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GEOLOGY AND UNDERGROUND WATERS OF NORTHEASTERN TEXAS

BY

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GEOLOGY AND UNDERGROUND WATERS OF NORTHEASTERN TEXAS.

By C. H. Gordon.

INTRODUCTION.

GEOGRAPHY.

The area considered in this report embraces 5,989 square miles in the extreme northeast part of Texas, comprising the counties of Bowie, Red River, Lamar, Delta, Hopkins, Franklin, Titus, Morris, Camp, and Cass.

The mean annual rainfall of the region is about 48 inches, ranging from 45 inches in the west to a little more than 50 inches along the Arkansas State line. The mean annual temperature is from 64° to 65° F. The district is traversed from east to west by three lines of railroads, the Texas & Pacific (Sherman branch), the St. Louis & Southwestern, and the Missouri, Kansas & Texas. The Marshall branch of the Texas & Pacific crosses the eastern part of the region and the Texas Midland, the Gulf, Colorado & Santa Fe, and the St. Louis & San Francisco all have their termini at Paris in the northwestern part of the region.

The rich soil of the black prairie lands early attracted settlers. According to the census of 1910 the population of the 10 counties named was 198,869, or an average of 33.7 to the square mile. The western part of the region is the most thickly settled, the two blackland counties, Lamar and Delta, leading, with an average of 51.5 and 54.7 per square mile, respectively. The average for the timber-belt counties is 28.3, Hopkins and Camp leading with 46.6 and 44, respectively.

PHYSIOGRAPHY.

Lying near the outer border of the Gulf Coastal Plain, the surface of the district has in general the low rounded relief and gentle seaward slope characteristic of that physiographic province. The elevation ranges from 237 feet above sea level at Sulphur, in the northeast corner of Cass County, to 649 feet above sea level at Cumby, near the western border of Hopkins County. The crest of the divide between

Red and Sulphur Rivers has an average eastward slope of about 3½ feet per mile, descending from an altitude of 601 feet at Paris to 295 feet at Texarkana, or a total of 306 feet. South of Sulphur River the reconstructed plain surface coincident with the tops of the present hills would slope toward the southeast, and within the limits of the district would range from 649 feet at Cumby to about 320 feet near the eastern boundary of Cass County.

The region is underlain by relatively soft strata which dip gently toward the coast, and in which the present relief has been developed by the dissection of the plain surface which characterized the region on its emergence from the sea. Degradation has left few if any traces of this old land surface, the chief topographic features now presented being the rolling and hilly uplands and the flood-plain and terrace areas, the former due largely to the differential erosion of the older beds of the coastal plain and the latter represented by the flat lowlands and adjoining terrace areas composed of redeposited sediments of comparatively recent fluviatile origin.

The upland areas, which rise from 100 to 200 feet above the flat-bottomed drainage ways, present an irregular rolling topography due entirely to differences in the adjustment of erosion to the different geologic formations. The northwest portion, comprising all of Lamar and Delta counties and most of Red River County, is underlain by Cretaceous strata consisting of marls, glauconitic sands, clays, and chalk, which have been carved by erosion into an undulating surface of low relief called rolling prairie, which constitutes an integral part of the black-prairie belt of Texas. The interior of this belt is marked by a low range of hills that extends across Lamar and Red River counties, due to the greater resistance to erosion offered by the chalk formation. This range apparently constitutes an extension of the Locksburg Wold in Arkansas, described by Veatch.[1] The Saratoga Wold, also mentioned by Veatch, is somewhat obscurely represented in Delta County near Enloe. In places the chalk ridge in Lamar and Red River counties presents a low northward-facing escarpment, due chiefly to a single hard layer 4 to 6 feet thick near the top.

The upland region south of a line extending a little north of east from Commerce through Boston, the county seat of Bowie County, lies within the province known as the east Texas timber belt. This region is characterized by a range of hills which constitutes the extension into Texas of the range known as the Sulphur Wold in Arkansas. It is essentially a deeply dissected dip plain, the substructure of which consists of the sandy beds of the lower Eocene. Over a considerable part of the region the slopes are still covered with timber.

The streams have comparatively wide, flat flood plains, bounded by terraces, the highest of which has an elevation of about 90 feet

[1] Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 14-16.

above the present flood plain. These high-level terraces cover considerable areas adjoining Red and Sulphur rivers in the eastern part of the district. Between Annona and New Boston nearly all of the country between the two rivers is of this type.

A marked feature of this and adjoining parts of the Coastal Plain is the presence of low mounds composed of sand, which occur over all the region except that covered by the most recent fluviatile deposits. These mounds are commonly from 2 to 3 feet high, though a few attain a maximum height of 6 feet. Some are elliptical; most of them are circular and are from 20 to 100 feet in diameter. The tendency toward elongation appears to be more marked in some places than in others, the longer axis usually extending in a northeast-southwest direction. As remarked by Veatch, they are particularly abundant in the terrace areas, where in wet weather they form low sandy islands in the midst of a water-covered clay country.

DRAINAGE.

The drainage of the region is effected mainly by Sulphur River, which flows from west to east entirely across the district. A feature of the drainage is the greater development of the southeastward-flowing system of tributaries, those flowing to the northeast being relatively few and for the most part unimportant. From this it follows that the divides are located much nearer the main streams on the south side than on the north, and the northward-facing slopes are shorter and steeper, a feature consequent upon the general coastward slope of the original plain surface and the effort of the streams to adjust themselves to the rock structure of the region. A small area in the southern part of Hopkins County is drained by tributaries of Sabine River, and the larger part of the region lying to the east is drained into Ferry Lake through Big Cypress and other creeks. Ferry Lake connects with Sodo and Cross lakes in Caddo Parish, La., these together constituting one body of water which occupies the lower portion of the valley of Big Cypress Creek. This body of water belongs to the class of lakes in the Red River Valley whose origin is attributed to log jams.[1]

The main streams and their tributaries that have cut to the level of ground water flow throughout the year, but many of the branches are wet-weather streams only. The soft rocks over which the streams flow yield to them an abundance of fine material, which is carried in suspension for long distances, discoloring the water and forming in quieter stretches of the streams grayish or brownish red deposits.

