of the list is due more to deficiency of collecting than to sparsity of fauna, although the Arkadelphia is by no means so fossiliferous as the Saratoga and parts of the Nacatoch.

Coelenterata:
- Coral.

Pelecypoda:
- Nucula (?)
- Leda sp.
- Cucullaea sp.
- Gryphaeaostrea vomer (Morton).
- Gryphaea sp. (small).
- Exogyra costata Say (variety with narrow costae).
- Pecten cf. P. argillensis Conrad.
- Pecten cf. P. simplicius Conrad.
- Pecten cf. C. serica Conrad.
- Veniella conradi (Morton).
- Crassatellites sp.
- Cyprimeria depressa Conrad (?)

Scaphopoda:
- Dentalium sp.

Gastropoda:
- Turritella cf. T. quadrilira Johnson.
- Turritella sp.

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[32] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, chap. 5, 1906.

Cephalopoda:
 Scaphites sp.
 Baculites sp.
Vertebrata:
 Shark teeth.

This list, though incomplete, is sufficient to establish close faunal relationship of the Arkadelphia with the Saratoga and the Nacatoch. The striking feature of the fauna is the apparent abrupt change in the species *Exogyra costata* Say, which assumes a distinct and easily recognizable varietal form (see Pl. XXVI, Fig. 2). The costae, although strong and uninterrupted, become narrow and have broader grooves between them, presenting a sharp contrast with the broad costae and narrow grooves of the typical *Exogyra costata.* The lines of growth intersecting the costae occasionally produce a slightly nodose effect, but the cancellated form is not found. Specimens of this variety have been found at the very base of the Arkadelphia, and although most of the upper part of the Nacatoch is not fossiliferous there is nothing to indicate that the more strongly costate Nacatoch form does not continue to the top of that formation unchanged.

CORRELATION

The Arkadelphia marl is in the upper part of the *Exogyra costata* zone and is represented in northeast Texas by the upper part of the Navarro formation.[33] No similar marl or clay appears at the top of the *Exogyra costata* zone in the eastern Gulf region,[34] although the variety of *Exogyra costata* Say that has narrow costae is found there at some places in the upper part of the section.

ORIGIN

The distinctive character of *Exogyra* found in the Arkadelphia marl and the sharpness of the lithologic break at the base of that formation suggest that a short time may have elapsed between the deposition of the Nacatoch and that of the Arkadelphia. It must be borne in mind, however, that so slight a change in the form of a species might be due merely to change in environment, such as that which is recorded by the lithologic differences in the two forma-

[33] Stephenson, L. W., A contribution to the geology of northeastern Texas and southern Oklahoma: U. S. Geol. Survey Prof. Paper 120, p. 158, 1918.
[34] Stephenson, L. W., Cretaceous deposits of the eastern Gulf region: U. S. Geol. Survey Prof. Paper 81, pl. 10, 1914.

PLATE XXVII

(Figures natural size unless otherwise marked)

FIGURE 1. *Hamulus squamosus* Gabb from the lower part of the Brownstown marl on the Mineral Springs road a mile east of Ben Lomond, Sevier County.

2. *Hamulus onyx* Morton from the Nacatoch sand on the old military road 2 miles northeast of Washington, Hempstead County (× 1½).

3. *Ostrea panda* Morton from the Ozan formation on the Hollywood road 8.5 miles west of Arkadelphia, Clay County.

4-6. *Ostrea plumosa* Morton from the Ozan formation on the White Cliffs road a mile south of Brownstown, Sevier County. Figures 5 and 6 are exterior and interior views of the same right valve.

7, 8. *Anonia argentaria* Morton from the Ozan formation on the Hollywood road 8.5 miles west of Arkadelphia, Clark County. Interior and exterior views of the same shell.

9, 10. *Paranomia scabra* (Morton) from the Saratoga chalk in a field west of the Nacatoch Bluff road 2.8 miles southwest of Okolona, Clark County.

11. *Cyprimeria depressa* Conrad from the Brownstown marl on road half a mile southeast of Delight, Pike County.

tions. The nature of the basal contact affords some ground for the belief that a slight break may exist. There is apparently no reason to believe that the deposition of the Nacatoch had built up the surface of deposits to the marine profile of equilibrium. If it had not done so the cessation of the supply of sediment would hardly have been so abrupt as to produce a basal contact of the sharpness observed, and if the diminution in the supply of sediment had so greatly reduced the marine profile that slight marine erosion occurred, subsequent Arkadelphia deposition would have implied subsidence. If sudden, this subsidence would have probably produced, in shallower water, a basal sediment merging upward into purer marl, a transition of which there is some evidence. If the subsidence was slow there would have probably been further submarine erosion before permanent deposition. Slow submergence without cessation of the supply of sediment would produce a deep-water sediment that rested abruptly on shallow-water sediment without deposits of intervening type, and the time that elapsed before permanent deposition would be somewhat greater. Apparently it is necessary to postulate subsidence to explain the deposition of the Arkadelphia. If this subsidence was relatively rapid, as the somewhat sandier and more argillaceous character of the basal few feet of the Arkadelphia seems to indicate, the time break at the base was correspondingly shorter. There is no reason to suppose subaerial exposure of the Nacatoch and subsequent subsidence.

PHYSIOGRAPHIC EXPRESSION

The Arkadelphia underlies relatively low, smooth topography, quite unlike the hill lands of the Nacatoch, to the north. The gradients of the smaller streams are perceptibly less, and there is a slight tendency to form wider bottoms. Low terraces are formed and part of the area of outcrop of Arkadelphia and the overlying Midway was originally unforested gravel prairie.[35]

[35] Hill, R. T., The Neozoic geology of southwestern Arkansas: U. S. Geol. Survey Ann. Rept. for 1888, vol. 2, p. 33, 1888.

TERTIARY SYSTEM

EOCENE SERIES

MIDWAY FORMATION

GENERAL CHARACTER AND HISTORICAL SUMMARY

In the writer's investigation of the Upper Cretaceous deposits it was necessary to delimit the extent of the formations, and accordingly he mapped the Cretaceous-Eocene contact with as much accuracy as the outcrops permitted. In the course of the search for the contact the lower part of the Eocene was examined. The Midway formation, of early Eocene age, overlies the Arkadelphia marl and is separated from it by a considerable unconformity. Its lower 30 to 50 feet consists normally of bedded calcareous clay containing at some places beds of dense gray limestone, which lie in a zone 3 feet to 10 feet above its base. The remainder of the Midway studied consists of monotonously uniform dark-gray noncalcareous clay.

The name "Midway series" was first used by Smith and Johnson[36] in 1887 to designate light-colored argillaceous limestone and yellowish sands that are exposed at Midway Landing and on Pine Barren Creek, in Wilcox County, Alabama, and that form the basal subdivision of the so-called "Lignitic" as the term was used by them. In 1894 Harris included the deposits below the "Lignitic" (restricted to beds between the base of the Nanafalia formation and the base of the Claiborne) and above the Cretaceous in the Midway "stage," giving the term co-ordinate rank with "Lignitic."[37] Harris traced outcrops of fossiliferous crystalline limestone and yellow sand containing the fauna of the Midway of Alabama from northeastern Arkansas southward along the edge of the Paleozoic upland to an outcrop located by Hill[38] "two miles west of Malvern, at the site of old Rockport," and stated that this locality "is the most western known limit of the Midway stage in Arkansas."[39]

In 1906 Veatch stated that "between the outcrops near

[36] Smith, E. A., and Johnson, L. C., Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee, and Alabama rivers: U. S. Geol. Survey Bull. 43, pp. 62-67, 70, 1887.

[37] Harris, G. D., Tertiary geology of southern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1892, vol. 2, p. 8, 9, 22-54, 1894.

[38] Smith, E. A., and Johnson, L. C., Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee, and Alabama rivers: U. S. Geol. Survey Bull. 43, pp. 62-67, 70, 1887.

[39] Harris, op. cit., p. 32.

Malvern and southwestern Travis County, Texas, no exposures (of the Midway formation) are known."[40]

In 1915 Stephenson[41] implied the presence of Midway in this area by stating that "from the vicinity of Arkadelphia, Ark., southwestward to the Rio Grande, upper Cretaceous deposits . . . are overlain almost continuously by marine Eocene strata which Harris has correlated with the Midway," but gave no description of localities in southwestern Arkansas. Since the publication of Veatch's paper,[42] in 1906, the known outcrop of the Midway has been gradually extended northeastward through Texas. In 1922 Thompson[43] showed the outcrop extending to Titus County, about 50 miles west of the Arkansas State line and it is now known to extend continuously into Arkansas.

The existence of the Midway formation in southwestern Arkansas was first established by a collection of fossils made by J. P. D. Hull[44] in January, 1924, from the base of Buzzard's Bluff, in Sec. 16, T. 14 S., R. 26 W., Miller County, Arkansas, in which Miss M. J. Rathbun of the U. S. National Museum found determinable Midway crustaceans.

In June, 1924, the Shreveport section of the Southwestern Geological Society devoted its annual outcrop trip to a field study of the Cretaceous-Eocene contact in southwestern Arkansas. As a result of this work Howe[45] published a statement of the discovery of the Midway on the outcrop, "one mile east of Hope." The outcrop mentioned was inaccurately located, and the information given was fragmentary. Hull[46] later corrected the locality to "the SE. ¼ of Sec. 1, T. 12 S., R. 24 W., on the highway between Emmet and Hope, Hempstead County" (about 6 miles northeast of Hope). In addition, Hull gave a list of fossils including two definitely Eocene species, identified by Howe,[47] from the

[40] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 33, 1906.

[41] Stephenson, L. W., The Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 90, p. 157, 1915.

[42] Op. cit.

[43] Thompson, W. C., The Midway limestone of northeast Texas: Am. Assoc. Petrol. Geologists Bull., vol. 6, No. 4, pp. 322-332, 1922.

[44] Hull, J. P. D., Guide notes on the Midway in southwestern Arkansas: Am. Assoc. Petrol. Geologists Bull., vol. 9, No. 1, p. 168, 1925.

[45] Howe, H. V., The Arkadelphia formation: Louisiana State University Bull., vol. 16, new ser., No. 5, pt. 2, p. 5, 1924.

[46] Hull, J. P. D., Guide notes on the Midway in southwestern Arkansas: Am. Assoc. Petrol. Geologists Bull., vol. 9, No. 1, p. 169, 1925.

[47] Howe, H. V., The Arkadelphia formation: Louisiana State Univ. Bull. vol. 16, new ser. No. 5, pt. 2, p. 4, 1924.

locality originally stated by Howe to be abundantly fossilliferous Arkadelphia, "three miles northeast of Emmet, on the Hope-Prescott road."

THE CRETACEOUS-EOCENE CONTACT

Though not specifically stated in the reports mentioned, it was generally known in 1925 that the outcrop 3 miles northeast of Emmet exposed the Cretaceous-Eocene contact. This is in the NW. ¼ of Sec. 26, T. 11 S., R. 23 W., on the highway from Emmet to Prescott, 2.9 miles from Emmet. At this place a ditch north of the road exposes a ledge of hard, yellow-weathering, gray earthy limestone about a foot thick. This ledge is concealed above by soil. The limestone is sandy and contains abundant fossil shells, very few of which are well preserved, and dark, long rhombs of calcite. It grades downward into a calcareous, slightly sandy clay and then into a calcareous waxy clay containing some poor shells, including probably *Ostrea pulaskensis,* an Eocene form.

About 3 feet below the hard limestone is a bed of marl, a foot thick, containing phosphatic nodules and some phosphatic fossil casts, as well as numerous foraminifera and small shells. In this zone there are yellowish lenses of sand, as much as 6 inches long and 1 inch thick, containing abundant rotten shells of foraminifera. The marl below them is thickly studded with small phosphatic nodules. Below this phosphatic zone the marl is not well exposed, but it apparently contains a few foraminifera and a fairly large number of thin shells, including possibly the Cretaceous *Anomia argentaria. Exogyra costata* has been found in the ditch at a slightly lower level. There is little doubt that the zone of phosphatic nodules marks the base of the Midway.

The outcrop of the Midway described by Howe[48] as "one mile east of Hope" and much more accurately by Hull[49] as "in the SE. ¼ Sec. 1, T. 12 S., R. 24 W., on the highway between Emmett and Hope" is 6.2 miles from Hope, on the highway between Hope and Emmet, and probably in the NW. ¼ Sec. 6, T. 12 S., R. 25 W.

[48] Howe, H. W., The Arkadelphia formation: Louisiana State University Bull. vol. 16, new ser., No. 5, pt. 2, p. 5, 1924.

[49] Hull, J. P. D., Guide notes on the Midway in southwestern Arkansas: Am. Assoc. Petrol. Geologists Bull., vol. 9, No. 1, p. 169, 1925.

This outcrop exposes also the basal Midway, if not the actual Cretaceous-Eocene contact. The road ditch and small gullies north of the road expose about 5 feet of calcareous gray clay containing an abundant microfauna and bits of fish bones and teeth. At two places a layer of phosphatic nodules is exposed about half way up from the base. It is a partly indurated calcareous bed filled with phosphatic nodules and pebbles, the largest half an inch in diameter, weathering black, and contains some glauconite grains and phosphatic oolites. In this layer foraminifera are seen to be conspicuously abundant by examination with a hand lense. Reworked Cretaceous megascopic fossils are fairly common but not determinable. Below the phosphatic zone the marl is less abundantly foraminiferal but carries a small amount of phosphatic material. Dr. Julia Gardner, of the U. S. National Museum, who has examined a large number of samples for the writer, states that the foraminiferal fauna below the phosphatic zone is Midway, and that the actual Cretaceous-Eocene contact is probably not exposed here. The plowed field near the creek bottom exposes, for 1,000 feet north of the road, gray soil containing phosphatic nodules. Examination with a hand lens shows that this soil contains numerous foraminifera. The plowed field north of this one, along the creek, is on deep black soil, which contains no noticeable foraminifera but a few phosphatic casts, probably washed down from above. This field is probably the weathered soil of the top of the Arkadelphia marl.

About a mile and a half southwest of this locality there is another probable outcrop of the contact. This is 4.7 miles northeast of Hope, on the road to Prescott, a little southwest of the bottom of Terre Rouge Creek. North of the road the ditch and small gullies expose about 10 feet of light brownish-gray calcareous clay, which is seen to be richly foraminiferal when examined with a hand lens. Near the base of the exposure there is a layer containing numerous phosphatic nodules, some as much as an inch in diameter, though most of them are smaller. These nodules have typical irregular, worn, pitted black surfaces and a gray interior, shown by fracture. Here fish vertebrae and teeth and some fragments of shells were found. Pockets of coarse glauconite, the largest an inch long, are set in the marl.

This zone stands about 10 feet above the creek level. Below it, poorly exposed, is about 2 feet of gray marl in which Dr. Gardner found a typical lower Midway fauna. In 1912 L. W. Stephenson noted at this locality *Gryphaea sp.* and *Exogyra sp.*, which are certainly Cretaceous and were probably derived from beds at a slightly lower level, now concealed by soil and wash. It is therefore certain that at this place there is an obscure Cretaceous-Eocene contact.

Two miles west of this place is the clearest outcrop of the contact seen by the writer. Its clearness may be due in part to the fact that the other outcrops cited had been visited and worked over several times. This outcrop is 4.4 miles north of Hope, along the road to De Ann, about a mile south of the bottom of the Flat Branch of Terre Rouge Creek. At the base of the road bank, on the west side of the road, is a massive, dirty chalk containing a few indeterminate organic remains. This chalk is at the top of the Arkadelphia marl. Its upper surface is slightly irregular, and on it rests a bed that ranges in thickness from half an inch to 10 inches. Where thin this bed is a sandy marl, in which most of the grains are rounded particles of black and gray phosphate, nodules of calcite, and grains of glauconite. The bed contains irregular nodules of light-gray phosphate, the largest half an inch in diameter, small fragments of *Ostrea,* fish teeth, and numerous foraminifera. Where thicker it is a gray, calcareous sandy clay in which are embedded masses of the dirty chalk like that exposed below, 6 to 9 inches in diameter. In this sandy clay are embedded specimens of *Exogyra costata* of the Arkadelphia type. Some of these probably rest on the underlying dirty white chalk and may have been embedded in its upper surface. The relations here clearly indicate that this sandy layer is the basal Midway and that the *Exogyra* in it are reworked from the underlying Cretaceous, together with the lumps of white marl. The sandy bed grades upward into marl containing hard, lenticular, irregular beds of earthy limestone, the largest 6 inches thick, pockets and pebbles of clay, pellets of calcite, and occasional grains of glauconite. This marl is studded with platy crystals of calcite and contains rather numerous but poorly preserved fossil shells, some of which have been identified by Dr. Stephenson as unquestionably Eocene. According to Dr. Gardner the foraminiferal assemblage includes several Cretaceous forms, but presumably these were reworked from the Cretaceous below. Above these beds of limestone are 3 feet of calcareous, gray, slightly sandy clay containing scattered lenses of limestone, then a second bed of hard, gray, earthy, fossiliferous limestone resembling the bed below. Above this crops out about 10 feet of bedded gray calcareous clay containing sparse scattered lenticles of limestone. The total thickness of the lower abundantly foraminiferal Midway along this road is about 35 feet; elsewhere it may be as little as 30 feet or as much as 50 feet.

These four outcrops of the Cretaceous-Eocene contact are confined to a strip, about 7 miles long, in eastern Hempstead and western Nevada County. No other outcrops of it have been found, although they were sought along the supposed line of contact east and west for many miles. The contact is not conspicuous, owing to the general lithologic similarity of the beds above and below it, and it is scarcely more likely to crop out than any other zone in the soft shales and marls above and below. Outcrops are notably poor over the width of outcrop of the overlying and underlying formations. The occurrence of the four known outcrops along this short stretch of the contact is perhaps due to the fact that the basal Midway in this stretch is somewhat hard and resistant. A large number of the creeks and gullies that cross the supposed line of contact have been examined without success, although this examination has narrowed the belt of outcrop within which the contact may be found. It is to be hoped that other outcrops will eventually be found, particularly east of Little Missouri River.