[1] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 60–62.

LITERATURE.

Most of the published accounts of investigations heretofore made in northeastern Texas are found in the reports of the Texas Geological Survey and of the United States Geological Survey. In two reports only are the waters of the region specially considered. Hill [1] in his exhaustive report on the geography and geology of the Black and Grand prairies of Texas gives detailed descriptions of the Cretaceous formations with special reference to the underground waters and all information available concerning the counties adjoining Red River. Veatch, in his report on the geology and underground water resources of northern Louisiana and southern Arkansas, has included some data bearing on the eastern part of the region. With these exceptions, the publications relating to the region, a fairly complete list of which follows, deal chiefly with questions of stratigraphy and natural resources other than water.

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PENROSE, R. A. F., Preliminary report on the geology of the Gulf Tertiary of Texas: First Ann. Rept. Geol. Survey Texas, 1889, pp. 1–101. Discusses the stratigraphy of the Tertiary formations of Texas and records briefly their occurrence in northeastern Texas (pp. 34–36). Describes the iron ores of eastern Texas, and mentions their occurrence in Cass and Marion counties (pp. 65–82).

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——— Geology of parts of Texas, Indian Territory, and Arkansas adjacent to Red River: Bull. Geol. Soc. America, vol. 5, 1893, pp. 297–338. Annona, or "White Cliffs," chalk considered as belonging to higher horizon than the Austin chalk.

——— Geology and geography of the Black and Grand prairies, Texas: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1899–1900. An exhaustive report on the Texas Cretaceous, with special reference to artesian waters.

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——— The age of the iron ores of eastern Texas: Science, vol. 23, 1894, pp. 22–25. Notes greater development of the nodular iron ore in Cass, Marion, Morris, Upshur, and Harrison counties, asserts that their age is "Lower Claiborne" or later.

——— The iron ores of eastern Texas: Trans. Am. Inst. Min. Eng., vol. 24, 1894, pp. 258–288, 862–863.

——— The Eocene Tertiary of Texas east of the Brazos River: Proc. Acad. Nat. Sci. Phila., 1895, pt. 1, pp. 89–160. Discusses the stratigraphy of the region and compares it with that east of the Mississippi as noted by Hilgard, Smith, and Johnson.

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

JOHNSON, LAWRENCE C., The iron regions of northern Louisiana and eastern Texas: House Doc. No. 195, 50th Cong., 1st. sess., 54 pp., 1 map, Washington, 1888.

TAFF, J. A., Report on the Cretaceous area north of the Colorado River: Third Ann. Rept. Geol. Survey Texas, 1891, pp. 269–379; map by J. A. Taff and S. Leverett. Descriptions of the Texas Cretaceous in this paper relate chiefly to regions in the central part of the State. Contains brief discussion of estimates of depths of artesian wells in Lamar and Fannin counties (pp. 371–373).

——— and S. LEVERETT, Report on the Cretaceous area north of the Colorado River: Fourth Ann. Rept. Geol. Survey Texas, 1892, pt. 1, pp. 239–354. Continues discussion in the Third Annual Report (1891) and describes with considerable detail the occurrence and extent of the subterranean artesian basins.

——— Chalk of southwestern Arkansas: Twenty-second Ann. Rept. U. S. Geol. Survey, 1900–1901, pt. 3, pp. 685–742. Discusses the stratigraphy of southwestern Arkansas and its relation to that of Texas. Correlates the "White Cliffs" chalk with the Austin chalk of the Texas region.

VEATCH, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: Prof. Paper U. S. Geol. Survey No. 46, 1906. Includes many facts bearing on the geology and underground waters of northeastern Texas. Follows Hill in assigning the "White Cliffs," or Annona, chalk to a higher horizon than the Austin chalk.

GORDON, C. H., The chalk formations of northern Texas: Am. Jour. Sci., 4th ser., vol. 27, 1909, pp. 369–373. Correlates "White Cliffs" and Annona chalk with the upper part of the Austin group, the lower part being represented by the Brownstown marl.

GEOLOGIC HISTORY.

PRE-CRETACEOUS.

In the mountains of eastern Oklahoma, as shown by Taff,[1] the rock exposures appear to indicate that deposition was continuous from very early geologic time down to the close of the Pennsylvanian ("Coal Measures") epoch. Similar conditions prevailed in central Texas, where rocks representing all the divisions of the Paleozoic, with the possible exception of the Devonian, occur in conformable sequence resting upon the beveled edges of an older series of sedimentary rocks, the pre-Cambrian Llano series.[2] In western Texas and western Oklahoma these rocks grade upward without a break into deposits with Permian and Triassic affinities.

Throughout this area and to the northwest a sea existed, over whose bottom a vast thickness of sediments was laid down. The thickness of the Cambro-Ordovician in Oklahoma is estimated by Taff[1] at 12,000 feet and of the Devonian at 600 feet. Drake[3] estimates the thickness of the Carboniferous at 24,500 feet. The land mass from which these sediments were derived lay to the south and southeast, the relative positions of the land and ocean areas being thus in a sense the reverse of those now existing.[4]

[1] Taff, J. A., Atoka folio (No. 79) and Tishomingo folio (No. 98), Geol. Atlas U. S., U. S. Geol. Survey, 1902 and 1903.

[2] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 89.

[3] Drake, N. F., Proc. Am. Philos. Soc., vol. 36, 1898, p. 361.

[4] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 17.

Near the close of the Carboniferous the offshore belt of greatest sedimentation, extending from central Texas around through Oklahoma and Arkansas across the Mississippi Valley and connecting with the great trough now represented in the Appalachian chain, was subjected to profound folding and was elevated into a mountain range overlooking a sea extending to the west and to the north. Following this came a long period representing Triassic and Jurassic time, during which the elevations were worn down and the materials deposited in the adjacent seas. The lapse of time represented in the truncated edges of the folded and faulted strata was evidently very great. Then came a southward tilting of the region whereby land and water conditions were reversed and the sea transgressed northward over a relatively smooth base-leveled plain.

CRETACEOUS.

With the advent of the Cretaceous, ushered in by the northward transgression of the sea, marine sedimentation took place, the materials being derived from the land areas on the north and west. These deposits consist of alternations of sands, clays, marls, and limestones, and their character and relations show that many changes took place in the position of the shore lines and that the depth of the sea over the depressed land areas varied greatly from time to time.

If the prevailing doctrine that limestones and marls indicate deep-water conditions be strictly held, the alternations of sands, chalks, and marls of the Upper Cretaceous indicate a complex series of movements in the Texas-Arkansas region, but to interpret in terms of crustal oscillation the alternations of formations indicating quiet conditions of deposition—such as limestones, shales, and clays—seems to the writer untenable. Although the accepted doctrine may be broadly admitted, it seems probable that beds corresponding to those usually classed as deep-sea deposits may be locally formed by causes other than the lowering of the sea bottom; for instance, the shifting of currents or the extension of barriers, however produced, will be registered in the character of the formations, and such changes as these may take place locally without change of elevation. Fluctuations of level did occur, however, irregularly over the whole region, the result being a warping which caused one shore line to cut obliquely across that of a preceding period, giving rise to the present wedge-shaped outcrops with the point of the wedge directed northeast in the direction of greatest depression. These relations are well shown in the map (fig. 2, p. 18),[1] indicating the position of the shore line at different stages in the process of adjustment to the warping surface. In the early stages of advance the sea transgressed far to the west

[1] Veatch, A. C., Geology and underground-water resources of northern Louisiana and southern Arkansas: Prof. Paper U. S. Geol. Survey No. 46, 1906, fig. 3, p. 18.

over western Texas into New Mexico. At the close of the Cretaceous it had withdrawn on the west, but continued depression toward the northeast had marked out the Mississippi embayment, the submergence of which continued into late Oligocene time. Owing to the transgression of the shore line in the Mississippi embayment, accompanied by the withdrawal of the sea on the west, the earlier formations are overlapped by the later, and in consequence the outcrops wedge out toward the northeast, in Arkansas.

POST-CRETACEOUS.

Upon the Upper Cretaceous beds in the south half of the district lie sands, clays, and ferruginous sandstones belonging to the Eocene. No stratigraphic break has been recognized between the two systems. Originally, the Eocene doubtless extended much farther north, covering the whole of the area here considered, the present exposures of the lower formations being due to the removal of the Eocene sediments by erosion.

At the beginning of the Eocene there was evidently a slight warping of the surface which allowed the ocean to advance farther up the Mississippi embayment than before. As a result the early Eocene beds slightly overlap upon the Cretaceous, though no stratigraphic break marks the close of the Cretaceous in the Gulf region. A marked change appears in the animal life, however, an entirely new fauna making its appearance. Dana suggests [1] that this abrupt change in animal life is perhaps due to an alteration in the direction and character of the ocean currents, with the consequent change in temperature and food supply, and to the destructive effects of earthquake waves resulting from the gigantic disturbances which produced the Rocky Mountains rather than to a time lapse.

Throughout the region in the epoch succeeding the Midway—that is, in the interval represented by the Wilcox formation, of the Eocene series—near-shore or swampy conditions prevailed with an occasional submergence by the ocean.

No Oligocene or Miocene deposits have been recognized in this part of northeastern Texas. The Miocene was essentially a period of erosion in this region, and if deposits of Oligocene age were laid down here they were largely removed during the Miocene epoch.

During the succeeding epoch (Pliocene) a mantle of sand, silt, and gravel was spread over the eroded surface. Again erosion followed, during which much of the material previously deposited was carried away or rearranged at lower levels. Pleistocene deposition succeeded, giving rise to marine sedimentation along the coasts and fluviatile deposits on the land (Port Hudson formation). This was

[1] Manual of Geology, 4th ed., 1895, pp. 877-878.

followed by another period of erosion, in which the present flood plains and principal terraces were formed, this constituting the closing stage of the Pleistocene. The present cycle is represented in the surficial flood-plain deposition and hill-land erosion now in progress.

GEOLOGY.

The geologic formations that outcrop in the district may be classed as (1) Upper Cretaceous, (2) lower Tertiary, and (3) surficial deposits. The Cretaceous includes the Comanche series (Lower Cretaceous) as well as the Gulf series (Upper Cretaceous), but only the latter appears at the surface in the district.

CRETACEOUS SYSTEM.

COMANCHE SERIES (LOWER CRETACEOUS).

Lower Cretaceous beds do not appear at the surface in northeastern Texas, but outcrop in eastern Oklahoma on the north side of Red

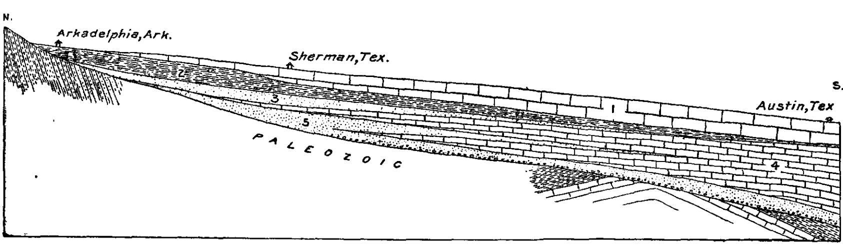


FIGURE 1.—Diagrammatic section of the Cretaceous rocks in northern Texas and southwestern Arkansas. (After Taff.) 1, White chalk; 2, blue marl; 3, sands at base of Upper Cretaceous; 4, Lower Cretaceous limestone; 5, sand at base of Lower Cretaceous. Reproduced from Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, p. 697.