LITHOLOGY AND OUTCROPS

The distribution of the lower calcareous, abundantly foraminiferal Midway is not known west of the outcrop of the contact at a place 4.4 miles north of Hope, on the road to De Ann. This lower Midway has been traced eastward nearly to the Ouachita River. It resembles closely the underlying Arkadelphia, particularly where it is weathered. It is somewhat more perceptibly bedded, slightly less calcareous, and contains glauconitic and phosphatic grains. It crops out south of the center of Sec. 4, T. 11 S., R. 22 W., a mile northeast of Prescott, on the road to Gurdon. Good outcrops of it are exposed in a gully on the old Okolona road 1.3 miles northwest of Beirne. Here there are 20 feet of very slightly calcareous light-gray clay, with poor bedding. At the base of this there is about a foot of massive sandy marl containing numerous small, irregular, brown and black phosphatic nodules and oolites, shark and fish teeth, echinoid spines, foraminifera and a few glauconitic grains. Below is bedded slightly calcareous clay, poorly exposed. It crops out also 4.4 miles northeast of Gurdon, on the road to Arkadelphia, in small road ditches. About 8.5 miles northeast of Gurdon, on the road to Arkadelphia, in the SW. ¼ Sec. 36, T. 8 S., R. 20 W., just west of Curtis, in Clark County, light brownish-gray calcareous bedded clay of the lower part of the Midway crops out.

North and somewhat west of Curtis, in the NW. ¼ Sec. 25, T. 8 S., R. 20 W., and also at a point a quarter of a mile south of the center of Sec. 24, T. 8 S., R. 20 W., there are outcrops of greenish-gray calcareous clay containing some imprints of small shells. In these beds Dr. Gardner found a foraminiferal fauna that is equivalent in general to that of the lower calcareous clay of the Midway 4.4 miles north of Hope, along the road to De Ann.

Above this lower calcareous zone, for at least 200 feet above its base, the Midway formation consists of dark-gray noncalcareous clay, which on the outcrop appears light brownish-gray and bedded and shows an irregular, conchoidal fracture. Fresher specimens are darker gray and nearly massive but show obscure lamination. This part of the formation is almost entirely free from sand, but contains at some places a few small flakes of muscovite. Some weathered outcrops of this clay contain beds of concretionary sand a fraction of an inch thick, streaks of limonite, and hard, black, broken nodular concretions. Fossils, either large or microscopic, are exceedingly rare in it. Beds of the Midway like this have been traced from a point near Red River to Big Deciper Creek. This upper, non-calcareous Midway clay, where it is unmixed with surficial sand, weathers deeply to a soft, deep, very dark gray soil. This soil presents a notable contrast to the black soil of the Arkadelphia marl, which is usually streaked with yellow tones where it is not completely decomposed. The upper part of the Midway was not studied.

ORIGIN

The unconformity separating the Midway formation from the Cretaceous beds below represents a very great lapse of geologic time, a lapse greater than any indicated in the Cretaceous formations. The magnitude of the change from the Cretaceous to the Eocene fauna is shown by Stephenson's striking statment that "a preliminary study of the faunas has shown that 168 or more species belonging to the subkingdom Mollusca existed in the zone of *Exogyra costata* of the upper Cretaceous. Of these not a single species is known with certainty to have been found in the basal Eocene or Midway formation."[50]. Scott's[51] recent attempt to minimize the importance of this unconformity has been refuted by Dr. Gardner.[52]

The conspicuously similar type of sedimentation above and below the contact and the widespread approximate parallelism between the strata above and those below tend to mask the real importance of the break, as does the physically inconspicuous nature of the contact at many places. The evidence gathered in this area has augmented the previous evidence that there is an erosional unconformity at the base of the Midway. Some of the most significant elements of this evidence have been summarized by Stephenson.[53]

The total evidence thus far available points clearly to a widespread retreat of the Cretaceous sea, the lapse of a long time, and a subsequent gradual transgression of the Eocene sea over a surface of low but locally considerable relief. During this time there was apparently little structural disturbance, so that the Midway sediments approximately paralleled the older sediments below.

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[50] Stephenson, L. W., The Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 90, p. 158, 1915.

[51] Scott, Gayle, On a new correlation of the Texas Cretaceous: Am. Jour. Sci., 4th ser,. vol. 12, No. 68, pp. 157-161, 1926.

[52] Gardner, J. A., On Scott's new correlation of the Texas Midway: Am. Jour. Sci., 4th ser., vol. 12, No. 71, pp. 453-455, 1926.

[53] Stephenson, L. W., The Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 90, pp. 155-182, 1915.

PHYSIOGRAPHIC EXPRESSION

The physiographic expression of the Midway is like that of the underlying Arkadelphia. South of its outcrop rises the dissected sandy country of the overlying Wilcox formation (the "Sabine" formation of Veatch[54]). To this topographic ridge of sandy hill-land Veatch applied the name Sulphur wold.[55] The belt of lower country between this ridge and the Saratoga cuesta, occupied by the Midway and Arkadelphia formations, has been followed by the main line of the Missouri Pacific Railroad from Fulton to Arkadelphia. For most of this distance it is on the outcrop of the Midway.

POST-MIDWAY TERTIARY EVENTS

The post-Midway Tertiary events in this area are recorded indirectly by the roughly parallel belts of formations that crop out south of this area, successively younger toward the coast. The Wilcox formation, which overlies the Midway, is interpreted as in large part a deposit left after a brief emergence at the end of Midway time by a transgressive and then a regressive sea,[56] events that probably exposed this area to subaerial erosion while the areas to the south were still submerged. Subsequent transgressing later Tertiary seas may have again extended over southwestern Arkansas, but of this there is no direct evidence. The general effect of the succession of events was probably, on the whole, regressional, the resultant southward movement of the shore line to its present position having been interrupted by temporary advances of the sea.

Toward the end of the Tertiary period the area stood considerably lower than it does now, and the normal physiographic cycle had developed on it a low-lying plain of slight relief, analogous to the nearly flat near-shore part of the present coastal plain. The existence of this base-levelled late Tertiary plain is clearly shown by the accordance of upland levels, which is strikingly evident in a general view of the area from some of the higher points, and by the remnants of terrace gravels and sands found at the highest

[54] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 34, 1906.
[55] Veatch, op. cit., p. 15.
[56] Berry, E. W., Lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91, p. 38, 1916.

points of the present surface, 400 feet above the alluvial bottoms. Whether any actual remnants of this peneplained surface exist in the area is doubtful, and the determination of its precise age must await further investigation. The conception that the deposits of this epoch constitute a single formation[57] has been practically abandoned, partly because such a conception involves the inclusion in it of heterogeneous gravels and sands that are manifestly older or younger, but principally because of a realization of the complexity of the geologic history and of the necessity of further detailed physiographic study upon which to base definite conclusions. A general correlation of this period of subaerial planation with the coastal submergence and deposition in late Pliocene time was suggested by Veatch.[58]

Matson's[59] study of the Pliocene Citronelle formation of the Gulf Coastal Plain disclosed four terrace levels of this age, the oldest and highest of which has no distinct landward scarp but is marked by sand and gravel outliers which in southern Louisiana reach elevations as high as 380 feet. The high peneplain in southwestern Arkansas is probably to be correlated with this oldest Pliocene plain, but this correlation will remain uncertain until physiographic study of the problem is made with the assistance of large-scale topographic maps, which are not yet available.

Deussen[60] has described the extension of the late Pliocene (?) Reynosa formation of the coastal plain of Texas northward into an upstream facies of gravel deposited on an ancient plain that sloped from 2 to 10 feet to the mile toward the southeast.

The Tertiary period closed with a gradual raising of the land, which brought the general level of the surface slightly higher than it now stands.

STRUCTURE

The Cretaceous formations described in this report dip to the south and southeast at low angles (see Pl. II, in

[57] McGee, W. J., The Lafayette formation: U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, pp. 347-521, 1891.

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

[59] Matson, G. C., The Pliocene Citronelle formation of the Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper, 90, p. 180-187, 1917.

[60] Deussen, Alexander, Geology of the coastal plain of Texas west of the Brazos River: U. S. Geol. Survey Prof. Paper 126, p. 105, 1924.

pocket). Dips of surface exposure are difficult to obtain, as there are few regular, continuous beds. In the formations that are distinctly bedded lenticularity and cross bedding predominate, and although the beds give the impression of southern and southeastern dip nearly everywhere, accurate measurement is possible at few places.

Two fairly accurate instrumental dips were obtained. Northwest of Saratoga there are three small outliers of the Saratoga chalk, south of which the basal contact of the main outcrop of the chalk is fairly well exposed. The irregularity of the unconformity at the base of the chalk is recorded in the lack of perfect concordance in the elevations obtained, but the best selection of points whose elevation and location was determined gives the strike as N. 85° E. and the dip as 80 feet per mile to the southeast.

A similar strike and dip was obtained south of Yancy on the base of the attenuated edge of the Annona chalk. The widest spread of points whose elevation and location on this contact were determined gave N. 69° E. for the strike and 72 feet per mile to the southeast as the dip. The distance covered in this determination of dip was nearly a mile, so the influence of local irregularities is greatly minimized. Another determination of strike and dip was made by carefully taking aneroid elevations on the probable top of a richly glauconitic bed in the Nacatoch that crops out north, east, and west of Washington. The strike and dip obtained was N. 63° E., and 65 feet per mile to the southeast. Although this determination is based on a bed that is not certainly continuous at a definite position, it is fairly concordant with the other determinations. Dip can be determined from well records, but many of these are not reliable. However, the base of the Brownstown is known rather accurately in the Tarver Brothers-Swofford well, near Washington, and in No. 4 well of the Hope Water Company, 9 miles S. 30° E. of that place. The dip component of the base of the Brownstown between these two wells is S. 30° E. at the rate of 67 feet per mile. This is not quite the direction of the true dip, hence the angle of dip is a little greater.

Another fairly reliable dip is afforded by the positions of the top of the Tokio in the Grassy Lake-Gun Club well, in Sec. 27, T. 12 S., R. 27 W., in Hempstead County; in the

Adams well, in Sec. 36, T. 12 S., R. 27 W., in Hempstead County; in the Gulf-Munn Shaw well, in Sec. 17, T. 14 S., R. 26 W., in Miller County; and in the Gillespie-Buzzard Bluff well, in Sec. 22, T. 14 S., R. 26 W., in Miller County. The two wells in Hempstead County are only a mile or so apart and are nearly in the line of dip with the two wells in Miller County, to the south, which are also within a mile of each other. These two pairs of wells are about 10 miles apart. By using the four possible couplings of these wells, which are about 10 miles apart along the dip, dips of 72, 77, 78, and 85 feet to the mile are obtained. The actual dip is probably intermediate between the extremes. The dip of the Saratoga near Okolona was estimated by barometer elevations to be 80 feet per mile in a direction approximately S. 10° E. Farther east, in the vicinity of Dobyville, instrumental elevations on the base of the Saratoga chalk gave a strike of N. 70° E. and a dip to the southeast of probably not more than 80 feet per mile. The general southeastward inclination of the strata is interrupted by local irregular dips, none of which are known to outline definite anticlines or synclines. Some of them are probably due to irregular settling and adjustment of the unconsolidated materials. Surface and near-surface slumping is occasionally extremely deceptive; it simulates actual structural dip. Structure contour maps made from water-well records show small irregularities of the apparent structural surfaces, but most of these may be due to irregularity in deposition.

The structural deformation in this area, as in most areas in the Coastal Plain, is not great. Broad, slight tilting and warping are common, but repetitions and alternations of these slight movements indicate a complex structural history. The tilting of the Paleozoic basement toward the south, begun in the earliest Cretaceous time, initiated the transgression of the early Cretaceous seas and continued with interruptions until Tertiary time and along the coast to a still later time. This progressive tilting is reflected in a broad way by the lower dips in the younger formations. The dip of the Paleozoic floor in this area is in places more than 100 feet per mile to the south, whereas the dip of the Upper Cretaceous formations ranges from 65 to 80 feet per mile in the same direction. The generally lesser coastward dip in the younger formations is indicated by dips of from 33 to 53 feet per mile, given by Matson[61] for the Catahoula sandstone in central Louisiana.

The earliest Cretaceous tilting was in general toward the south. Miser[62] has shown, however, that the Trinity of Arkansas is older than the Trinity of southeastern Oklahoma, a difference in age due to progressive westward overlap, and therefore that the floor was first tilted toward the east as well as toward the south.

In southwestern Arkansas the eastward truncation of the Washita, the Fredericksburg, and the successive members of the Trinity, indicates a period of uplift and erosion in at least the eastern part of the area mapped prior to the transgression of the basal Upper Cretaceous sea and the deposition of the Woodbine formation. There is no definite evidence of structural folding in Lower Cretaceous time before the deposition of the Upper Cretaceous in this area. The records of deep wells examined, however, apparently show marked irregularities in the position of beds in the Trinity in closely adjacent wells. These irregularities may be due entirely to the lenticularity of the beds of the Trinity, but there is some reason to believe that they are in part structural. A small outcrop of Trinity 2 miles south of Lockesburg, in Sevier County, on the road from that place to Ben Lomond, is broken and slickensided, and the beds apparently stand nearly vertical, although the overlying Woodbine is undisturbed. Apparent steep dips in the Trinity just northeast of the center of Lockesburg are probably not structural.

In northern Louisiana, on the Sabine uplift, there is evidence of a pronounced erosional unconformity produced near the end of Lower Cretaceous time, old folds and depressions in the Lower Cretaceous being apparently in places reflected the Upper Cretaceous.[63]

The beds of the Washita age are significantly thin and in places are missing on the top of the uplift, although a thick section, measuring possibly over 1,200 feet, is recorded in

[61] Matson, G. C., The Catahoula sandstone: U. S. Geol. Survey Prof. Paper 98, p. 218, 1917.

[62] Miser, H. D., Lower Cretaceous (Comanche) rocks of southeastern Oklahoma and southwestern Arkansas: Am. Assoc. Petrol. Geologists Bull., vol. 11, No. 5, p. 449, 1927.

[63] Crider, A. F., Relation of Upper Cretaceous to Eocene structures in Louisiana and Arkansas: Am. Assoc. Petrol. Geologists Bull., vol. 7, No. 4, p. 381, July-August, 1923.

wells west of it.[64] This fact is attributed partly to uplift during Washita time and partly to uplift and truncation at the end of Lower Cretaceous time.

In southwestern Arkansas the uplift in the area affected at the end of Lower Cretaceous time was apparently repeated before the transgression of the Tokio formation, which truncates the Woodbine and Trinity eastward. It is suggestive that this area of uplift was the site of volcanism in the period between the deposition of the Trinity and the Tokio formation.[65]

Although there are several unconformities in the Upper Cretaceous series, the angular discordance of the formations is so slight that it cannot be clearly recognized from well records, and apparently no folding occurred during the deposition of the series in this area. In spite of the magnitude of the break between the Cretaceous and the Eocene deposits the concordance of the two is clearly shown by the slight difference in the thickness of the Arkadelphia marl along the outcrop and probably also down the dip from the outcrop. The evidence of well logs in northern Louisiana shows that "it is not possible to detect greater difference between a fold contoured on some horizon in the Upper Cretaceous and one contoured on some horizon in the Claiborne than would result from inaccuracies and measurements in rotary made logs."[66] The thickening of the Wilcox away from the Sabine uplift affords some evidence that uplift and possibly major folding occurred during or prior to the deposition of the Wilcox, but the principal crustal movements that tilted and deformed the Upper Cretaceous beds occurred later, possibly at the end of the Claiborne deposition. Folding and warping continued to a much later time nearer the present coast line, affecting Oligocene, Miocene and later sediments, but this deformation probably did not affect the beds in southwestern Arkansas.

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[64] Grimm, M. W., personal communication.

[65] Miser, H. D., and Ross, C. S., Diamond-bearing peridotite in Pike County, Arkansas: U. S. Geol. Survey Bull. 735, pp. 310-312, 1923.

[66] Crider, A. F., Relation of Upper Cretaceous to Eocene structure in Louisiana and Arkansas: Am. Assoc. Petrol. Geologists Bull., vol. 7, No. 4, p. 381, July-August, 1923.

DEVELOPMENT OF THE MISSISSIPPI EMBAYMENT

The Mississippi embayment is due to a broad structural depression or trough, the formation of which was begun in Cretaceous time. It is evident that this movement involved a general eastward tilting of the strata in southwestern Arkansas, in addition to a southward tilting. The direction of the dip in any area in this region therefore accords somewhat with the position of the area with respect to the axis of the embayment, the areas near the axis showing dips in which the eastern component dominates and those at greater distance from the axis showing dips in which the southern component is proportionately greater. The tilting toward the coast antedated the beginning of the depression. Final conclusions as to the history of the embayment can hardly be reached until a thorough study has been made of the thickness and the relations of the Cretaceous formations beneath the embayment itself, but some inferences can be drawn from the relations of the formations exposed at the surface.

Reasons have already been given for believing that this area, or at least its eastern part, was uplifted and tilted westward after the deposition of the Lower Cretaceous beds and probably also after the deposition of the basal Upper Cretaceous. There is accordingly little evidence of eastward tilting in southwestern Arkansas in Lower Cretaceous or earliest Upper Cretaceous time. There was, however, a slight eastward tilting in later Upper Cretaceous time, which is shown by the overlap of the Tokio formation.

The apparently successive overlap of the formations northeastward and the apparently increasing northeastward dip of the younger formations seem at first to lead to the conclusion that there was progressive eastward warping toward the embayment.[67] The same appearance could have been produced by the northward overlap of several formations toward a shore line extending approximately from east to west, by subsequent eastward tilting, and by horizontal truncation by erosion. The younger formations in general strike more nearly northeastward than those below.

[67] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 18, 19, 1906.