River and farther northeast, in Arkansas. The lowest formation, known as the Trinity sand, is composed of fine, clean sand with occasional pebbles and bowlders of white quartz and other crystalline rock derived from the old Paleozoic land surface. In some places the sands are interlaminated with thin layers and lenses of clay; in other places they contain vegetal remains and brackish-water shells. Throughout a large portion of the Black and Grand prairie region in Texas this formation constitutes an important water-bearing stratum, which supplies thousands of artesian wells, many of which flow. In northeastern Texas, however, the southward dip of the strata has carried these sands too far below the surface to be conveniently reached by the drill except in a relatively narrow belt along the south side of Red River in Lamar and Red River counties.

The Trinity sand, which represents near-shore deposits, is succeeded upward by the limestones and marls of the Fredericksburg and Washita groups, a change indicative of deeper water. The Fredericksburg group is represented by the Goodland limestone and the Washita group by the Denison formation, Fort Worth limestone, and Preston formation. As the sea in which these sediments were deposited progressed northwestward upon the sinking land surface the lime formations lapped upon and graded into the sandy shore formations and hence are much thinner in this region than in the southern part of the State.

The stratigraphic relations are shown in figure 1 (p. 14).

GULF SERIES (UPPER CRETACEOUS).

CLASSIFICATION.

The sequence and lithologic character of the formations composing the Upper Cretaceous in northeastern Texas is shown in the accompanying table, which includes also Veatch's table for western Arkansas. The correlations are suggested by the author. Veatch considers the Annona and Brownstown to be equivalent to the lower part of the Navarro and Taylor, and the Bingen to be the littoral equivalent of the Woodbine, Eagle Ford, and Austin.

Classification of the Upper Cretaceous in northeastern Texas and southwestern Arkansas.

Northeastern Texas (Gordon).			Southwestern Arkansas (Veatch).		
Formations.		Character of rocks.	Formations.		Character of rocks.
Navarro formation and Taylor marl.	Arkadelphia clay.	Dark-blue to black laminated clays. Sulphur Bluff.	Arkadelphia clay.		Black laminated clays.
	Nacatoch sand.	Green sands grading into marls below. Delta County.	Nacatoch sand.		Sand with occasional quartzitic layers.
	Marlbrook marl.	Sandy and clay marls. Chalk at Enloe Sands near Ladonia. Blue marly clay.	Marlbrook marl.		Very calcareous clay with marine fossils.
Austin group.	Annona chalk.	White chalk.	Annona chalk.		White chalk.
	Brownstown marl.	Blue clay marl.	Brownstown marl.		Blue calcareous clay.
Eagle Ford clay.	Blossom sand member.	Sands and sandy clays interlaminated.	Sub-Clarksville sand.	Bingen sand.	Water-bearing sand.
	....	Dark laminated clays.	Eagle Ford clay.		Blue calcareous clay.
Woodbine sand.	....	Lignitiferous sands, sandy clays, and sandstones.	Woodbine sand.		Lignitiferous sands and clays with plant remains.

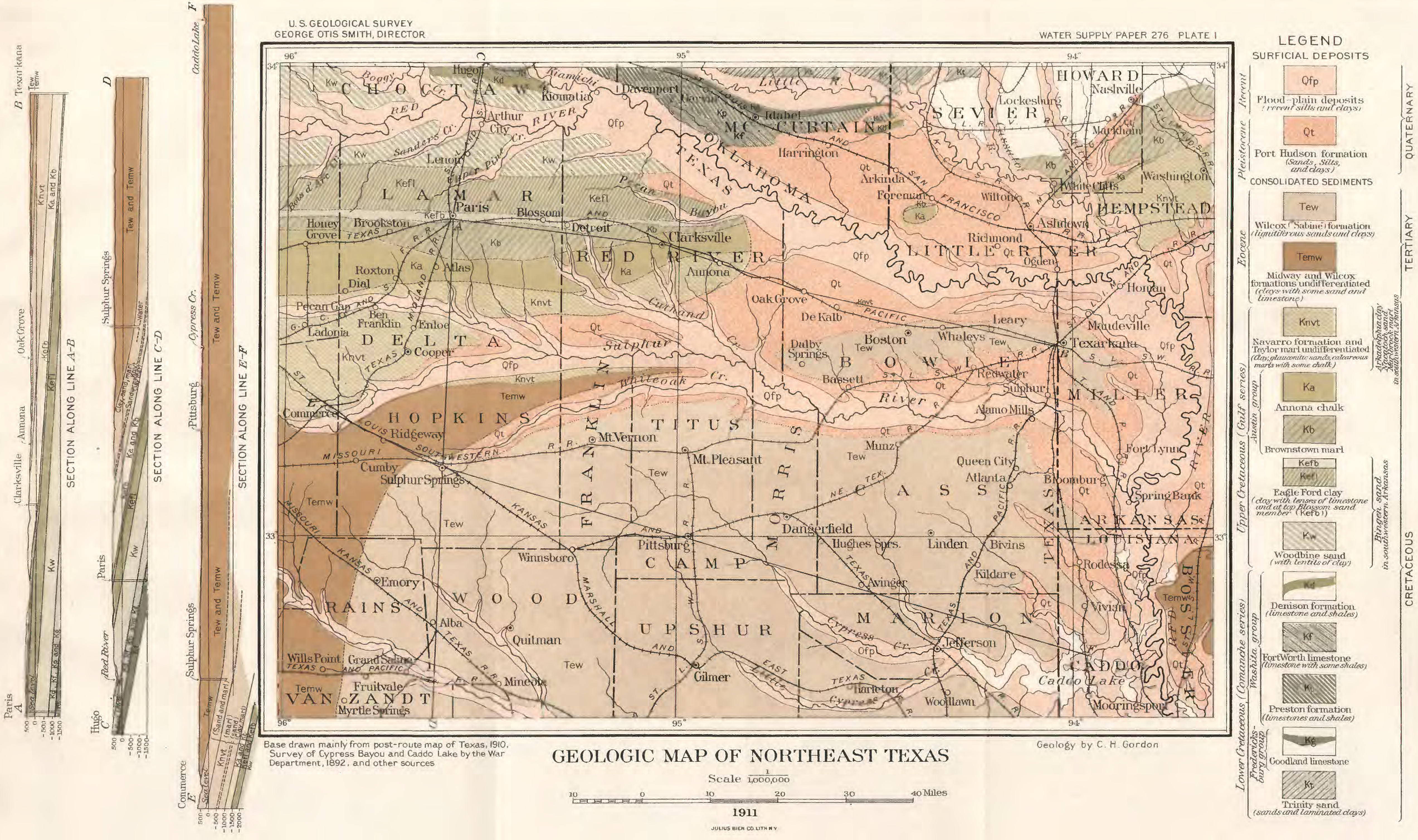
With the exception of the chalks, the rocks are characterized for the most part by a general lack of consolidation. The marls and clays especially disintegrate readily, yielding a thick mantle of black soil through which the underlying formations rarely protrude. No stratigraphic breaks occur within the Upper Cretaceous, and the gradations between its different formations is so gradual that these can be mapped in most places only with the greatest difficulty, if at all.

The chief exposures of the rocks of the gulf series occur in the northwestern part of the area between South Fork of Sulphur River and Red River. Farther east, in Texas, these formations are covered by surficial deposits which consist largely of unconsolidated sands, clays, and marls, and some indurated beds of sandstone and chalk. The beds dip southeastward at a low angle, at a rate of about 50 to 55 feet per mile, in the district north of North Fork. In their eastward extension and also where they lie under cover toward the south, as indicated by the few well records available, they appear to have a steeper dip.

WOODBINE SAND.

The Woodbine consists of ferruginous and argillaceous sands accompanied by bituminous laminated clays. The sands are for the most part unconsolidated and contain many remains of plants, a feature which distinguishes them from other Upper Cretaceous formations. When unweathered the sands appear white and friable, but contain more or less iron in the form of pyrite and glauconite as well as other ingredients, which on decomposing materially affect the character of the waters derived from them. In places solutions of the oxidized iron minerals have consolidated the sands into dark-brown ferruginous sandstone or siliceous iron ore. In large part the sands break down into deep loose soils. The clays are laminated and are for the most part impure, sandy, and lignitic. In northeast Texas the formation is characterized by the presence of argillaceous and calcareous layers interlaminated with the sand and by the occurrence of plant remains in considerable numbers, together with a peculiar molluscan fauna. A large part of the plant collection noted by Hill was obtained by Vaughan at Arthurs Bluff on Red River in Lamar County.

The Woodbine sand underlies the area adjacent to Red River in the northern part of Lamar and Red River counties and as far west as Dexter in Cooke County. From Red River it extends southward coextensively with the lower cross-timber country, but has not been recognized south of Brazos River. The region of its outcrop is generally characterized by a loose sandy soil, mostly covered with coarse post-oak and black-jack timber, here and there broken by small prairies where the beds contain an increased proportion of clay. From Red River to the Brazos the western boundary of the belt is marked by a range of low hills and knobs whose existence is due to the greater resistance to erosion offered by the more consolidated ferruginous beds of the lower part of the formation (called Dexter sand by Taff and Hill). The Woodbine is traversed for miles by Red River, but owing to its unconsolidated character and its covering of timber and alluvial deposits exposures of it are infre-



Base drawn mainly from post-route map of Texas, 1910, Survey of Cypress Bayou and Caddo Lake by the War Department, 1892, and other sources

Geology by C. H. Gordon

GEOLOGIC MAP OF NORTHEAST TEXAS

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

10 0 10 20 30 40 Miles

1911

JULIUS BIEN CO. LITH N.Y.

quent, occurring only in undermining bluffs, as at Arthurs Bluff north of Paris and at Pine Bluff in the northeast part of Lamar County. At Rock Ford, in Red River County, sand, in part glauconitic, occurs in the bluffs, which also show near the top several layers of white fossiliferous limestone. The area in which the Woodbine outcrops in northeastern Texas is shown approximately on the map (Pl. I).

In this region the formation has an estimated thickness of 600 to 800 feet. In the Paris well the drill penetrated 820 feet of sand and clay beds which have been assigned to the Woodbine; some of the lower beds, however, may belong to the underlying Denison formation. Southward it diminishes in thickness until it disappears by overlap in the vicinity of the Brazos. Eastward in Arkansas the Woodbine, there called the Bingen sand, coalesces, according to Veatch,[1] with the sands at the top of the Eagle Ford (Blossom sand member) by the thinning out of the intervening Eagle Ford clay. According to Veatch, therefore, the Bingen sand, which is the lithological counterpart of the Woodbine sand in Texas, is the time equivalent of all the beds of the Upper[2] Cretaceous below the Brownstown marl. (See fig. 2.)

As the Brownstown was considered by Veatch to lie immediately above the Austin chalk, the conclusion was drawn that the Bingen sand contained the littoral equivalents of the Austin and the Eagle Ford.[3]

EAGLE FORD CLAY.

Character.—The lower two-thirds of the Eagle Ford formation in northeastern Texas consists chiefly of dark, laminated clays, and the upper 50 to 75 feet is made up of brown, ferruginous, glauconitic sands interlaminated with clay. Inasmuch as the upper sandy beds constitute a water horizon of some value, a subdivision of the formation based on lithological distinctions seems warranted. To the upper sandy portion, therefore, the term Blossom sand member is applied, from the town of Blossom, which is located in eastern Lamar County upon the outcrop of the beds.[4]

Thickness.—The total thickness of the Eagle Ford clay in this region, as recognized in the Paris well section (p. 45), is 600 feet. This well is located directly upon the outcrop of the Blossom sand member and it doubtless includes very nearly the full thickness of the beds. Eighty feet of the sands was penetrated, the whole of

[1] Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 23–24.
[2] Veatch says "Lower" Cretaceous, but this is evidently a typographical error.
[3] Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 18.
[4] Am. Jour. Sci., 4th ser., vol. 27, 1902, pp. 371, 373.

which with the exception of a few feet of soil is regarded as representing the Blossom. The formation thins rapidly eastward, there being but 174 feet of hard sands that can be referred to this formation in the Texarkana well (p. 59), east of which it is not known.