This direction of strike is also explicable by the thinning of the formations northward, toward the shore line, and subsequent eastward tilting. Unless other evidence of a gradual shift of the shore line toward the northeast can be presented, this surface distribution of the formations does not alone indicate the time of the beginning of the warping that formed the embayment. It is clear that there is a swing in the direction of strike in individual formations—that is, the strike of all the formation is more nearly northeastward in the eastern part of the area than in the western part. An examination of the distribution of the formations indicates that this swing is due to a greater degree of eastward warping in the eastern part of the area and to warping that has affected all the formations alike.

The actual direction of the shore line can apparently not be determined. The change in the lithologic character of most of the formations toward the northeast, a change to types formed nearer a shore, suggests that this northeastern part of the area was not far removed from the shore line and that accordingly the shore extended nearly east and west. If the position of the thin edge of the Annona chalk indicates even approximately the direction of the shore line it extended a little toward the southeast when that formation was deposited.

The most significant guide to the time the embayment was formed is the relative extension of the formations into the embayment. In Arkansas the extension of beds of the *Exogyra costata* zone northward into the embayment on the surface is strikingly greater than the similar extension of the older beds.

Deposits of glauconitic sand interbedded with drab or gray clay, regarded as the Nacatoch sand, crop out along the edge of the Mississippi embayment in northeastern Arkansas and are the only representatives of the Cretaceous[68] there, although lower beds of the Cretaceous may be buried beneath the embayment.[69]

A specimen of *Exogyra cancellata* was found in an excavation sunk for a caisson for the Illinois Central Railroad

[68] Stephenson, L. W., and Crider, A. D., Geology and ground waters of northeastern Arkansas: U. S. Geol. Survey Water-Supply Paper 399, p. 36, 1916.

[69] Idem, p. 35.

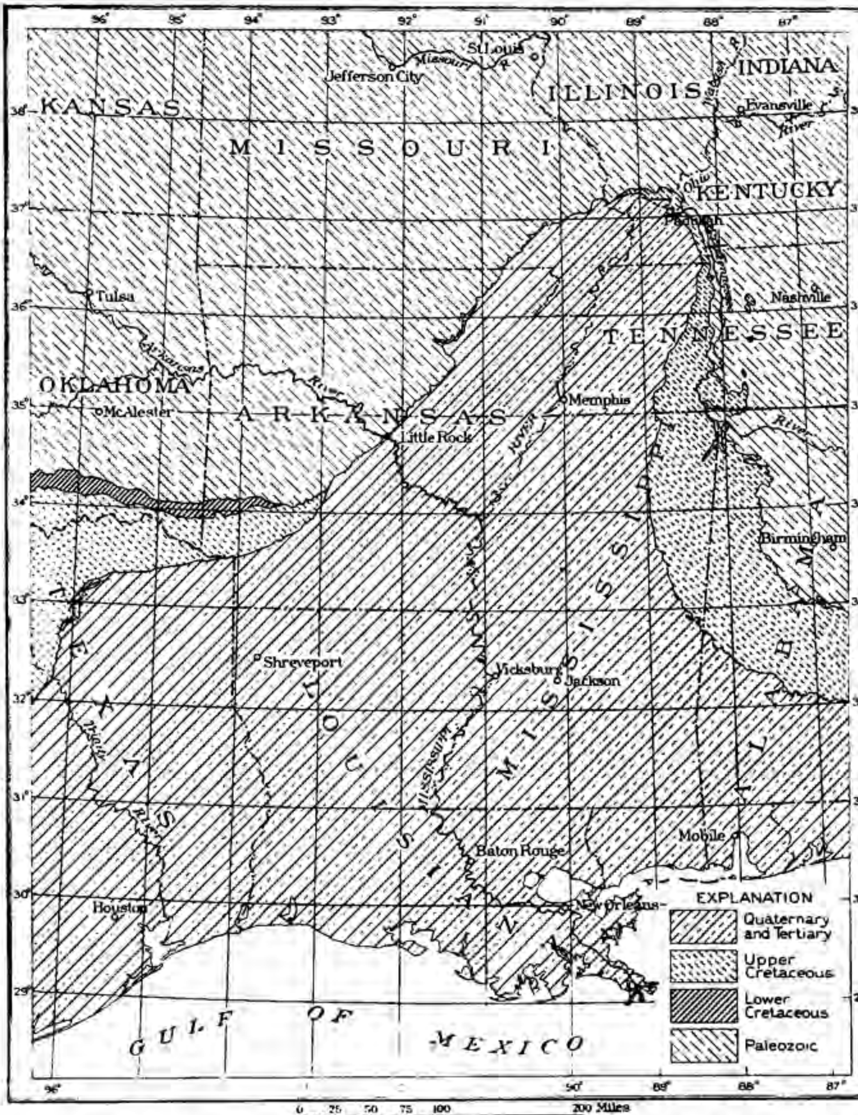

Figure 4.—Generalized map showing the distribution of the Cretaceous deposits in the Mississippi embayment.

bridge near Cairo, Ill.,[70] presumably from the McNairy sand member of the Ripley formation, which has been traced to southern Illinois. This fossil indicates that beds of the age of the Saratoga chalk extend into the embayment. It thus

[70] Stephenson, L. W., Cretaceous deposits of the eastern Gulf region: U. S. Geol. Survey Prof. Paper 81, p. 18, 1914.

seems certain that the embayment was developed to about its maximum extent early within the time zone of *Exogyra costata,* but there is little evidence of any eastward warping prior to that time in Arkansas.

East of Mississippi River the Tuscaloosa, the basal formation of the Upper Cretaceous, is found as far north as Kentucky,[71] so that the embayment evidently extended that far northward in that area in earliest Upper Cretaceous time. It may reasonably be inferred that there was a westward shift of the axis of the embayment and that this shift initiated the eastward downwarping in the Arkansas area some time before the deposition of the beds of the *Exogyra costata* zone. The downwarping continued with the deposition of the later Cretaceous and Tertiary formations.

PHYSIOGRAPHY

The present topography has been etched by erosion from the uplifted gently southward-sloping peneplain formed in southwestern Arkansas during the Pliocene epoch. The general accordance of upland levels and the prevalence of gravel deposits on the highest points suggest the existence of this peneplain, but it is doubtful whether any actual remnants of the old surface have been preserved.

The highest terrace plain on which observations have been made is found along the drainage divide between the towns of Belton and McCaskill, in Hempstead County. Aneroid measurements show that the elevation of this terrace drops from 500 feet to 470 feet in a southeasterly direction from Belton to McCaskill, a distance of nearly 4 miles. If this slope were projected it would probably not pass over the highest parts of either the Highland or Saratoga cuestas, on which gravel patches have been found, but much reliance cannot be placed on slope determined by unchecked aneroid measurements of elevation.

This high terrace consists of a mixture of sand and pea-sized gravel with a relatively small proportion of cobbles. The surficial cover down the drainage in both directions from this high terrace consists largely of coarse gravel and shows that the reworking of these terrace deposits removed

[71] Wade, Bruce, The occurrence of the Tuscaloosa formation as far north as Kentucky: Johns Hopkins Univ. Circ. new ser., No. 3, pp. 102-106, March, 1917.

their finer constituents. Patches of coarse gravel found at high levels are clearly the residium of former terraces and stand indefinitely below the original elevation of the terraces from which they were derived.

Other remnants of terrace gravel that stand about the same elevation cap the heights in the vicinity of Jewel, in Little River County; and the ridge that extends northwestward from Ben Lomond, in Sevier County, at an elevation of 475 feet, is strewn with novaculite gravel derived from terraces. Remnants of high terraces are more poorly preserved in areas farther north, where they cover the older formations.

Somewhat below these highest terrace levels there are others. Of these the wide terrace in the vicinity of Compton, in Hempstead County, which stands at an elevation of about 440 feet, is clearly associated with a small branch of the middle fork of Ozan Creek and may possibly be a later aggradational terrace. Still others, such as those near Foreman, in Little River County, and Tollette, in Howard County, are not definitely related to present streams.

In late Pliocene and early Quaternary time the general level of the area was raised[72] and the existing streams began to carve out their valleys. The larger streams probably preserved their general original courses, and at the conclusion of the period of uplift the major features of the present topography were developed, but the area stood somewhat higher than at present. The conception of this movement as a single uniform uplift is probably too simple. Two high-level terraces that represent cessation or reversal of the movement have been noted, and there may have been a general still higher peneplained surface of which no remnants are preserved.

During this period of uplift the smaller streams dissected the area and removed practically all remnants of the higher terraces. A few of these streams maintained their original courses and, like the main streams, are antecedent, but most of them became more or less adapted to the structure. These subsequent streams are divisible into three general groups but include intermediate types that partake in part of the

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

characters of each. There are lateral streams, which flow along the faces of the cuestas; short obsequents, which head in the faces of the cuestas; and longer streams, which flow down the dip slopes. These longer streams ramify toward their heads into numerous tributaries. Some have cut by headward erosion through the scarps of the cuesta and diminished the drainage area of the opposing obsequent streams. Yellow Creek and Mill Creek are examples of this type.

After the cessation of the uplift there was apparently a period of quiescence sufficiently long to allow the development of mature valley profiles, and the major streams may have reached the stage at which extensive lateral cutting began, accompanied by some aggradation.

After this stage in the development of the topography had been reached there was a depression of sufficient magnitude to initiate a period of extensive stream aggradation and the formation of widespread terrace deposits along the principal rivers. The origin and character of these terraces is suggested by the name "second bottoms," which is commonly applied to them. These deposits, chiefly sands and blue clays, were included by Veatch[73] in the Port Hudson formation, of Pleistocene age.

The clearest evidence of this period of aggradation is afforded by the abnormally flat floors of many of the smaller streams, especially at points near the heads of these streams, where the flat, sand-covered bottoms present a strong contrast to the rather steep sides of the valleys. The history of this period of aggradation was doubtless complex and, like the history of the older higher terraces, can be deciphered only by a detailed study of accurate topographic maps. At least two terrace levels are recognizable along some of the streams. On some of the terraces, such as that southeast of Prescott, at an elevation of from 310 to 330 feet, about 100 feet above the bottom of the Little Missouri, only a thin gravelly veneer covers the bed rock. On others, at about the same elevation, there are from 50 to 100 feet of sand and clay. The extensive terrace near Ashdown, Wilton, and Ogden, in Little River County, stands at nearly the same elevation as the one at Prescott and was probably formed at about the same time. The well-preserved terrace

[73] Veatch, A. C., idem, p. 50.

southeast of Fulton stands at a level of approximately 270 feet, about 60 feet above the bottom land of Red River. This is apparently a more recent terrace than that south of Prescott.

After these extensive terrace sands were deposited the rivers were rejuvenated once more, probably by a relatively low uplift, but possibly by some climatic change that decreased the load of the streams. As a result of the rejuvenation the rivers trenched their beds 50 to 100 feet below their former level, as indicated by the elevation of the terraces above the present bottoms. The renewal of erosion at this time probably led to the capture of the headwaters of Dick Lever Creek by Blue Bayou, in Howard County, but it has not obviously affected the drainage in any other important way. The consequent drainage of the uplifted terraces began at this time. Owing to the comparatively recent uplift and the porous texture of the soils of the terraces, the drainage network on the terrace areas is less extensive than elsewhere. At this time also was begun the formation of the natural mounds of the region. These roughly circular elevations, 20 to 100 feet in diameter and 3 to 6 feet high, are distributed over this and adjoining areas in numbers so great as to preclude the possibility of their human origin. Most of them are on level, sandy terrace plains, but many are found on Cretaceous terranes composed of various kinds of soil and on slightly sloping hillsides. Very few are found on the present alluvial flood plains. When sectioned vertically they show no difference whatever from the underlying and adjacent subsoil. They have been ascribed to the action of wind, springs, gas vents, ants, slow water erosion at low level, uprooting or decay of masses of trees or bushes, as well as to human action. No satisfactory theory to explain all their peculiarities has yet been offered. Most of the theories proposed are analyzed by Veatch,[74] and for further information the reader should consult his paper. Recent events in this area include the gradual progress of the physiographic cycle toward completion, the development of landslips along the river bluffs, and the formation of oxbows and cut offs by the rivers.

[74] Veatch, A. C., idem, pp. 55-59.

ECONOMIC GEOLOGY

CHALK AND CHALK MARL

The availability of the chalk of southwestern Arkansas for the manufacture of Portland cement and lime products has been considered in detail in an earlier report of the U. S. Geological Survey.[75] The pure chalk of the Annona that crops out near Foreman, White Cliffs, and Saline Landing is suitable for making cement when mixed with a proper proportion of the readily available marl that crops out in this area. The American Portland Cement Company is now (May, 1929) erecting a plant with an annual capacity of 600,000 barrels one-half mile west of Foreman. The Arkansas Portland Cement Company, a subsidiary of the Ideal Cement Company of Denver, Colo., is also erecting a Portland cement mill with an annual capacity of 1,000,000 barrels near the town of Saratoga, Howard County. The Lime Products Company is producing agricultural lime and fillers for automobile tires and asphalt pavements at White Cliffs.

The chalk marls occur throughout the area of the chalk and chalky beds. The essential ingredients of these are calcium carbonate usually in a chalky state, ferric oxide and magnesium carbonate and, in addition, sand and clay. The chalk marls meet all the requirements as a fertilizer that are met by ground limestone.

CLAY

The clay resources of the area are considerable but have not been extensively developed. Scattered notes on the development of clay in Hempstead, Miller, Pike, and Nevada counties were given by J. C. Branner in 1908.[76] Without analyses and experimental tests of plasticity and shrinkage it is impossible to do more than to suggest the utilization of the many known clay deposits. The thick and extensive, slightly sandy clays of the Tokio formation appear to possess the properties requisite for the manufacture of clay products of good grade, possibly of tiles, pottery, and special bricks. The pure non-calcareous clays of the Midway possess good plasticity but probably poor porosity and too high shrinkage for use except for special products. The clays higher in the Midway are more sandy and probably also contain more iron

[75] Taff, J. A., Chalk of southwestern Arkansas: U. S. Geol. Survey Twenty-second Ann. Rept. 1900-1901, pt. 3, pp. 693-742, 1902.
[76] Branner, J. C., The clays of Arkansas: U. S. Geol. Survey Bull. 351, 1908.

and are presumably better fitted for the manufacture of general clay products. A few beds of dark clay in the Woodbine formation and a few beds of gray clay in the Nacatoch formation may possibly be utilized. The Brownstown, Ozan, Marlbrook and Arkadelphia formations are probably too calcareous throughout to be used directly for making clay products, but some beds in them may be used to promote fluxing and porosity if added to other clays.

The requirements for common brick clay are rather loose and are met both by the Cretaceous clays and by many beds of surface clay in the terrace deposits, which have a fairly large content of fine sand, and burn red. Surface clays have been used for making brick at Hope and Emmet.

SAND

None of the sand in the area seems to be well adapted to special technical use. Quartz sand sufficiently pure for making glass or refractories has not been seen. Sand of sufficient purity for use in constructing buildings can be obtained from beds in the Nacatoch and Tokio formations. The more angular grains of the sand in the Tokio probably make it somewhat superior for this purpose. Screened river bottom and terrace sands are also available. Some of the tuffaceous sands of the Woodbine are sufficiently cohesive for use as molding sand, but it is doubtful whether they are sufficiently refractory.

GRAVEL

The economic value of the gravel deposits in the Trinity, Woodbine, and Tokio formations has been considered by H. D. Miser.[77] This gravel has been extensively used as road material and railroad ballast. Large banks of gravel, both in the basal gravel member of the Woodbine and in terrace gravels, are now being worked near Horatio by the Kansas City Southern Railroad. Terrace and alluvial gravels are also being excavated near Delight, in Pike County. The best gravel deposits are found in the sandy Cretaceous formations, on which the roads are naturally good. Unfortunately, the Cretaceous gravels are not found near areas underlain by the marly formations, where the roads are poor. There are, however, some extensive deposits

[77] Miser, H. D., and Purdue, A. H., Gravel deposits of the De Queen and Caddo Gap quadrangles: U. S. Geol. Survey Bull. 690, 1918.

of terrace gravel that are somewhat better situated and that should be more widely used. The high terrace gravel near Jewel, in Little River County, is being used in surfacing the road across the bottom of Little River to Horatio. The alluvial and terrace gravels of Mine Creek between Mineral Springs and Nashville could be used to advantage in surfacing roads in southern Howard and northern Hempstead counties. Other extensive deposits of terrace gravel are available near Belton, in Hempstead County, and Prescott and Boughton, in Nevada County, and less extensive deposits are available at many places.

GLAUCONITE

The glauconite deposits of the Nacatoch sand constitute a potential economic resource of this area. Glauconite is a hydrous postassium-iron silicate of varying composition, containing from 2 to 8 per cent of K_2O, or potash. Potash and its various compounds are used in making fertilizers, 250,000 to 300,000 tons of K_2O being so used every year in the United States. The supply is now derived largely from German and French deposits of soluble salts of potassium. The output of potash in the United States is only about one-quarter of the consumption and is practically all derived from the potassic brine of Searles Lake, in California. During the European War (1914-1919) the complete stoppage of the German supply from the market necessitated the development of sources of potash in this country, including the recovery of the potash in the waste products of the blast furnace, cement, sugar, and alcohol industries. The largest possible source of potash in this country is found in the potassium-bearing silicate minerals, such as glauconite, from which the potash must be extracted by chemical treatment. However, evidence is now accumulating that large areas in southwestern Texas and New Mexico are underlain by beds of soluble potash salts, which may ultimately be made available to commercial exploitation,[78] and may minimize the value of the glauconite of this area as a possible source of potash.

The problem of the chemical treatment of glauconite for

[78] Mansfield, G. R., Economic geology of fertilizer minerals, in Mineral Raw Materials of the Fertilizer Industry, published by the National Fertilizer Association, Washington, D. C., 1926, p. 18.

the recovery of its content of potash has been under intensive attack since the World War. Recent work by the Electro Company at Odessa, Del.,[79] and by the laboratories of the U. S. Department of Agriculture[80] has resulted in a process that gives promise of being commercially practicable. By this process all the raw material of glauconite is converted into merchantable products—potash, alumina, iron oxide, and silica. The success of the process seems to depend upon the market available for the silica, which is of necessity produced in disproportionately large quantities. Its use as a clarifier is proposed.

The largest and most accessible deposits of glauconite, which are also those of the highest grade, are found in New Jersey and northern Delaware.[81] The economics of the fertilizer industry are considered fully elsewhere.[82] Most of the factories are along the Atlantic seaboard, because the cost of German potash is lower there. As a consequence of their location there the eastern and southeastern States are the largest users of fertilizer because the charges for its transportation to inland States are so high as to prevent its extensive use there. If the manufacture of potash from glauconite should prove to be commercially feasible the greensand deposits in southwestern Arkansas are favorably situated for exploitation.

Analyses already published[83] show that the potash content of the greensand of the Nacatoch varies from 2.80 to 4.53 per cent as compared with a content as high as 6 or 7 per cent in greensand from New Jersey and Delaware. The lower grade of the Arkansas deposits might not prohibit their successful development for use in adjoining areas, where potash from the east would have to bear considerably higher charges for transportation. Magnetic concentration of greensand of low grades has been suggested and would certainly be practicable.

The extent of the greensand unit of the Nacatoch has

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[79] Moxham, A. J., Purifying ore by chemical methods: Iron Age, vol. 113, pt. 2, p. 1637, 1924.

[80] Turrentine, J. W., Whittaker, C. W., and Fox., E. J., Potash from greensand (glauconite): Indust. and Eng. Chemistry, vol. 17, No. 11, p. 1177, 1925.

[81] Mansfield, G. R., Potash in the greensands of New Jersey: U. S. Geol. Survey Bull. 727, 1922.

[82] Brand, Charles J., The economics of the fertilizer industry, in Mineral raw materials for the fertilizer industry, published by the National Fertilizer Association, Washington, D. C., 1926.

[83] Ashley, G. H., Notes on the greensand deposits of the United States: U. S. Geol. Survey Bull. 660, p. 48, 1917.

been described on pages 117-121. Over most of its outcrop there is a cover of surface soil and sand of variable thickness. Considerable areas of greensand, however, lie under only slight cover or are actually exposed. Most of the greensand is soft and could easily be mined by steam shovel with only slight interference by occasional harder, calcareous beds. The areas near Washington are close to a line of railroad transportation.

Experiments made by the United States Department of Agriculture show that plants, in their early stages of growth, will assimilate potash directly from greensand.[84] Later experiments of the Maryland Agricultural Experiment Station indicates that the application to soils of greensand composted with sulphur and manure may prove to be a practical and efficient method of providing available potassium for crops.[85] The value of potash as a fertilizer for cotton and other crops is well known to agricultural experts, and it would seem desirable, experimentally, to use some of the best greensand of the Nacatoch without treatment on such soils in this area as are deficient in potassium.

Most of the glauconitic beds in the Ozan formation are of lower grade than those in the Nacatoch and are uniformly thin, so that they can hardly be considered a source of potash for chemical treatment, but where it is available this greensand also might be used directly as a fertilizer.

LIGNITE

Some beds in the Tokio formation are lignitic. The outcrop described by Veatch[86] at the "Coal Shaft," about a mile north of Ben Lomond, in the NW. ¼ SE. ¼ Sec. 32, T. 10 S., R. 29 W., exposes 18 inches of lignitic black sandy clay bedded between gray and white soft quartz sand. This outcrop is stratigraphically below the upper fossiliferous clay tongues of the Tokio. According to J. N. Garner, of Nashville, a thin bed of lignite is exposed near the center of Sec. 10, T. 10 S., R. 27 W., about 3 miles southwest of Nashville, in the banks of Mine Creek. This bed was covered by high water when visited, but blocks of fairly good

[84] True, R. H., and Geise, F. W., Experiments on the value of greensand as a source of potassium for plant culture: Jour. Agr. Research, vol. 15, pp. 483-492, Dec. 2, 1918.

[85] McCall, A. G., and Smith, A. M., Effect of manure-sulphur composts upon the availability of the potassium of greensand: Jour. Agr. Research, vol. 19, pp. 239-256, June, 1920.

[86] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 23, 1906.

lignite were lying along the creek. The bed is near the top of the formation. Attempts have been made to utilize the lignitic material at both places for blacksmithing, but with little success.

ARTESIAN WATER

The artesian water resources of the area have been described in detail by Veatch.[87] The principal water-bearing horizons are at the top of the Nacatoch sand and in the uppermost sandy beds of the Tokio formation. Water may be found at several levels in the Nacatoch, but the strongest flow usually occurs at its top, just below the overlying impervious Arkadelphia marl. According to Veatch[88] the water found in the Nacatoch becomes salty at distances from the outcrop owing to the leaching of the minerals in the formation. A little water may at some places be found in the basal few feet of the Saratoga chalk. The Buckrange sand, at the base of the Ozan formation, carries water in varying, and in places considerable, quantities, but it is usually hard and impotable. The Tokio formation consists of several beds of quartz sand intercalated among thicker beds of clay. These clay beds diminish in thickness to the north and east and accordingly in these directions the formation becomes principally sand. All the sand beds may be water bearing, but the largest supplies are usually found in the highest sand bed and in the very porous basal gravel. The Woodbine formation, below the Tokio, contains beds of sand and gravel that are water bearing, but in this area the formation includes much volcanic material and red clay, and its mineral composition is thus such that it is likely to yield only bitter and impotable waters.

The underlying Trinity formation contains many beds of sand and two persistent gravel members on the outcrop. Beneath the outcrop the beds of sand and gravel are apparently more irregularly distributed through the formation. Many of them carry water, but it is almost invariably salty, as might be expected from the numerous marly beds in the formation and the occurrence in it of thick beds of gypsum and nodular masses of celestite.

The terrace sands and gravels are at many places water bearing.

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[87] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 74-81, 1906.
[88] Veatch, A. C., op. cit.

OIL AND GAS

In the search for oil and gas probably more than seventy wells have been drilled in the area mapped. Most of them were started on the Eocene or Cretaceous outcrop with the hope of obtaining a commercial output from the Cretaceous sands. This exploratory drilling has been justified by the occurrence of oil and gas in large quantities at the same geologic horizons at somewhat greater depths elsewhere in Arkansas and in northern Louisiana and by the occurrence of asphaltic sands in the Trinity formation on its outcrop.[89] The results of the drilling have been almost entirely negative. Small showings of gas and oil have been reported from about twenty wells, and although the formations have undoubtedly been slightly warped no pronounced anticlinal structure has been disclosed by a study of the records of wells drilled for oil and gas and of those of the more numerous but shallower wells drilled for artesian water. Showings of oil or gas from beds in the Trinity formation have been recorded in about a dozen wells and from beds in the Tokio formation in several wells. Some have also been recorded in a few wells from beds in the Nacatoch formation, from beds in the Woodbine formation, from the upper part of the Ozan formation, and from the Buckrange sand lentil at the base of the Ozan. The results of exploration have been discouraging, but the area cannot yet be entirely condemned for oil and gas production, although prospecting could probably be done to greater advantage farther from the outcrop of the formations, where they lie under deeper cover. The Trinity formation appears to afford better chances for oil and gas than the younger formations, both because of the greater number of showings found in it to date and because of the possibility that the beds of the Trinity are deformed structurally to a greater degree than the beds of the overlying Gulf series. The suggestion has been made that the peridotite intrusives near Murfreesboro may have lifted the adjacent Trinity in such a manner as to produce structures favorable for the accumulation of oil or gas.[90] A similar suggestion may be made for the area south of Lockesburg, where the Trinity is recognizably de-

[89] Miser, H. D., and Purdue, A. H., Asphalt deposits and oil conditions in southwestern Arkansas: U. S. Geol. Survey Bull. 691, pp. 276-280, 1918.

[90] Miser, H. D., and Purdue, A. H., op. cit.

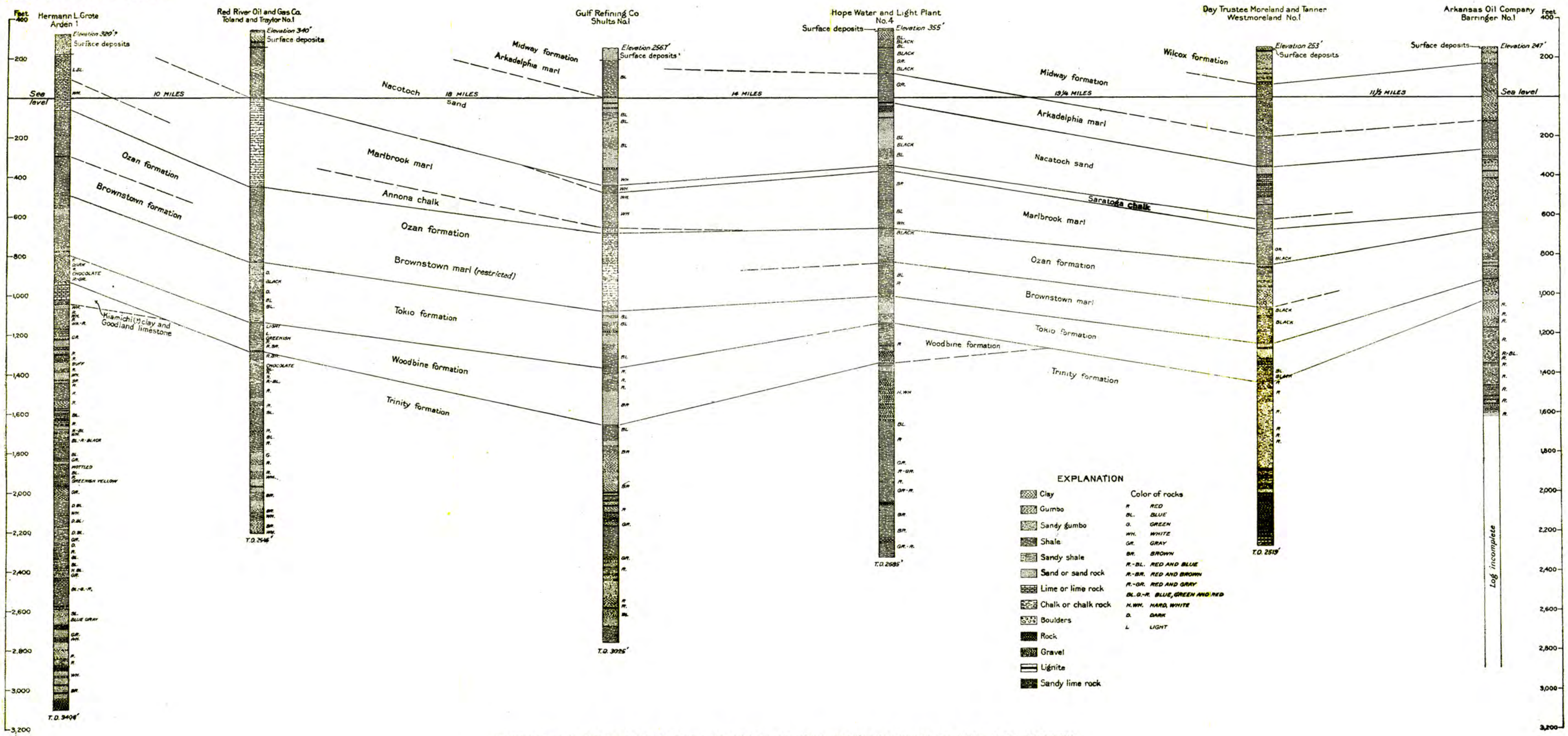
formed structurally, as is noted on page 164. The Paleozoic rocks that underlie the Trinity formation where it crops out are so intensely folded and fractured that they are not likely to contain oil or gas in large quantities. Accordingly, exploratory drilling should be carried only slightly below the Cretaceous rocks in this area, although the possibility should be recognized that in areas farther south, away from the outcrop, the Paleozoic rocks may be less metamorphosed. As the Paleozoic floor dips to the south rather steeply, most of the wells drilled at distances of more than a few miles from the contact have not completely penetrated the Cretaceous beds.

APPENDIXES

APPENDIX A

In the preparation of this report most of the available records of deep wells drilled for oil, gas, or water in this area have been examined. The interpretation of the well records in this area and in southwestern Arkansas in general has been hampered by a lack of knowledge of the stratigraphy. The interpretation of the records of wells drilled in southern Arkansas in general is not within the province of this report, but the correlation of the best well records in the area studied by means of more accurate knowledge of the stratigraphy now available may be a useful guide to correlation elsewhere in Arkansas and northern Louisiana. Most of the deep wells drilled in the area are indicated on Plate I (in pocket). The parts of the land sections in which some of these wells are drilled are not known and the location of a few of the older wells can be given only approximately. The records of some of the wells are not available to the writer or are scanty and untrustworthy. The correlation of those of the remainder is shown in the appended table (in pocket). The drillers' descriptions of the formations penetrated in a few wells are given in detail, and the samples and cores examined correlated with some of these descriptions. A few of the most detailed records have been plotted on Plate XXVIII.

The average driller can not easily obtain an accurate record of the formations penetrated by a well drilled by the rotary method. He makes most of his lithologic distinctions chiefly by the performance of the bit and pump and partly by an examination of mixed cuttings and of fragments adhering to the bit. Material that is plastic when wet, that sticks to the bit, and that slows or stops the pump, is usually called "gumbo." "Shale" is usually clay which drills more easily than "gumbo." "Chalk" is used mostly for fairly hard material that gives white cuttings. "Sand" is detected by cuttings, and "pack sand" is a little harder. Beds in which the bit makes slow progress are "rock." The experience of the driller, and his knowledge of the formations, affect his record considerably. Where two adjacent formations that have some lithologic resemblance have not been differentiated by the driller the word "indeterminate" has been inserted in the table.



CORRELATION OF DRILLERS' LOGS OF WELLS IN THE SOUTHERN PART OF THE AREA MAPPED

PARTIAL RECORD OF ARDEN NO. 1 WELL, DRILLED BY HERMANN L. GROTE IN THE NORTHEAST CORNER OF SEC. 2, T. 13 S., R. 31 W.

(Description of samples by H. D. Miser; correlations by C. H. Dane)

Age	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log: Material	Thickness, Feet	Depth, Feet
Quaternary.	Alluvium?	15-90	Fine buff sand.	Surface deposits.	15	15
		90-99	Coarse buff sand.	Quicksand (water sand, 90-99 feet).	84	99
Upper Cretaceous (Gulf series).	Marlbrook marl.	99-380	Gray calcareous clay.	Light blue chalk.	126	225
	Annona chalk.			White chalk.	155	380
	Ozan formation.	380-507 and 511-608	Slightly calcareous dark shaly clay containing pyrite and fragments of shells.	Dark shale.	127	507
				Hard lime rock.	4	511
				Dark shale; fossil shells.	97	608
				Gray sand.	4	612
	Brownstown marl.	612-812	Large fragments of slightly calcareous dark clay; contains small fossils.	Dark shale; fossil shells.	200	812
	Tokio formation.	812-815	Large fragments of soft greenish-gray glauconitic sandstone. Largest fragment contains a fossil.	Soft greenish sand rock; fossil shells.	3	815
		815-844	Slightly calcareous dark clay; contains small fossils.	Dark shale; sand rock; pyrites.	29	844
		844-850	Dark clay and pyritic, glauconitic sand.	Salt water; gas.	6	850
		850-880	Slightly calcareous dark clay containing small fossils.	Dark shale.	30	880
		880-895	Glauconite, gray sand, and dark clay.	Gray sand; salt water.	15	896
		895-1074	Sandy, fossiliferous clay containing sand grains as much as 1-10-inch in diameter, and some small bits of carbonaceous material.	Dark shale; fossil shells.	79	1074
		1074-1076	Well rounded and subangular pebbles of novaculite, the largest ¾-inch in longest diameter.	Coarse, hard gravel; gas.	2	1076
		1076-1081	Coarse gray sand.	Gray sand rock.	5	1081
		1081-1114	Pebbles of novaculite.	(Missing).	33	1114
	Woodbine formation.	1146-1154	Red clay.	Dark shale.	32	1146
				Red shale.	8	1154
				Dark shale.	10	1164
				Red shale.	30	1194
		1194-1199	Novaculite pebbles half an inch or less in diameter, and coarse sand.	Coarse sand; gas.	5	1190
		1199-1219	Light brown or chocolate colored clay.	Chocolate shale.	20	1219
		1219-1347	Red and gray banded clay.	Bluish-gray shale with streaks of red shale and soft lime; gas.	28	1247

PARTIAL RECORD OF ARDEN NO. 1 WELL—Continued

Age	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log: Material	Driller's Log: Thickness, Feet	Driller's Log: Depth, Feet
Lower Cretaceous (Comanche series).	Kiamichi clay (?) and Goodland limestone.	1256-1338	One sample of cuttings consists almost entirely of finely broken white limestone containing some fragments of dark clay and pyrite. Another sample consists of large fossils.[1]	(Missing).	9	1256
				Hard limestone with fossil shells. Gas and oil shows near bottom.	82	1348
		1346-1358	Fairly large fragments of pyrite containing gray sand and large fossils.	Bluish-gray shale.		1474
				Iron pyrites and sandy blue lime.	12	1358
	Trinity formation.		Numerous samples of the Trinity formation from this well have been examined by H. D. Miser.	Bluish-gray shale.		1363
				White pack sand; salt water; streaks of lignite and pyrite.		1373
				Blue shale.		1385
				Red shale.		1413
				White shale.		1420
				Red and chocolate shale; iron pyrites.		1433
				White and red streaked shale.		1464
				White sandy shale.		1474

[1] Dr. T. W. Stanton, of the U. S. Geological Survey, expresses the opinion that the specimens of Gryphaea obtained from this bed are Comanche, and probably Fredericksburg in age.

Beds correlated with the Trinity formation are recorded from this well to a depth of 3,406 feet. According to Miser the well probably passed through the De Queen limestone member at a depth of 2,200 feet.