Fossils.—As a whole the Eagle Ford is not very fossiliferous except in the upper arenaceous division (Blossom sand member). A few

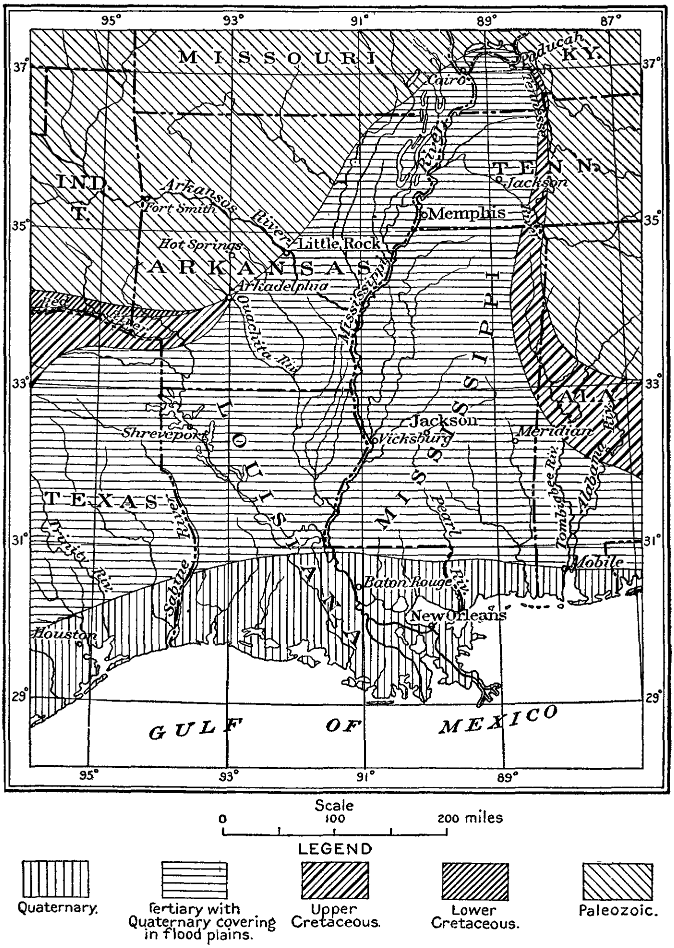


FIGURE 2.—Map showing overlap of Upper Cretaceous on Lower Cretaceous and of Tertiary on Cretaceous in the Mississippi Valley. (After Veatch.)

forms of Ammonites preserved with their nacreous shell coloring occur sparingly throughout the formation, and the blue limestone concretions are generally filled with the remains of certain invertebrate forms. In addition to an abundance of fish remains, chiefly teeth, the Blossom sand member contains an abundance of the characteristic forms *Ostrea lugubris* = *O. belliplicata*, *Inoceramus fragilis*, *I. labiatus,* and a small form like *O. congesta.* Hill[1] gives the following list of fossils obtained from the Eagle Ford formation:

Planticeras syrtalis Mort. var. cumminsi Cragin.
Ammonites woolgari Mort.
Sphenodiscus dumblei Cragin.
Buchiceras inequiplicatus Shumard.
B. swallowi Shum.
Tapes hilgardi Shum.
Anchura modesta Cragin.
Fusus graysonensis Cragin.
Natica striatacostata Cragin.
Neritopsis biangulatus Shumard.
Ostrea lugubris Conrad=O. belliplicata Shum.
Ostrea sp. (like O. congesta).
Inoceramus fragilis Hall and Meek.
I. labiatus Schlotheim.
Fish teeth.

Lower clays.—The lower part of the formation consists essentially of blue and black laminated bituminous clays accompanied by thin laminated clay limestones and nodular septaria of blue limestone; thin laminæ of sand occur in this portion, showing a gradual transition from the Woodbine sand below. The central and larger part of the formation is made up of blue and black marly clays, which include thin beds of arenaceous limestone and numerous hard nodular septaria, some of which attain a diameter of 3 feet; these septaria are composed of dense blue limestone with cross fissures filled with calcite and selenite. Selenite in minute crystals is disseminated generally through the clays, in places in considerable quantities, and the water flowing through these beds is generally bitter and disagreeable to the taste.

The clays constitute a belt of prairie extending east and west across Lamar and Red River counties north of the Texas Pacific Railway, and bounded on the north by the Woodbine sand and on the south by a narrow strip of sandy land representing the outcrop of the Blossom sand member. The outcrops of the clay make the black waxy land north of Paris.

Blossom sand member.[2]—The clays of the Eagle Ford grade upward into brown sandy ferruginous glauconitic beds interlaminated with thin beds of clay. The clays are filled with fossiliferous concretionary masses of limestone similar to those in the middle part of the formation; in places these weather out as bowlders. Locally the sands are highly fossiliferous, some layers being composed in large part of the casts of shells. The full thickness of these beds was not observed in the area to which this report relates, but at Sherman (2 miles west of the area) the following succession occurs.[3]

[1] Hill, R. T., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 7, p. 328.

[2] Blossom sand member = "sub-Clarksville" sand of Veatch, Prof. Paper U. S. Geol. Survey No. 46. "Fish beds" of Taff and Hill=Blossom sand member (in part). *Ostrea belliplicata* bed of Taff=Blossom sand member (in part).

[3] Hill, R. T., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 7, 1899–1900, p. 326.

Section of Blossom sand member at Sherman, Tex.