This is the only well in the area in which Goodland limestone and probably Kiamichi clay has been recognized. This fact is of the greatest importance, for it establishes the character of the Woodbine formation at the base of the Upper Cretaceous in the southern part of the area. Both the driller's log and Miser's description of the cuttings show that red clay forms a considerable part of the Woodbine. Were it not for the presence of the Goodland limestone in this well it would be impossible to separate the red beds of the Woodbine from the Trinity below. Inasmuch as the Goodland is cut out eastward, it is at many places impossible to identify the Woodbine, although its presence may be suspected, as a zone of red clay rather persistently appears beneath beds of apparent Tokio lithology. Similar banded red clays occur at the base of the Upper Cretaceous series in the general vicinity of the Monroe gas field, in northern Louisiana.

RECORD OF SHULTS NO. 1 WELL, DRILLED BY GULF REFINING CO., 500 FEET EAST AND 300 FEET SOUTH FROM NORTHWEST CORNER OF SEC. 33, T. 13 S., R. 26 W., NEAR FULTON, ARK.

(Drillers, A. H. Tarver and H. C. Fouts. Drilling began March 19, 1916; well completed June 9, 1916. Elevation of surface, 256.7 feet above sea level. Driller's record furnished by Gulf Refining Company; character of samples described by H. D. Miser.)

Age	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log: Material	Thickness, Feet	Depth, Feet
Quaternary.	Alluvium or terrace deposit.			Red sandy loam.	59	59
Eocene	Midway formation.			Blue gumbo shale.	194	253
Upper Cretaceous (Gulf series).	Arkadelphia marl.					
	Nacatoch sand.			Hard, broken rock and sand; artesian water.	72	325
				Blue gumbo shale.	20	345
		300	Very dark clay.	Hard, blue, sandy gumbo.	44	389
				Hard, blue, sandy clay.	40	429
				Hard sand rock.	1	430
				Soft sand.	10	440
				Sand rock.	11	451
				Tough, blue gumbo.	59	510
		648-692	Called "artesian-water sand rock." Two large pieces are sandy limestone and two smaller pieces are dark and buff clay, but most of sample is loose sand and small pieces of gray clay with the sand predominating.	Hard rock.	2	512
				Hard sand.	10	522
				Sandy gumbo.	44	566
				Hard sand rock.	2	568
				Sandy gumbo.	44	612
				Hard sand rock.	6	618
				Hard white gumbo.	62	680
				Soft sand.	15	695
	Saratoga chalk.			Hard white gumbo.	35	730
	Marlbrook marl.	692-776	Tough dark clay.	White shale.	50	780
				White soapstone.	133	913
	Annona chalk.			Hard chalk rock.	25	938
	?					
	Ozan formation and Brownstown marl.			Chalk-rock formation.	374	1312
				Blue shale.	23	1335
	?					
	Tokio formation.			Hard sand rock.	15	1350
				Blue shale.	18	1368
				Hard sand rock.	7	1375
				Hard sand.	15	1390
				Hard blue shale.	18	1408
				Sand rock.	8	1416
				Blue shale.	16	1432
				Sandy gumbo.	10	1442
				Rock.	5	1447
				Blue gumbo.	15	1462
				Hard sand with streaks of pyrite, showing water.	38	1500
				Tough blue gumbo.	129	1629

RECORD OF SHULTS NO. 1 WELL—Continued

Age	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log		
				Material	Thickness, Feet	Depth, Feet
Upper Cretaceous (Gulf series).	Woodbine formation.			Hard red shale.	27	1656
				Hard rock.	2	1658
				Red sand and shale.	17	1675
				Tough red gumbo.	20	1695
				Rock.	1	1696
				Tough red gumbo.	44	1740
— ? —	— ? —			Brown sand rock; hard streaks.	175	1915
Lower Cretaceous (Comanche series).				Blue sticky shale.	85	2000
				Hard sand.	23	2023
				Tough brown gumbo.	132	2155
				Sand rock.	13	2168
				Brown gumbo.	25	2193
				Hard sand.	20	2213
				Brown gumbo.	29	2242
				Brown shale.	14	2256
				Hard rock.	4	2260
				Hard sand.	10	2270
				Hard rock.	4	2274
				Hard brown shale.	17	2291
				Tough gumbo.	5	2296
				Hard rock.	4	2300
		2300-2406	One piece is part of shell, two or three pieces of red clay; several pieces of bluish clay and several of a sandy compact, greenish earth.	Hard sand.	10	2310
		2300-2371	Gray sand and a little red clay and gray clay.	Gumbo.	12	2322
				Rock.	3	2325
				Red gumbo and shale.	5	2330
				Gypsiferous rock.	12	2342
	Trinity formation.			Red gumbo.	13	2355
				Hard rock.	11	2366
				Gumbo and boulders.	18	2384
				Hard rock.	8	2392
		2406-2451	Laminated light greenish gray clay containing a few red spots.	Hard shale and boulders.	24	2416
		2451-2537	Sample consists of three pieces of hard calcareous pyritiferous sandstone and one piece of dark clay.	Broken rock with gray gumbo.	26	2442
				Hard slate and shells.	147	2589
		2537-2546	Gray plastic clay and some red clay.			
		2546-2549	Two pieces of gray, hard, compact fossiliferous limestone.			
		2566-2654	Gray sand and some gray and red clays.	Hard gray limestone.	12	2601
		2654-2745	Tough red clay.	Red shale with hard streaks of sand.	103	2704
		2745-2748	Sample is a piece of a large shell.			
		2748-2912	Tough red clay.	Hard broken sand rock.	76	2780
				Tough red gumbo.	10	2790
				Hard rock.	3	2793
				Red gumbo.	27	2820
				Hard red shale.	20	2840
				Hard rough rock.	6	2846

RECORD OF SHULTS NO. 1 WELL—Continued

Age	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log		
				Material	Thickness, Feet	Thickness, Feet
Lower Cretaceous (Comanche series).				Hard blue sandy shale.	20	2866
				Tough blue gumbo.	25	2891
				Hard broken sand rock; salt water.	39	2930
				Hard broken slate with streaks of sticky shale; artesian flow of salt water.	95	3025

RECORD OF SWOFFORD NO. 1 WELL, DRILLED BY A. H. TARVER, 200 FEET NORTHWEST OF SOUTHEAST CORNER OF NW¼ SEC. 14, T. 11 S., R. 25 W.

(Description of samples by C. H. Dane)

Age	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log: Material	Driller's Log: Depth, Feet
Upper Cretaceous (Gulf series).	Nacatoch sand.			Surface sand.	0- 45
				Pack sand	45- 54
				Hard pack sand.	54- 58
				Hard blue sand.	58- 95
				Sandy chalk.	95- 170
	Saratoga chalk.			Hard chalky shale.	170- 200
				Hard sandy lime.	200- 204
	Marlbrook marl.			Gummy chalk.	204- 232
				Gumbo.	232- 234
				Chalk.	234- 243
				Blue sandy shale.	243- 294
				Gummy chalk.	294- 358
				Gumbo.	358- 362
	Ozan formation.			Blue sandy shale.	362- 400
				Gumbo.	400- 404
				Hard shale.	404- 428
				Gumbo.	428- 480
				Gray sand; small show of gas.	480- 481
		[1] 481	Gray micaceous, very sandy marl containing a few broken shells.	Gray sandy shale.	481- 525
				Shale.	525- 560
				Gumbo.	560- 564
				Gummy chalk.	564- 580
				Gumbo.	580- 587
				Sandy shale.	587- 610
				Gummy shale.	610- 625
				Gumbo.	625- 630
		[1] 630	Olive gray micaceous marly sand, fragments of oyster shells; numerous small shells; foraminifera; a very few small, soft, black carbonaceous pockets.	Hard gray sand.	630- 650
	Brownstown marl.			Gumbo.	650- 658
				Gumbo and boulder.	658- 685
				Blue sandy shale.	685- 783
				Gumbo and gypsum.	783- 787
				Blue sandy shale.	787- 816
				Tough gumbo.	816- 823
				Blue sandy shale.	823- 838
				Gumbo.	838- 846
	Tokio formation.	[1] 847	Very fine gray clayey sand; numerous small muscovite flakes and very numerous small lignitic fragments; some lignitic lenses up to 1 inch long and ⅛ inch thick parallel to bedding.	Pack sand.	846- 847
		[1] 848	Same material as core at 847 feet.	Brown sand.	847- 849
		[1] 849	Impure shaly lignite and gray, very slightly sandy clay with shreds of lignite.	Lignite.	849- 855
				Blue sandy shale.	855- 879
				Packed water sand.	879- 880
				Hard packed sand.	880- 930

[1] Core.

RECORD OF SWOFFORD NO. 1 WELL—Continued

Age	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log	
				Material	Depth, Feet
Upper Cretaceous (Gulf series).	Tokio formation.	[1] 935	Fine grained light gray sand and slightly darker gray clay with lignitic plant fragments 1/16-inch long; distinctly laminated by variation in percentage of carbonaceous material.	Hard sandy shale.	930- 965
	?				
	Woodbine formation?			Gummy shale and pyrites.	965- 981
				Hard pyrites.	981- 983
				Gummy shale and pyrites.	983-1013
				Gumbo.	1013-1019
				Shale and boulders.	1019-1029
				Gumbo.	1029-1034
				Blue shale.	1034-1050
				Gumbo.	1050-1053
				Hard sandy lime.	1053-1065
	?				
Lower Cretaceous (Comanche series).	Trinity formation.			Red gumbo.	1065-1075
				Red shale and gumbo.	1075-1105
				Red shale.	1105-1112
				Red gumbo.	1112-1118
				Red rock.	1118-1120
				Broken rock, red.	1120-1130
				Gumbo.	1130-1135
				Sandy shale and boulders.	1135-1163
				Red gumbo.	1163-1170
		[1] 1171	Hard, light gray calcareous sandstone containing subangular to subrounded grains of quartz, 0.01 to 0.20 mm. in diameter, in calcareous cement. A few fragments of oyster shells.	Hard lime.	1170-1177
				Limy shale.	1177-1198
				Anhydrite.	1198-1210
		[2] 1235	Some gray crystalline anhydrite. Most of the material is pure light gray clay which swells and crumbles in water. Contains irregular masses of anhydrite; in some layers is spotted thickly with very small grains of anhydrite. Interlayered and interveined very irregularly with pure white finely crystalline gypsum.	Anhydrite, gummy streaks.	1210-1236
		[1] 1261	Coarsely crystalline anhydrite, mottled light gray, nearly white, and olive gray; the light gray is dense or very fine grained, the olive gray is crystalline.	Anhydrite.	1236-1273
				Gumbo.	1273-1275
				Lime rock, sandy.	1275-1279
				Anhydrite	1279-1310

[1] Core. [2] Core; broken material.

RECORD OF SWOFFORD NO. 1 WELL—Continued

Age	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log	
				Material	Depth, Feet
Lower Cretaceous (Comanche series).	Trinity formation.	[1] 1315	Light grayish and pea green, sandy calcareous marl. Very fine white quartz grains. Contains black carbonaceous imprints, possibly imprints of plants.	Pack sand, green.	1310-1317
				Gumbo.	1317-1318
				Sandy shale.	1318-1322
				Hard sand and gypsum.	1322-1325
				Pack sand and shale.	1325-1345
				Hard sand.	1345-1369
				Sandy red shale.	1369-1379
				Pack sand.	1379-1393
				Red gumbo.	1393-1397
				Hard sandy shale.	1397-1408
				Sandy rock.	1408-1410
				Hard sandy shale.	1410-1433
				Red gumbo.	1433-1437
				Red shale.	1437-1447
				Red gumbo.	1447-1449
				Hard sand.	1449-1451
		[1] 1454	Fine grained salmon buff sand, packed but poorly cemented.	Red sandy shale, hard.	1451-1475
				Pack sand.	1475-1480
				Hard sandy shale.	1480-1487
				Hard red shale.	1487-1495
				Blue gummy shale.	1495-1510
				Pack sand.	1510-1515
				Hard blue sandy shale.	1515-1525
				Hard shale and shells.	1525-1552
				Hard sandy shale.	1552-1560
				Gummy blue shale.	1560-1569
				Hard shale with gummy streaks.	1569-1585
		[3] 1590	Light gray, very slightly sandy calcareous clay containing numerous small fragments of oyster shells.	Sandy lime, gray.	1585-1590
				Broken lime, gummy.	1590-1595
				Gummy shale, red.	1595-1605
				Red rock.	1605-1608
				Gummy red and blue shale.	1608-1614
		[1] 1623	Gray clayey limestone, in part limy gray clay containing numerous fragments of *Ostrea*.	Hard gray lime.	1614-1644
		[1] 1641	Hard light gray limestone with numerous fragments of broken shells. (Dr. Stanton identified *Ostrea franklini* Coquand.)		
				Hard blue shale.	1644-1652
				Gummy shale.	1652-1658
				Broken lime.	1658-1662
				Hard blue shale.	1662-1668
				Hard lime.	1668-1670
				Hard lime shale, streaks lime.	1670-1685
				Blue shale.	1685-1697
				Hard lime and shells.	1697-1702

[1] Core. [3] Piece from bit.

RECORD OF SWOFFORD NO. 1 WELL—Continued

Age	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log	
				Material	Depth, Feet
Lower Cretaceous (Comanche series).	Trinity formation.	[1] 1704	Light greenish gray, limy clay with numerous *Ostrea* and fragments of other shells. (Dr. Stanton identified *Ostrea franklini* Coquand, of Trinity age.)	Blue shale, streaks lime.	1702-1732
				Gummy shale.	1732-1740
				Lime.	1740-1744
				Blue shale, streaks lime.	1744-1768
				Lime.	1768-1770
				Brown shale and lime.	1770-1789
				Rock.	1789-1790
		[1] 1790	Very pale green, extremely fine grained, slightly calcareous sandstone.	Hard green sand with lime concretions.	1790-1813
				Hard sandy gray lime	1813-1830
				Gumbo.	1830-1831
				Blue gummy shale.	1831-1835
		[1] 1841	Fine grained very pale green, slightly calcareous sandstone.	Hard shale.	1835-1845
				Gypsum.	1845-1847
				Blue shale and lime.	1847-1855
				Red gumbo.	1855-1861
				Gumbo.	1861-1863
				Hard sandy lime.	1863-1880
				Hard shale and lime.	1880-1888
				Lime, sandy.	1888-1892
				Hard gray sand.	1892-1903
				Hard sandy lime rock (very hard reamed roller bit to bottom).	1903-1910
				Hard gray lime.	1910-1916
				Gummy lime.	1916-1925
				Broken sandy lime, very hard.	1925-1941
		[1] 1944	Very fine grained white friable sand, packed but not cemented. Largest grains 0.07 mm. Mostly subrounded fine grains.	White water sand.	1941-1947
		[1] 1945	Very fine white quartz sand, packed but not cemented. Grains of colorless or faint gray quartz 0.01 to 0.03 mm. in diameter. A few faint salmon colored grains, usually larger, up to 0.15 mm.		
		[1] 1946	Very light gray-green quartz sandstone with streaks of light green clay. Considerable variability in size of grains, mostly small (0.001 to 0.01 mm.), with larger grains (0.1 to 0.2 mm.) set in this fine grained matrix.		

[1] Core.

RECORD OF SWOFFORD NO. 1 WELL—Continued

Age	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log	
				Material	Depth, Feet
Lower Cretaceous (Comanche series).	Trinity formation.		Larger grains conspicuously subangular, a few subrounded. Smaller grains also subangular to subrounded. A few coral red grains and a few gray ones.		
				Hard red and blue shale with streaks of lime.	1947-1980
				Hard sandy shale.	1980-1985
				Lime.	1985-1989
				Red and blue shale.	1989-2005
				Broken red rock and sandy.	2005-2015
				Red shale.	2015-2020
				Red rock, lime streaks.	2020-2029
		[1] 2029	Mottled heliotrope, purple and dark cinnamon fine clayey sand. Contains high percentage of clay but does not become plastic when wet. Sand grains up to 0.1 mm. Non-calcareous.	Red shale.	2029-2034
				Hard sand rock.	2034-2038
				Lime rock, gummy.	2038-2042
				Red and blue gummy shale, streaks of lime.	2042-2076
				Hard gummy shale with lime.	2076-2080
				Broken gummy lime.	2080-2084
				White sand.	2084-2085
				Red bed.	2085-2090
				Sand and gravel, hard.	2090-2095
		[2] 2095-2098	Almost entirely small angular chips of light and dark gray and flesh colored novaculite. Some fragments show parts of original small pebble surface. A few pieces of quartz and small pebbles of medium-grained gray sandstone. Several pieces of pyrite.	Gravel formation, very hard, small show.	2095-2105
		[2] 2099	Chips of gray, white, and flesh colored novaculite, some colorless and yellowish quartz; some pyrite.		
				Red shale	2105-2125
				Broken lime.	2125-2131
				Red shale.	2131-2133
				Hard lime rock.	2133-2144
				Hard red shale, streaks of lime.	2144-2160
		[1] 2162	Extremely fine grained, very pale green clean sand, sparingly mottled and streaked with red sand.	Green sand.	2160-2165

[1] Core. [2] Cuttings.