	Feet.
6. Sandy clay shales with *Ostrea lugubris*	10
5. Thin slabs of brown sandstone with rounded conglomerate of jasper pebble. *Ostrea lugubris* and fish teeth	5
4. Blue laminated clay, weathering into limonitic colors	10
3. Massive agglomerate of shells of *Ostrea lugubris*	2
2. Sandy clay shale in thin alternations of clay and sand; clay efflorescent and drab colored on drying; contains *Ostrea lugubris*.	40
	67

The description given in the section of the beds at Sherman corresponds well with the character of the strata as they appear in Lamar and Red River counties.

The outcrop of the Blossom sand member extends in a band approximately a mile in width from a point nearly north of Annona, where Pecan Bayou intersects the bluff of Red River, to the western limit of the area, except where interrupted by overlying Quaternary formations. Outcrops occur at different places along the south side of Pecan Bayou, which flows for the greater part of its course on the formation; and in Lamar County they appear almost continuous along a line through Blossom and Paris, both of which places are located upon these beds. On the south the sands are bounded by the black waxy soils derived from the marly clays of the Brownstown marl, the lower formation of the Austin group. Four miles north of Clarksville the contact of the Blossom sand member with the overlying Brownstown marl was observed in a ravine. The section obtained here was as follows:

Section in ravine 4 miles north of Clarksville.

	Feet.
Brownstown marl:	
7. Clay marl with an abundance of *Exogyra ponderosa* in the lower 12 inches	6
Blossom sand member of Eagle Ford clay:	
6. Sand, in places mixed with marly clay	3
5. Blue marly clay (exposed)	6
4. Covered (about)	10
3. Yellow sand with fossil impressions	10
2. Drab fissile clay	2
1. Yellow sand above, grading into drab arenaceous clay below. Contains iron concretions showing impressions of fossils	20
	57

From 10 to 20 feet below the top of these beds in Grayson County, as described by Taff,[1] is a bed of coarse sand or grit, in places a conglomerate, called the "Fish bed," from the large number of fish teeth contained in it. This bed was not definitely recognized in Lamar and Red River counties. The beds are generally highly fos-

[1] Taff, J. A., Fourth Ann. Rept. Geol. Survey Texas, p. 303.

siliferous, though in general the material is in a friable condition, owing to weathering and oxidation. Ostreas (*Ostrea lugubris*=*O. belliplicata*) are numerous and in places farther west make up most of certain beds to which the term "shell bed" very appropriately applies.

The Blossom sand member, though comparatively insignificant stratigraphically, is important, because it constitutes the only available water-bearing horizon over a considerable portion of south Lamar and Red River counties. It is from this sand that the water supply at Clarksville is obtained, a fact which, in the absence of known outcrops, led Veatch[1] to give it the name "sub-Clarksville" sand. At Paris, according to the well record given on page 45, these sands have a thickness of 80 feet.

AUSTIN GROUP.

General character and relations.—From Sherman in Grayson County southward to the Colorado in Travis County the Austin chalk constitutes the most persistent and characteristic formation of the Cretaceous in Texas. Throughout this area its thickness is estimated by Taff to be about 600 feet. From the base to the top the rock consists for the most part of soft bluish-white chalk, chiefly in beds from 2 to 6 feet thick, interspersed here and there by a succession of thinner layers. The beds are generally separated by very thin sheets of calcareous marl, which in places thicken to 3 to 12 inches. Toward the top the beds become more massive, being from 4 to 6 feet thick, with very little separating marl between them.

Interstratified with the soft layers in places are nonpersistent harder arenaceous layers, which on weathering project in rounded subangular surfaces.

On weathering, the chalk loses the bluish cast seen in fresh exposures and becomes white or cream colored. It usually has an earthy texture and when fresh can be readily cut with a handsaw. Here and there nests of pyrites and crevices filled with calcite appear. Under the microscope[2] the material shows calcite crystals, minute amorphous calcite, and the shells of foraminifers, mollusks, echinoids, and other marine organic débris such as usually constitute chalk formations.

From Sherman eastward the basal portion of the Austin becomes more argillaceous and assumes the character of clay marl or marly clay. Beginning at the base in the vicinity of Sherman this change in character reaches higher and higher as the formation extends eastward until at Atlas, Clarksville, and White Rock north of Annona in Texas and at White Cliffs in Arkansas only the uppermost beds pre-

[1] Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 25.

[2] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1899–1900, p. 329.

sent the character of true chalk. Among previous writers Taff[1] seems to be the only one who recognized the true relations of the chalk deposits of northeastern Texas and southwestern Arkansas. The statements by this author accord so well with the independent conclusions of the writer that they are given entire:

> The lower part of the chalk formation of northern Texas changes to marl in the vicinity of Sherman, and still farther east higher beds successively become chalky marl, so that within a comparatively short distance only the upper part of the chalk formation as it occurs farther south is true chalk. In other words, the white chalk transgresses upward in the series of Cretaceous rocks from the vicinity of Sherman, Tex., eastward into Arkansas.
>
> The fossils of the main chalk which are not found below the chalk in northern Texas south of Sherman occur in the chalky marl beneath the chalk from the vicinity of Paris, Tex., eastward. The fauna, including the characteristic species of fossils, such as *Exogyra ponderosa, Gryphæa vesicularis, Astrea larva*, and others which occur only in the upper beds of the chalk in central Texas, are found in great abundance in the marl at the base of and beneath the white chalk in southwestern Arkansas.[2]
>
> This chalk grows thinner in outcrop northeastward as it approaches the Paleozoic border and elevated mountain districts until it ends in chalky marl near the center of the Cretaceous area of southwestern Arkansas.