RECORD OF SWOFFORD NO. 1 WELL—Continued

Age	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log: Material	Driller's Log: Depth, Feet
Lower Cretaceous (Comanche series).	Trinity formation.	[2] 2165	Dark brick red non-sandy plastic clay.	Red shale, streaks of lime. Rock. White water sand. Red rock. Red sandy shale. Hard lime rock. Broken lime mixed with green sand and red shale.	2165-2213 2213-2214 2214-2221 2221-2223 2223-2240 2240-2263 2263-2285
		[2] 2285-2301	Brick red, slightly sandy clay. Small chips of novaculite.	Lime, some lignite and green sand.	2285-2312
		[2] 2301-2312	Red, sandy calcareous clay; slacks in water. Chips of gray novaculite. Fragments of light non-calcareous green sandstone; some light gray clayey limestone.		
		[2] 2312-2323	Small sample, mostly red sandy clay, some quartz and fine grained green sandstone, red and light gray novaculite.	Yellow gummy shale.	2312-2323
		[2] 2323-2377	Light brick red, sandy, calcareous clay, a few pieces of gray calcareous clay, and a few fragments of novaculite.	Red sandy shale.	2323-2377
		[2] 2377-2393	Mostly hard brick red, very fine grained calcareous sandstone and fragments of light and dark gray novaculite, and one small pebble.	Red sand rock.	2377-2389
		[2] 2393-2405	Sand grains 0.05 to 0.6 mm. in diameter. Mostly colorless quartz; some novaculite, and green and red sandstone. Also broken larger pieces of sandstone and quartz and particularly of novaculite with chips up to 3 mm. in length.	Very hard red sand rock.	2389-2422
		[2] 2405-2422	Loose grains of colorless quartz; yellowish, greenish and gray novaculite; reddish, greenish and gray sandstone. Size 0.05 mm. to 0.6 mm; subrounded; a few well rounded.		
		[3] 2405-2425	Dull brick red, very slightly sandy clay, slacks readily in water.		
				Red gummy shale. Tough red gumbo. Hard red shale. Shell streaks. Red gummy shale.	2422-2555 2555-2573 2573-2598 2598-2601 2601-2610

[2] Cuttings. [3] Probably from below the sand cuttings, from 2420-2425.

RECORD OF SWOFFORD NO. 1 WELL—Continued

Age	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log	
				Material	Depth, Feet
Lower Cretaceous (Comanche series).	Trinity formation.	[2] 2730-2740	Mostly brick red very fine grained calcareous sandstone. Some with tiny veinlets of calcite. Some gray, dense limestone.	Hard red shale (with shell streaks about 5 feet).	2610-2736
				Gray conglomerate.	2736-2738
		[1] 2740 (top)	Hard, very fine grained light greenish sandstone mottled flesh colored and light green on small scale. Flesh colored areas are cleaner sand, green are mixed with clay. Some thin sandy lenses of clay.	Hard red shale.	2738-2848
		[1] 2740 (bottom)	Dark brick red, fine grained sandstone. Some very fine muscovite with rather numerous pebbles of ferruginous red sandstone 1 to 1.5 mm. in diameter having a glossy clay coating and a few similar pebbles of green clay.		
		[4] 2740	Earthy light green sandstone. Variable in small patches from light greenish slightly sandy clay to salmon colored nearly clean, fine grained sandstone.		
		[2] 2750-2760	Light brick red sandy shale, some calcareous. Some pieces of greenish sandstone.		
		[2] 2770	Brick red, slightly calcareous sandy shale with light greenish gray extremely fine grained argillaceous, calcareous sandstone.		
		[2] 2780	Very fine grained sandy calcareous brick red shale.		
		[2] 2790	Calcareous red very fine grained sandy shale and gray sandy limestone.		
		[2] 2800	Brick red sandy calcareous shale; large percentage is hard, light purplish gray argillaceous, calcareous sandstone.		
		[2] 2810	Extremely fine grained red calcareous sandstone and light gray limestone. The light gray limestone is nearly pure. Also intermediate purplish, very calcareous sandstone.		

[1] Core. [2] Cuttings. [4] Large pieces.

RECORD OF SWOFFORD NO. 1 WELL—Continued

Age	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log	
				Material	Depth, Feet
Lower Cretaceous (Comanche series).	Trinity formation.	[2] 2820	Brick red calcareous sandy shale and hard, light gray argillaceous limestone.		
		[2] 2830	Very fine grained light brick red calcareous sandy shales, gray calcareous shales, purplish gray, calcareous very fine grained sandstone.		
		[2] 2840	Red sandy shale and light purplish gray argillaceous sandy limestone.		
		[2] 2850	Red sandy shale and red calcareous sandy shale. Some purplish gray sandy limestone.	Broken lime.	2848-2861
		[2] 2860	Light brick red sandy calcareous shale.		
		[2] 2870	Red sandy shale and gray limestone.	Red shale.	2861-2887
		[2] 2880	Light brick red very fine grained clayey sand.		
		[2] 2890	Calcareous brick red sandy shale.	Broken lime.	2887-2895
		[2] 2900	Red sandy shale. Gray and purplish gray impure sandy limestone.	Red shale, shell streaks.	2895-2946
		[2] 2910	Red sandy shale and gray sandy limestone.		
		[2] 2920	Light brick red, very sandy clay. Some extremely fine grained red sand. Some light gray calcareous, very fine grained sand.		
		[2] 2940	Red sandy shale and light purplish gray limestone.	Hard green sand.	2946-2953
		[1] 2946	Fine light greenish sand consisting of subangular to subrounded grains of quartz. Some very small, most of them between 0.02 and 0.13 mm., largest reaching to 0.21 mm. Color of most grains faint green and gray green; a few salmon and red. Smaller grains appear colorless. Lenses and flakes of green clay and flesh colored clay, $\frac{1}{16}$-in to $\frac{3}{8}$-inch in diameter; some slightly sandy. Cemented but not calcareous.		
		[2] 2950	A very few chips of red sandy shale.		

[1] Core. [2] Cuttings.

RECORD OF SWOFFORD NO. 1 WELL—Continued

Age	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log	
				Material	Depth, Feet
Lower Cretaceous (Comanche series).	Trinity formation.	[4] 2950	Fine grained, light gray sandstone with bedding plane streaks of light greenish gray clay, which color the sandstone as a whole a faint green. One pellet of shale ¼-inch long by ⅛-inch thick.	Red sand.	2953-2955
		[1] 2955	Brick red argillaceous, extremely fine grained sandstone. Contains a few small pellets of red shale. Numerous very small light greenish gray spots.	Broken lime, yellow.	2955-2971
		[2] 2960	Light brick red sandy calcareous shale.		
		[2] 2961	Dark brick red, very fine grained clayey sandstone.		
		[2] 2970	Brick red, sandy, slightly calcareous shale.		
		[4] 2981	Very fine grained hard, cinnamon colored sandstone containing practically no clay. Most grains subangular. Subrounded flesh colored and white grains of quartz. Some small, dark grains. A few small flakes of dark brick red sandy shale.	Dark red iron ore rock.	2971-2988

[1] Core. [2] Cuttings. [4] Large pieces. Well abandoned at 2,988 feet.

It is unfortunate that the cores reported taken at a depth of 1,057 feet in sandy lime and 1,065-1,075 feet in red gumbo (first red) were lost by the operators and were therefore not available. The 105 feet of red beds between depths of 1,065 and 1,170 feet may include part of the Woodbine formation.

The cuttings of brick-red calcareous sandy shales, calcareous sandstone, and gray limestone taken from the lower part of the well appear to be different from the Trinity outcrop but resemble somewhat the cuttings and samples taken from the lower part of the Grote well, in Sec. 2, T. 13 S., R. 31 W. Until evidence to the contrary is furnished by fossils these deep red beds must be regarded as of Trinity age. There is need of cores of deep formations logged as lime or lime rock, from which fossiliferous material might be obtained.

RECORD OF SECREST AND ALLEN, DUCKETT NO. 1 WELL, IN THE SW¼, SW¼, SEC. 24, T. 13 S., R. 24 W. ELEVATION 375 FEET

Age	Formation	Driller's Log: Material	Driller's Log: Depth, Feet
Eocene.	Wilcox formation.	Sand	0 to 10
		Lignite	16
		Rock	17
		Sand	25
		Red clay	42
		Shale	60
		Rock	61
	Midway formation.	Shale	110
		Gumbo	122
		Shale	160
		Gumbo	212
		Shale	314
		Rock	315
		Gumbo	346
		Shale	432
		Rock	433
Upper Cretaceous (Gulf series).	Arkadelphia marl.	Gumbo	461
		Shale	510
		Gumbo	546
		Shale	602
		Gumbo	626
		Shale	644
	Nacatoch sand.	Sand; small show of oil	790
		Gumbo	822
		Brown lime rock	828
		Shale	836
		Brown lime	840
		Gumbo	856
		Brown lime	864
		Gumbo	872
		Sandy rock	880
		Gumbo	892
		Gypsum	910
		Soft rock	930
		Sandy gumbo	938
		Sandy shale	965
		Hard shale	980
	Saratoga chalk.	Chalk mixed with shale	992
		Chalk rock	1012
	Marlbrook marl.	Shale	1038
		Chalk rock	1047
		Shale and gumbo	1070
		Soft chalk	1093
		Chalk rock	1098
		Gumbo	1107
		Sandy shale; shells carrying pyrites and chalk	1196
		Chalk and gumbo	1258
	Annona chalk.	Hard chalk and pyrites	1261
		Soft chalk	1302
		Hard chalk	1312
	Ozan formation.	Gumbo	1348
		Shale and chalk	1378
		Rock	1380
		Gypsum	1394
		Gumbo, "bear hide"	1410
		Shale, mixture shells	1440
		Rock	1442
	?		
	Brownstown marl.	Shale	1478
		Tough gumbo	1490
		Sand rock	1491
		Shale	1516
		Shale, thin layers of rock	1533
		Sand rock	1536
		Sand and shale	1544
		Gumbo	1553
		Sand rock	1555
		Gumbo	1572
		Sand, sandy shale and shells carrying pyrites	1609
		Shale and gumbo	1621

RECORD OF SECREST AND ALLEN, DUCKETT NO. 1 WELL—Continued

Age	Formation	Driller's Log	
		Material	Depth, Feet
Upper Cretaceous (Gulf series).	Tokio formation.	Soft rock	1625
		Packed sand and pyrites	1631
		Sand rock and pyrites	1669
		Very hard pyrites	1672
		Gray pack sand	1690
		Black gumbo	1700
		Sand rock	1706
		Hard sand, showing of gas	1765
		Sand	1770
		Sand rock	1772
		Gumbo	1788
	?		
	Woodbine formation (?).	Sand rock	1796
		Pack sand	1824
		Gumbo	1832
		Sand rock	1836
		Gumbo	1840
		Shale	1845
		Gumbo	1853
		Packed sand	1861
		Sand rock and hard pyrites	1868
		White lime	1872
		Red shale	1886
		Gumbo	1903
		Gray shale	1922
	?		
Lower Cretaceous (Comanche series).	Trinity formation.	Red gumbo	1964
		Sand rock	1965
		Shale	1970
		Red gumbo	1988
		Lime rock	1990
		Shale	1995
		Lime rock	1997
		White gumbo	2008
		Soft shale	2030
		Gumbo	2038
		Rock	2039
		Gumbo	2078
		Shale and gumbo	2105
		Lime rock	2110
		White gumbo	2114
		Lime rock	2115
		Gumbo	2137
		Packed sand	2144
		Rock	2145
		Hard sand	2154
		Rock	2159
		Sand	2165
		Rock	2166
		Sand and shale	2179
		Gumbo and shale	2180
		Lime	2190
		Lime	2224
		Fishing	2254

RECORD OF HOPE WELL NO 4. OF HOPE WATER AND LIGHT PLANT, HOPE, ARK.

(Drilling begun August, 1914; well completed April 20, 1916. Elevation of surface above sea level, about 355 feet. Driller's record furnished by Charles M. Richards, superintendent of plant. Description of samples by H. D. Miser. No sample taken above 565 feet was preserved.)

Age	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log: Material	Driller's Log: Thickness, Feet	Driller's Log: Depth, Feet
Quaternary				Soil.	10	10
				Sand.	2	12
Eocene.	Midway formation.			Clay, yellow.	23	35
				Clay, blue.	17	52
				Shale, black.	23	75
				Gumbo, blue.	27	102
				Rock, hard, shell-like.	1	103
				Shale, black.	32	135
				Shale, gray.	43	178
				Shale, black.	52	230
				Rock, hard, shell-like.	1	231
Upper Cretaceous (Gulf series).	Arkadelphia marl.			Shale, gray.	139	370
				Rock, hard.	8	378
	Nacatoch sand.			Shale, sandy.	14	392
				Rock, hard.	36	428
				Rock, soft sand.	25	353
				Rock, hard.	4	457
				Rock, hard sand.	8	465
				Rock, sand, soft, water-bearing.	85	550
				Shale, blue.	10	560
		565-570	Some small pieces of soft calcareous glauconitic fine grained sandstone. The glauconite in these pieces is so abundant that the sandstone is dark gray. Most of the sample is glauconite, which has become concentrated in the drilling; it is black with a greenish cast. Some fragile fossil-remains in the small pieces of sandstone.			
		570-575	Greenish gray calcareous fine grained earthy sand containing some glauconite.			
		575-580	Greenish gray glauconitic, calcareous, fine grained sand containing small pieces of shells.			
		580-583	Greenish gray glauconitic fine grained calcareous sand in which are small pieces of shells.	Sand rock, black.	40	600
		583-590	Greenish gray glauconitic, calcareous, fine grained sand.			
		590-600	Greenish gray glauconitic, calcareous, earthy, fine grained sand.			
		600-620	Greenish gray glauconitic, calcareous, earthy, fine grained sand.			

RECORD OF WELL NO. 4 OF HOPE WATER AND LIGHT PLANT—Continued

Age	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log: Material	Thickness, Feet	Depth, Feet
Upper Cretaceous (Gulf series).	Nacatoch sand.	620-650	No sample.	Shale, blue.	50	650
		650-695	Gray calcareous sandy earth (marl).	Shale, sandy.	50	700
	Saratoga chalk.	695-710	Gray soft, highly calcareous earth, which slacks readily in water.			
		710-728	Gray soft, highly calcareous earth, which slacks readily in water.	Rock, soft lime.	25	725
	Marlbrook marl.	728-770	Gray, soft, highly calcareous fossiliferous earth, which slacks readily in water. Light gray, much lighter in color than the two preceding samples.	Shale, brown.	125	850
		770-805	Gray soft calcareous clay; two pieces of fibrous vein calcite or aragonite in sample.			
		805-900	Gray soft calcareous clay like that just above.	Shale, slate.	40	890
		900-925	Gray soft calcareous clay.			
		925-950	Gray soft calcareous clay.	Shale, blue.	60	950
		950-980	Very light gray calcareous clay; chalky in appearance but highly plastic.	Gumbo, white.	65	1015
		980-1015	Gray calcareous clay, not so light as that just above. Two or three pieces of a shell and one specimen of a foraminifer in sample.			
	Ozan formation.	1015-1037	Bluish gray fossiliferous calcareous clay. Some fine gray sand and much pyrite. About a dozen foraminifera were found.	Shale, blue.	10	1025
		1037-1040	Contains one piece of hard, fossiliferous dark gray limestone. Also calcareous sandy earth and fragments of fossils. Very small sample.	Shale, black.	15	1040
		1040-1080	Gray micaceous sandy, calcareous earth containing some pieces of shells. Two pieces of hard, dark gray limestone like that in preceding sample. Several specimens of foraminifera were found.	Rock, hard.	2	1042
				Shale, blue.	18	1060
		1080-1110	Dark gray calcareous clay, fine quartz sand, and some glauconite. Two or three foraminifera were seen.	Sand rock, soft.	40	1100

RECORD OF WELL NO. 4 OF HOPE WATER AND LIGHT PLANT—Continued

Age	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log: Material	Thickness, Feet	Depth, Feet
Upper Cretaceous (Gulf series).	Ozan formation.	1110-1128	Mixture of different kinds of material. One subangular pebble of novaculite 1½ inches in diameter; most of larger pieces are micaceous dark gray calcareous sandy clay; few of larger pieces are glauconitic calcareous sandstone; fine material is glauconite and sand. Some minute fossils and foraminifera. One spine probably of a sea urchin.	Shale, blue.	25	1128
		1128-1140	Gray sandy, micaceous fossiliferous calcareous clay.			
		1140-1190	Mixture. Comminuted shells, among which is a shark tooth; glauconitic, calcareous sand like first sample; dark gray calcareous, fossiliferous, micaceous clay; and two small dark flint pebbles (3 mm. in diameter); loose glauconite and sand grains. Sand grains are translucent, well rounded to subangular, and 0.5 mm. or less in diameter. Foraminifera.	Shale, sandy.	75	1200
	Brownstown marl.	1190-1365	Dark gray calcareous clay. One rather perfect pelecypod.	Shale, blue. Shale, blue. Gumbo, red. Shale, blue.	25 45 15 60	1225 1285 1300 1360
	Tokio formation.	1365-1383	Dark gray slightly calcareous clay, pieces of lignitiferous matter, and very small amount of quartz sand.	Shale, blue. Gumbo, red. Shale, blue.	45 15 60	1285 1300 1360
		1383-1389	Gray quartz sand. The grains are angular and subangular. Average diameter is less than 0.25 mm. Considerable pyrite. Some pyrite cements sand grains together. Lignitiferous matter. Mixed with sand are some pieces of clay like that in bed above.	Gumbo.	30	1390
		1389-1400	Chiefly dark gray calcareous clay, some pieces of which are fossiliferous. Part of sample is sand like that in preceding sample. A little lignitiferous matter.			

RECORD OF WELL NO. 4 OF HOPE WATER AND LIGHT PLANT—Continued

Age	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log: Material	Driller's Log: Thickness, Feet	Driller's Log: Depth, Feet
					57	1447
Upper Cretaceous (Gulf series).	Tokio formation.	1400-1415	Contains some lignitiferous matter and a few pieces of clay like that above, but is mostly glauconitic, very fine grained quartz sand.	Sand rock, soft.		
Upper Cretaceous (Gulf series).	Tokio formation.	1415-1420	A complex mixture. Calcareous sandy clay and fine quartz sand in almost equal quantities, a few pieces of lignitiferous matter, a few pieces of glauconitic, calcareous sand like first sample, and some pieces of shells. The minor constituents are probably foreign to the beds at this depth. Several foraminifera.			
Upper Cretaceous (Gulf series).	Tokio formation.	1420-1430	Very fine gray quartz sand and a little glauconite. Sand grains subangular.			
Upper Cretaceous (Gulf series).	Tokio formation.	1430-1432	No sample.			
Upper Cretaceous (Gulf series).	Tokio formation.	1432-1480	Angular to subangular quartz sand, grains averaging less than 0.25 mm. in diameter. A little pyrite and glauconite are present. Mr. Richards says this is water-bearing sand yielding 400,000 gallons a day and that, before pumping, the water rose to within 32 feet of surface.	Shale, sandy. Sand rock, soft.	23 10	1470 1480
Upper Cretaceous (Gulf series).	Tokio formation.	1480	White sand, washed more than the preceding sample.			
Upper Cretaceous (Gulf series).	Tokio formation.	1481-1487	Sample consists of four pieces of firm rock, which is sandy, micaceous, glauconitic, calcareous, and laminated. One piece shows what appears to be a good fossil foraminifer or some other simple organism. Pyrite is seen in small crystals in three pieces and on one it is abundant. This rock would probably be classed as an impure sandstone.	Sand rock, hard.	20	1500

RECORD OF WELL NO. 4 OF HOPE WATER AND LIGHT PLANT—Continued

Quaternary	Formation	Depth at Which Sample Was Obtained, Feet	Character of Sample	Driller's Log: Material	Driller's Log: Thickness, Feet	Driller's Log: Depth, Feet
		1300-1500	Pieces of carbonized wood, which were picked out of the drillings through about 200 feet. While at Hope Mr. Miser saw one piece of wood 3 or 4 inches long, obtained at this horizon.			
	Tokio formation.	1487-1495	Sample consists chiefly of fine, white quartz sand. A little glauconite, some pyrite, and a few feldspar grains are present. One piece of a shell is in sample. A large number of pieces of dark calcareous clay.			
		1495-1501	A drab micaceous sandy clay.			
	?					
Upper Cretaceous (Gulf series).		1501-1585	Mixture in about equal amounts of micaceous, sandy, greenish gray earth and micaceous, calcareous, glauconitic sand containing here and there some small kaolinized feldspar. A few small crystals of pyrite.	Shale, blue. Gumbo Shale, sandy.	30 10 45	1530 1540 1585
		1585-1595	Mixture of drab clay with a smaller amount of red clay. Contains small amounts of pyrite, quartz sand and a few fragments of shells, but these are probably foreign.			
	Woodbine formation.	1595-1610	Mixture of red clay (chiefly) with some sandy, drab clay and loose glauconitic quartz sand. All but the red clay are probably foreign.	Gumbo, red.	20	1605
		1610-1675	Main constituent, red clay. The minor constituents are drab colored sandy clay, sand, pyrite, and lignitiferous matter. Three specimens of foraminifera were found.	Rock, hard. Gumbo. Rock, soft.	10 35 25	1615 1650 1675
		1675-1700	Fine, angular quartz sand makes up most of the sample. Some red clay and some dark clay. Three specimens of foraminifera.	Rock, hard.	25	1700
?	?					

Numerous samples of the Trinity formation from this well are described by Miser in Miser, H. D., and Purdue, A. H., Asphalt deposits and oil conditions in southwestern Arkansas: U. S. Geol. Survey Bull. 691, p. 275, 1918.

RECORD OF HENRY NO. 1 WELL, DRILLED BY LAWSON ARKANSAS SYNDICATE (ALLEN OIL COMPANY), IN THE SE¼ SE¼ OF SEC. 30, T. 12 S., R. 23 W.

Age	Formation	Driller's Log	
		Material	Depth, Feet
Quaternary		Shale and gravel.	48
Eocene	Midway formation.	Hard, blue gumbo.	115
Upper Cretaceous (Gulf series).	Arkadelphia marl.	Shale; streaks of blue gumbo.	502
	Nacatoch sand.	Hard sand rock.	505
		Gumbo.	520
		Sand rock.	542
		Shale and streaks of gumbo.	563
		Hard sand rock; gas.	583
		Gumbo.	618
		Hard sand rock.	632
		Black shale.	666
		Gumbo.	672
		Lime rock; streaks of hard packed sand.	690
		Blue-gray gumbo; streaks of black shale.	720
		Very hard white gumbo showing much lime and thin streaks of black shale.	786
		Hard, gray gumbo and streaks of hard lime rock.	828
	Saratoga chalk.	Soft lime and occasional hard streaks.	872
	Marlbrook marl.	Dry, hard, flaky, black shale.	880
		Lime rock and breaks of gumbo.	1069
	Annona chalk (?)	Chalk.	1100
	Ozan formation.	Tough gumbo.	1118
		Dark brown shale.	1140
		Hard shale.	1160
		Shale and boulders.	1183
		Dark brown shale.	1300
		Brown rock.	1320
	Brownstown marl.	Soft shale.	1325
		Gumbo.	1344
		Shale and shell.	1386
		Gumbo.	1404
		Shale.	1419
		Gumbo.	1459
		Brown shale.	1493
		Lime rock.	1496
	Tokio formation.	Broken formation; sand and shale.	1516
		Sand rock and shale.	1526
		Sand rock.	1545
		Sand rock and pyrites.	1596
		Tough gumbo.	1605
		Brown rock and pyrites.	1614
		Sand and pyrites.	1622
		Shale and boulders.	1630
		Lime and shale.	1638
		Tough gumbo.	1647
		Brown shale.	1658
		Sand, gas.	1676
	?		
	Woodbine formation (?).	Brown red rock and shell; pyrites; much gas.	1698

RECORD OF HENRY NO. 1 WELL—Continued

Age	Formation	Driller's Log: Material	Driller's Log: Depth, Feet
Upper Cretaceous (Gulf series).	Woodbine formation (?).	Hard, brown shale.	1705
		Hard, brown rock and pyrites.	1710
		Hard sand; gas rock.	1716
		Water sand.	1717
		Rock and pyrites.	1730
		Brown and black shale.	1750
		Lime and shale.	1760
		Broken lime.	1775
		Water gravel.	1778
		Lime and shale.	1833
Lower Cretaceous (Comanche series).	Trinity formation.	Hard lime mixed with shells.	1892
		Red shale.	1940
		Red gumbo.	1950
		Red shale.	1980
		Sand rock.	1992
		Gumbo and gypsum.	1998
		Sand rock and pyrites.	2040
		Gumbo.	2050
		Sand rock.	2056
		Gumbo and gypsum.	2065
		Sandy red shale.	2113
		Tough gumbo.	2135
		Broken sandy shale, and gas.	2152
		Gumbo.	2157
		Red shale.	2190
		Broken sand and shale.	2226
		Black lime gas; small breaks.	2261
		Blue shale.	2324
		Hard sand.	2333
		Sand shale; show of gas a d water.	2342
		Sand shale and streaks of hard sand.	2376
		Rock.	2375
		Shale and broken streaks of rock.	2405
		Lime.	2413
		Hard sand; mixed red and blue shale.	2436
		Hard sand rock.	2444
		Mixed shale; red, black, blue, and white.	2452
		Lime rock.	2461
		Hard sand, brown, cemented (6 inches).	2530
		Red and brown shale.	2590
		Soapstone.	2601
		Hard sand.	2611
		Water sand.	2620
		Tough red gumbo.	2636
		Mixed shale.	2644
		Sand and lime.	2660
		Brown shale.	2668
		Red, hard sand and mixed lime.	2670
		Brown shale and mixed gray shale.	2690
		Brown shale and mixed asphalt.	2708
		Hard lime.	2718
		Mixed shale.	2733
		Hard sand rock.	2770
		Shale mixed with soft lime.	2776
		Red sand rock, hard.	2778
		Hard, red sand, rock.	2790
		Hard sand mixed with lime, red; gas showing in bottom.	2853
		Lime and shells mixed.	2870

APPENDIX B

In February, 1923, the United States Geological Survey published[91] the results of a detailed examination of a complete set of samples from every 10 feet penetrated to a depth of 2,143 feet by the Ingram No. 5 well of the Standard Oil Company of Louisiana in the El Dorado field in Arkansas. The proportions of sand, clay, and calcium carbonate in each sample were estimated and plotted in a percentage log, as shown in Plate XXIX, which is reproduced from the plate accompanying the original report. Mineralogic examination was made of each sample and the fossils found were determined by Dr. Stephenson and Dr. Julia Gardner, of the United States Geological Survey. As a result of this work the beds penetrated were divided into ten lithologic zones, as indicated in the plate. A description of the lithology of each zone is given in the publication cited. Zones 1 and 2 were correlated with the Yegua formation, zone 3 with the St. Maurice formation, zones 4, 5 and 6 with the Wilcox formation, zones 7 and 8 with the Midway formation, and zones 9 and 10 with the Arkadelphia marl of Cretaceous age. Since the publication of this correlation a subdivision of the Claiborne group has been found practicable in northern Louisiana,[92] and a more detailed description of the Eocene and uppermost Cretaceous formations is now available.

The careful description of the lithology of the formation in the Ingram No. 5 well permits the correlation of the lithologic zones found in that well with the divisions recognized by Spooner[93] in the stratigraphic sequence. The sandy shale and sand of zones 1 and 2 represent the Yegua formation, of the Claiborne group. The lignitic sandy shale of zone 3 appears to correspond with the St. Maurice beds of Spooner,[94] the equivalent of the upper part of the St.

[91] Gilluly, James, and Heald, K. C., Stratigraphy of the El Dorado oil field, Arkansas: U. S. Geol. Survey Bull. 736, pp. 241-248, 1923.

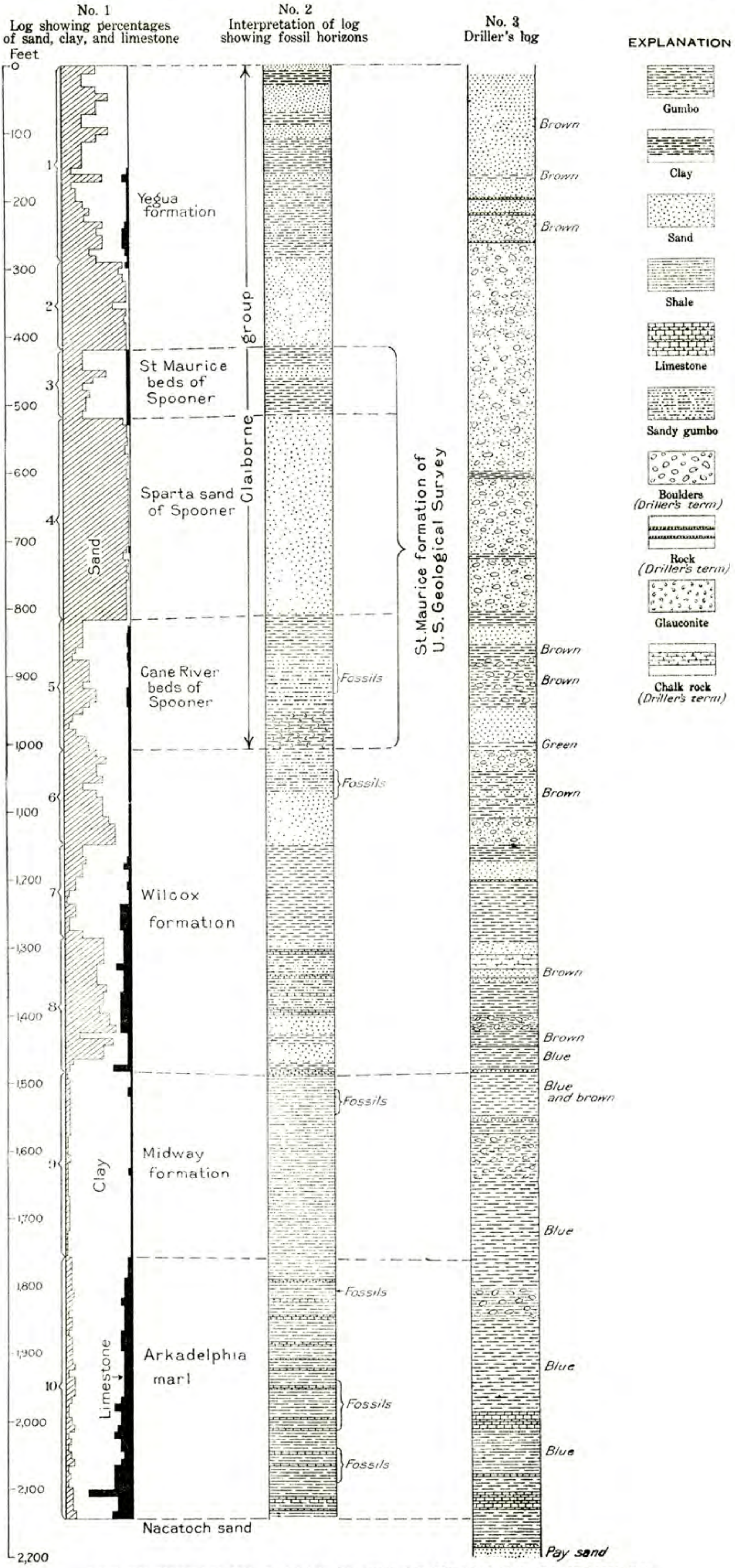
[92] Spooner, W. C., Interior salt domes of Louisiana, in Geology of salt dome oil fields, by DeGolyer and others, 1926.

[93] U. S. Geological Survey has not yet adopted this classification of formations.

[94] Spooner, W. C., idem.

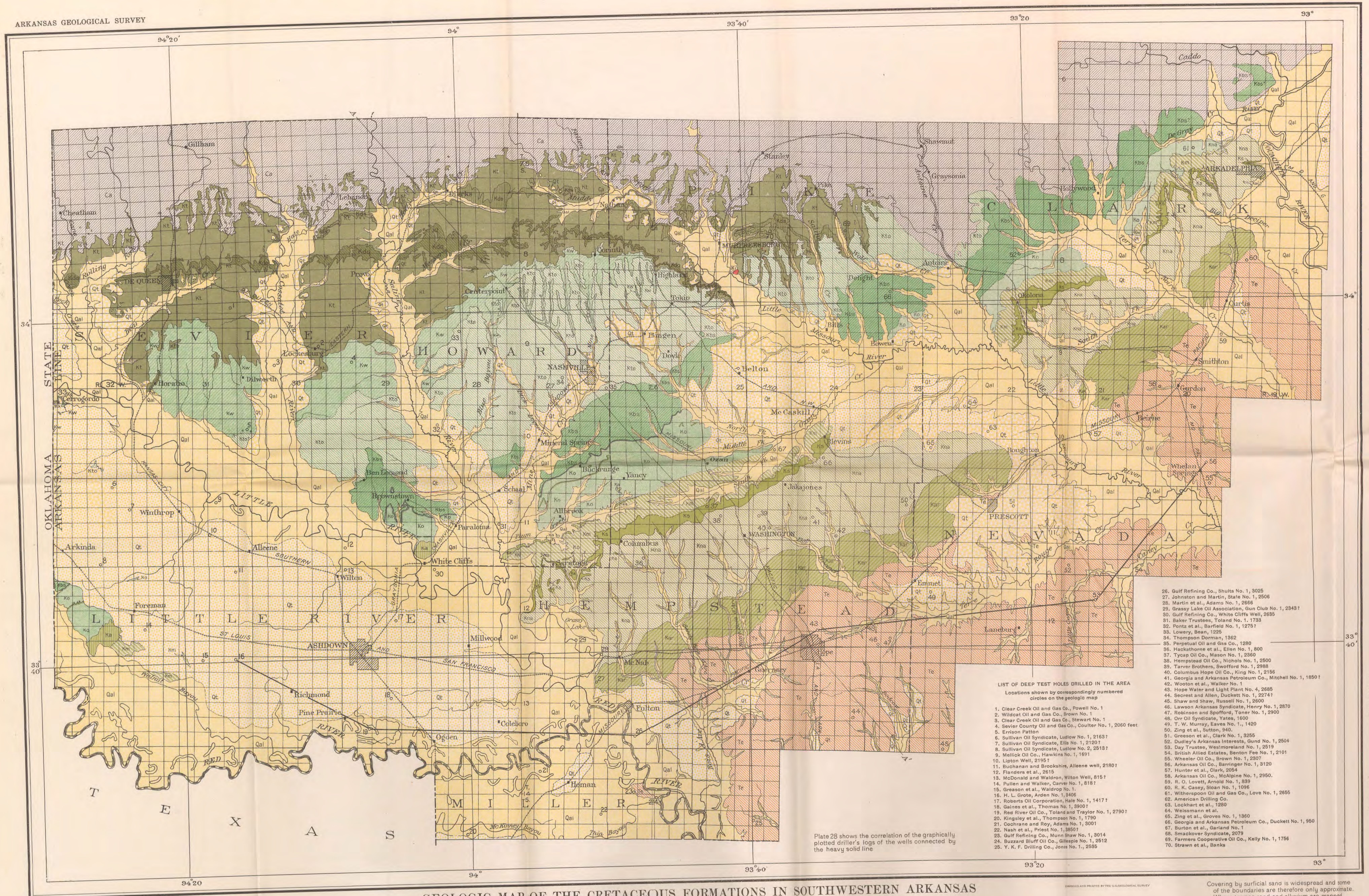
Maurice formation as defined by Harris.[95] Zone 4 is apparently the Sparta sand of Spooner.[96] Zone 5, which is distinguished by the presence of glauconite and calcium carbonate, the glauconite being especially abundant in the lower 20 feet, answers to the description of the Cane River beds of Spooner.[97] The lignitic shaly sands of zones 6, 7, and 8 are lithologically like the Wilcox formation, and Miss Gardner reported a typical Wilcox association of forms[98] in the upper part of zone 6. The practically pure clay of zone 9 corresponds well with the lithology of the Midway on the outcrop in southwestern Arkansas as described in this report, and zone 10 is clearly Upper Cretaceous, as L. W. Stephenson identified a fragment of *Inoceramus* in a sample representing a depth of 1,760 feet.[99] The lithology of zone 10 agrees well with that of the Arkadelphia marl on the outcrop in southwestern Arkansas. The striking way in which the lithologic zones in this well correspond with the formations now recognized is a convincing proof of the value of this method of investigation.

[95] Harris, G. D., The St. Maurice and Claiborne stages: Am. Paleont., vol. 6, No. 31, 1919.
[96] Spooner, W. C., op. cit.
[97] Spooner, W. C., idem.
[98] Gilluly, J., and Heald, K. C., op. cit., p. 345
[99] Idem, p. 246.



LOG OF INGRAM NO. 5 WELL OF THE STANDARD OIL COMPANY OF LOUISIANA, IN THE EL DORADO FIELD, ARKANSAS

INDEX



GEOLOGIC MAP OF THE CRETACEOUS FORMATIONS IN SOUTHWESTERN ARKANSAS

Prepared by the U. S. Geological Survey

Scale 1: 250,000

10 0 10 Miles

1928

Base map assembled from township plats of U. S. General Land Office by Section of Cartography, U. S. Geological Survey

EXPLANATION

SEDIMENTARY ROCKS

QUATERNARY

Recent — Qal — Flood-plain deposits (*Silt, sand, and gravel*)

Pleistocene — Qt — Sand and gravel terraces and terrace remnants at several levels. Probably includes some Pliocene terraces

TERTIARY

Eocene — Te — Midway formation (*dark noncalcareous clay*) and Wilcox formation in part (*Sand, clay, and lignite*)

UNCONFORMITY

CRETACEOUS

Upper Cretaceous (Gulf series)

Kar — Arkadelphia marl (*Dark-gray fossiliferous marl*)

UNCONFORMITY

Kna — Nacatoch sand (*Chiefly quartz sand; some glauconitic sand and gray clay*)

UNCONFORMITY

Ks — Saratoga chalk (*Chiefly white sandy chalk; some sandy marl and clay*)

UNCONFORMITY

Km — Marlbrook marl (restricted) (*Dark, pure marl*)

Ka — Annona chalk (*White chalk*)

Ko — Ozan formation (*Dark sandy micaceous marl and marly sand; Buckrange sand lentil (glauconitic) at the base and a thicker glauconitic bed*)

UNCONFORMITY

Kbs — Brownstown marl (restricted) (*Dark marl with sandy marl east of the Little Missouri River*)

UNCONFORMITY (OVERLAP)

Kto — Tokio formation (*Intertonguing beds of gray clay and quartz sand, with some lignite and a basal bed of novaculite gravel*)

UNCONFORMITY

Kw — Woodbine formation (*Tuff and tuffaceous sand, with a basal gravel and other gravel beds; some red and dark clay*)

UNCONFORMITY

Lower Cretaceous (Comanche series)

Kk — Kiamichi clay (*Fossiliferous marl and shell breccia*)

Kg — Goodland limestone (*Hard, sandy gray limestone*)

Kt — Trinity formation (*Fine-grained quartz sand, variegated clay, limestone, marl, gypsum, and novaculite gravel*) (*Limestones separately mapped*) — Dierks limestone lentil; De Queen limestone member

UNCONFORMITY

CARBONIFEROUS

Mississippian and Pennsylvanian

Ca — Atoka formation, Jackfork sandstone, and Stanley shale (*Folded and faulted hard shale and sandstone*)

IGNEOUS ROCKS

CRETACEOUS

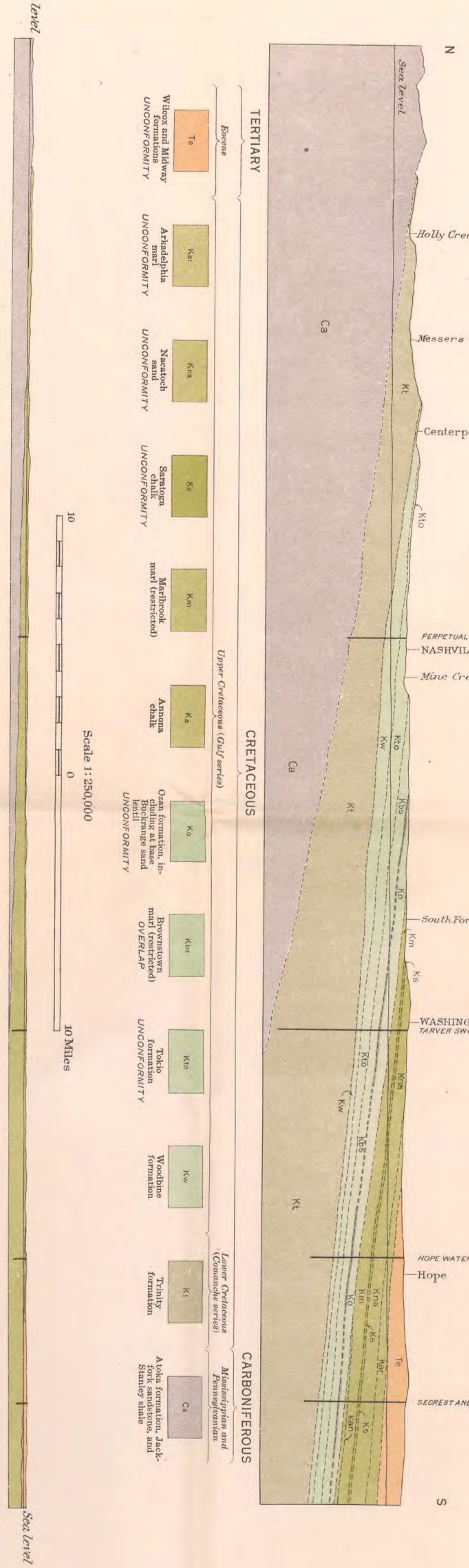
Ki — Peridotite plugs

Covering by surficial sand is widespread and some of the boundaries are therefore only approximate. Where terrace sand and alluvium are mapped concealment is practically complete

Geology by C. H. Dane and P. D. Torrey, 1926

North of latitude 34° and west of longitude 93°30' by H. D. Miser and A. H. Purdue

Mapping of the Annona chalk at Rocky Comfort and White Cliffs adapted from J. A. Taff



GEOLOGIC SECTION (ALONG LINE A-A' IN PLATE 1) FROM NORTHWEST TO SOUTHEAST ACROSS THE CRETACEOUS OUTCROP IN SOUTHWESTERN ARKANSAS

(NATURAL AND EXAGGERATED SCALE)

BASED ON SURFACE MAPPING AND INTERPRETATION OF FOUR WELL RECORDS

VERTICAL SCALE OF EXAGGERATED SECTION ABOUT NINE TIMES

Eocene — Cretaceous — Carboniferous

Scale 1: 250,000

10 0 10 Miles

TABULATED CORRELATIONS OF DEEP TEST WELLS IN PART OF SOUTHWESTERN ARKANSAS

Well No.	Operator	Lease and Number	Part of Section	Section	Twp. South	Range West	Elevation	Surface Formation	Depth to Top of Midway	Depth to Top of Arkadelphia	Depth to Top of Nacatoch	Depth to Top of Saratoga	Depth to Top of Marlbrook	Depth to Top of Annona	Depth to Top of Ozan	Depth to Top of Brownstown	Depth to Top of Tokio	Depth to Top of Woodbine	Depth to Top of Trinity	Total Depth	Notes
	LITTLE RIVER COUNTY																				
7	Sullivan Oil Syndicate	Ellis No. 1	NE corner	15	11	32		Terrace sand (Tokio)										320?	590?	2120?	
8	Sullivan Oil Syndicate	Ludlow No. 2	SE corner	32	11	32		Terrace sand (Brownstown)									156	457?	675?	2513?	
14	Pullen & Walker	Carver No. 1		26	12	32		Terrace sand (Annona?)							?	?	420	Log incomplete	Not reached	818?	
10		Lipton well		22	11	31		Alluvium, terrace sand (Brownstown)									?	476	704?	2195?	
11	Buchanan & Brookshire	Alleene well		2	12	31		Terrace sand (Brownstown)									205	505	739	2180?	
16	Hermann L. Grote	Arden No. 1	NE corner	2	13	31		Alluvium, terrace sand (Marlbrook)						225	380	612	812	1114	1358	3406	Kiamichi clay and Goodland limestone from 1,256 to 1,358. The correlation of this log and description of cuttings are given on pages 183 and 184.
13	McDonald & Waldron	Wilton well	NW corner	6	12	29		Alluvium, terrace sand (Annona?)							?	?	430	695?		815?	
17	Roberts Oil Corporation	Hale No. 1	NW¼ of SE¼	22	12	29		Terrace sand (Marlbrook)						?	?	?	648	899?	1092	1417?	
18	Gaines et al.	Thomas No. 1		15	13	29		Terrace sand (Nacatoch)				Absent?	265	?	?	?	1020	1305?	1398?	3900?	
19	Red River Oil & Gas Leasing & Drilling Company	Toland and Traylor No. 1	NE¼ of SE¼	29	13	29		Alluvium (Nacatoch)				Absent?	340	?	790	?	1172	1479[1]	1624?	2790?	
30	Gulf Refining Company	White Cliffs well		6	12	28		Alluvium (Annona)							21	?	383	690	797?	2635	This correlation differs somewhat from that given by H. D. Miser in U. S. Geological Survey Bulletin 691J, 1918.
	HOWARD COUNTY																				
31	Baker Trustees	Toland No. 1	NE¼ of NW¼	23	11	28	270?	Terrace sand (Ozan)								84	200[2]	499[3]	607	1733	
32	Pontz et al.	Barfield No. 1 or Peevers No. 1	300 feet S. and W. of NE corner of SE¼ of NW¼	18	10	28		Alluvium (Tokio)										118[4]	365	1275?	
33	Lowery Bean		NE¼	17	9	28		Woodbine											130	1225	
34	Thompson-Dorman			33	9	27		Terrace sand (Tokio)										187	525?	1362	
35	Perpetual Oil & Gas Company		SE¼	36	9	27	358	Alluvium, terrace sand (Tokio)										122½	460	1280	Amended from correlation of H. D. Miser.[5] Paleozoic encountered at 1,260 feet.
	MILLER COUNTY																				
20	Kingsley et al. (Kriss et al.?)	Thompson No. 1		33	14	28		Terrace sand (Wilcox)	155?	?	614									1796	Log incomplete.
24	Buzzard Bluff Oil Company	Gillespie No. 1	SW corner	22	14	26	255	Terrace sand (Midway?)		520[6]	653	?	Indeterminate	1308	1377	1544	1786	2006?	2238?	2512	
21	Cochrane & Roy	L. C. Adams No. 1		8	14	27	328	Alluvium (Midway)		?	310	Absent	710	1005	?	1240?	1435	1700	1905	3001	
23	Gulf Refining Company	Munn-Shaw No. 1	200 feet N. and 300 feet W. of SE corner	17	14	26	296.7	Terrace sand (Midway)		425	571	?	995	?	?	1530	1698	1931	2173	3014	
	HEMPSTEAD COUNTY																				
29	Grassy Lake Oil Association	Hempstead County Gun Club No. 1	450 feet N. and 60 feet W. of SE corner of SW¼ of SE¼	27	12	27	267	Alluvium (Nacatoch)				157	Indeterminate	?	?	?	880	1138	?	2343?	
28	Martin et al.	Adams No. 1	S½	36	12	27	325	Nacatoch				?	300	?	508	727	984	1265	1400	2666	See footnote 7.
27	Johnston & Martin	State No. 1	NW corner of SW¼	12	13	27	285	Terrace sand (Nacatoch)				420	Indeterminate	?	715	925	1117	1423	?	2506	
26	Gulf Refining Company	Shults No. 1	300 feet S. and 500 feet E. of NW corner	33	13	26	256.7	Terrace sand (Midway)		?	253	695	730	913	938	?	1335	1629	1915	3025	The driller's log and description of cuttings from this well are given on pages 185 to 187.
37	Tycap Oil Company	Mason No. 1	300 feet N. and 300 feet W. of SE corner	7	11	25	400?	Marlbrook						Absent	165	?	645	920?	?	2360	
39	Tarver Brothers	Swofford No. 1	200 feet N. and W. of SE corner of NW¼	14	11	25	437	Nacatoch				170	204	Absent	362	650	846	965?	1065	2988	The driller's log and a description of cuttings from this well are given on pages 188 to 196.
38	Hempstead Oil Company	Nichols No. 1	S½ of SE¼ of NE¼	17	11	25		Nacatoch				?	95	Absent	284	512	730	847?	?	2500	
40	Columbus Hope Oil Company	King No. 1	NW¼ of NW¼	24	11	25	390?	Nacatoch				?	227	Absent	470	664	890	1015?	?	2156	
25	Y. K. F. Drilling Company	Jones No. 1	330 feet N. and W. of SE corner of NW¼ of SW¼	26	14	25	343	Wilcox	?	770	935	?	?	?	?	1841	2059	2275?	2435?	2535	
66	Georgia & Arkansas Petroleum Company	Duckett No. 1	NW¼	28	10	24		Terrace sand (Saratoga)					52	Absent	201	?	642	Probably absent	821	950	
41	Georgia & Arkansas Petroleum Company	Mitchell No. 1	SW¼ of NW¼	16	11	24		Nacatoch				?	280	Absent	495	?	840	985?	?	1850?	
44	Secrest & Allen	Duckett No. 1	SW¼ of SW¼	24	13	24	375	Wilcox	61	433?	644	980	1012	1258	1312	1442?	1621	1788?	1922?	2274?	The driller's log and correlation of this well are given on pages 197 and 198.
43	Hope Water and Light Plant	Well No. 4		28	12	24	355	Terrace sand (Midway)		231	378	700	725	Absent	1015	1190	1365	1501?	1700?	2685	This correlation is corrected from that of H. D. Miser in U. S. Geological Survey Bulletin 691J. The driller's log and description of cuttings are given on pages 199 to 203.
47	Robinson & Spofford	Toner No. 1	200 feet N. and E. of SW corner of NE¼	29	12	23	325	Midway		?	348	683	700	Absent	?	?	1350	Probably absent	1510[8]	2900	
46	Lawson Arkansas Syndicate (Allen Oil Company)	Henry No. 1	SE¼ of SE¼	30	12	23	442	Terrace sand (Midway)		?	502	828	872	1069	1100	1320	1496	1676?	?	2870	The driller's log and correlation of this well are given on pages 204 and 205.
	PIKE COUNY																				
68	Smackover Syndicate			31	8	23		Terrace sand (Brownstown)									110	Absent	193	2073	Reached Paleozoic rocks at 340 feet.
	NEVADA COUNTY																				
65	Zing et al.	Grove No. 1		22	10	23		Terrace sand (Nacatoch)				?	?	Absent	?	?	725?	Probably absent	1036	1360	
49	T. W. Murray	Eaves No. 1		11	12	23	290?	Terrace sand (Midway)		160	288	?	612	Absent	?	1082	?			1420	
45	Shaw & Shaw	Russell No. 1	NE corner of SW¼ of SW¼¼	36	13	23		Wilcox	230	?	832	1173	1218	1394	1470	?	1810	1966?	2130	2600	
51	Greeson et al.	Clark No. 1		10	11	22		Terrace sand (Midway)		?	194	?	?	Absent	?	?	1010	?	1280	3255	
52	Dudley's Arkansas Interests	H. Gund No. 1		32	11	21		Terrace sand (Midway)		?	429	700	750	Absent	?	?	1281	Probably absent	1415	2504	
53	Day Trustee; Moreland & Tanner.	Westmoreland No. 1	330 feet S. and W. of center	10	12	21	253	Wilcox	190	452?	609	870?	917	Absent	1100?	1314?	1500	Probably absent	1690	2519	
54	British Allied Estates	Benton Fee No. 1	West side of NW¼ of SW¼ of NE¼	31	11	20	187.9	Terrace sand (Wilcox)	117	?	568	?	870	Absent	?	?	1380	Probably absent	1569	2101	
	CLARK COUNTY																				
58	Arkansas Natural Gas Company	W. N. McAlpine No. 1	SW¼ of NW¼	32	9	20	220	Alluvium, Terrace sand (Midway)		?	220	?	500	Absent	560	?	925	Absent	1030	2950	This well penetrated the Paleozoic rocks at an indeterminate depth.
56	Arkansas Oil Company	Barringer No. 1	SE¼ of NW¼	26	10	20	247	Wilcox	74	370?	512	?	832	Absent	908	?	1171	Absent	1281	3120	
60	R. K. Casey	Sloan No. 1		18	8	19		Terrace sand (Midway)		?	158	?	408	Absent	449	?	701	Absent	?	1096	

[1] The Woodbine in this well logged as follows:

Feet
1479-1520, shale; light, dry.
1520-1550-shale; light, dry.
1550-1562, shale; greenish, dry.
1562-1568, shale; red, dry.
1568-1620, shale;sandy, red-brown.
1620-1624, gravel; dark, hard.

[2] The basal gravel of the Tokio formation is recorded as 9 feet thick in this log.

[3] The beds correlated with the Woodbine in this log are as follows:

Feet
499-500, sand rock.
500-506, water sand.
506-530, gumbo.
530-531, sand rock.
531-555, gumbo.
555-561, flint rock.
561-659, water sand.
569-575, gravel.
575-590, gumbo.
590-607, gravel bed.

[4] The Woodbine is logged mostly as gumbo and gravel and includes some red gumbo.

[5] The complete log is given in Miser, H. D., "Asphalt Deposits and Oil Conditions in Southwestern Arkansas": U. S. Geological Survey Bulletin 691J, 1918.

[6] This figure is taken from the log. Samples examined from this well show that the base of the Midway is somewhat below this depth.

[7] The log of this well is detailed but is likely to be misleading because of the erroneous logging of 125 feet of chalk and chalky shale in the lower part of the Nacatoch and the logging of 24 feet of sand carrying water and gas at the base of the Ozan formation, which is likely to be mistaken for the top of the Tokio. When correlated as in the table the top of the Woodbine is logged thus: 1265-1290, gumbo, green calcareous, micaceous sand, very fine grained, and fossiliferous. Few hard pyritiferous sandstone lentils.

[8] *Ostrea franklini* Coquand, a common Trinity species, has been identified by T. W. Stanton from a core taken at 2,394 feet in this well. At 2,665 feet cuttings examined by the writer consisted of broken novaculite chips, small tan-gray and red novaculite pebbles, and a few pyritized sandstone pebbles.