Hill[3] considered the chalk near Annona and westward as representing a higher horizon than the Austin chalk, which he describes as having largely thinned out east of Paris, but says that its exact relationship is subject to later determination. To the marls underlying the chalk at White Cliffs, Ark., which he rightly considered the equivalent of the lower part of the Annona chalk, he gave the name Brownstown. Veatch[4] appears to have accepted Hill's conclusions in assigning the Annona chalk to a higher horizon than the Austin, which he states does not appear east of Paris, Tex. In this he differs, however, from Hill, who states that "the most eastern outcrop of this chalk [Austin] is in Little River County, in the southwest corner of Arkansas."[5]

The field work of 1906 and 1907 having settled conclusively that the Annona chalk corresponds to the upper beds of the Austin, and that the underlying Brownstown marl is the eastern equivalent of the lower portion of the same formation, it seems appropriate to include both of these under the term Austin group.

Brownstown marl.—In Red River and Lamar counties and west to Sherman the Blossom sand member, constituting the uppermost beds of the Eagle Ford clay, grades rather abruptly into the light-blue calcareous and sandy clay or marl (Brownstown) representing the lower formation of the Austin group. Toward the top the proportion of lime increases, so that the upper beds are decidedly chalky and in places

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[1] Taff, J. A., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1900-1901, pp. 698-700.

[2] The writer's observations show these fossils to be present in northeastern Texas from the marls at the base of the chalk up to the marls of the Navarro formation.

[3] Hill, R. T., op. cit., p. 341.

[4] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 19.

[5] Hill, R. T., op. cit., p. 330.

grade horizontally into true chalk. This variation in the composition of the Austin group gives rise to variation in the relative thickness of the chalk and marl divisions and in the relative width of their outcrops, the one varying inversely as the other. Four miles south of Paris the marls appear on fresh exposure bluish-white and chalky, much resembling chalk, but softer. On weathering they become drab to yellowish-brown, grading upward into a black waxy soil. The lower portions are more arenaceous, forming along the northern border of the formation outcrop a strip of soil called "mixed land" or "tallow-ridge land." The width of the outcrop of the marls south of Paris is from 5 to 6 miles, indicating a thickness of about 300 feet, while that of the overlying chalk on the south is correspondingly lessened. The chalk belt widens toward the east and west, the marl belt narrowing to a mile or less north of Annona. The marls here pass under the later Quaternary deposits along with the overlying Annona and higher beds, but they evidently thicken rapidly eastward, for according to Veatch they have a thickness in southwestern Arkansas of 600 feet, thinning out again to about 150 feet in the eastern part of the area.[1]

The name Brownstown, as shown by Veatch, was first applied by Hill [2] to marl beds typically developed at Brownstown, Ark., the stratigraphic position of which was not recognized until later.[3] As now defined, the term includes the blue marly clays and clay marls between the Blossom sand member of the Eagle Ford and the Annona chalk in Texas and the equivalent beds in Arkansas which rest upon the Bingen sand, which is considered to be the representative of the Eagle Ford clay and the Woodbine sand as developed in Texas.

Annona chalk.—The chalk beds constituting the upper formation of the Austin group in northeastern Texas were named Annona chalk by Hill,[4] who correctly recognized their equivalency to the chalk occurring on Little River in Arkansas, to which he had previously applied the term White Cliffs chalk.[5] The formation consists of bluish and creamy white chalk similar to the corresponding beds of the Austin chalk farther south. At White Cliffs, Ark., the chalk beds are about 100 feet in thickness and underlain by argillaceous chalk marl grading downward into sandy chalk marl.[6] The exposures in Texas are less

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[1] Veatch, A. C., op. cit., p. 25.

[2] Hill, R. T., Ann. Rept. Geol. Survey Arkansas for 1888, vol. 2, pp. 86–87; Bull. Geol. Soc. America, vol. 1894, p. 302, pl. 12.

[3] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 340.

[4] Hill, R. T., Bull. Geol. Soc. America, vol. 5, 1894, p. 308 (there spelled Anona); Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1899–1900, p. 340–341. In the former paper Hill says: "It is not known what has become of the Austin chalk in this section (Paris), but my hypothesis, backed by some evidence, is that to the southward it has been faulted down. The Annona (White Cliffs) chalk is an entirely distinct and higher bed." In the later publication he says: "The writer has considered this chalk (Annona) to represent a higher horizon than the Austin, but its exact relationship is subject to future determination."

[5] Hill, R. T., Ann. Rept. Geol. Survey Arkansas for 1888, vol. 1888, pp. 87–89.

[6] Taff, J. A., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, pp. 706–707.

extensive, but so far as can be determined the rock presents essentially the same characters near Annona and westward to Sherman.

The first appearance of the chalk in Texas is to the north of Annona in Red River County, from which place it takes its name. At this point its outcrop is about 4 miles in width and is cut off on the east by deposits of Quaternary age. From this point the chalk extends west through Clarksville, Atlas, and Roxton in Lamar County, and thence west to Sherman. From Atlas the northern border swings northward to Petty on the Texas & Pacific Railway, thence westward about a mile north of Honey Grove. About 3 miles west of Clarksville the exposures of chalk and accompanying marls are interrupted by Quaternary deposits, partly filling a broad shallow valley now occupied by the headwater branches of Cuthand Creek.

The composition of the chalk is shown by the following analyses:

Analyses of the Austin chalk.

	1	2	3	4	5
Calcium carbonate	82.51	84.48	84.14	90.15	70.21
Silica and insoluble silicates	11.45	9.77	10.14	5.77	23.55
Ferric oxide and alumina	3.61	1.25	4.04	2.14	1.50
Magnesia	1.19	Trace.	[a] 1.68	.58	.58

[a] Mg and H_2O.

1. Texas chalk; locality not given. Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1899-1900, p. 329.
2. Rocky Comfort, Arkansas (Annona chalk). Idem.
3. Annona chalk, 7 miles south of Paris. Analysis furnished by J. A. Porter, Paris, Tex.
4. Quarry of the Alamo Cement Works, 3 miles north of San Antonio, Tex. Average material used in the manufacture of cement. Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, p. 737.
5. Average fresh rock from quarry of the Texas Portland Cement Works, 3 miles west of Dallas, Tex. Lower 20 feet of white chalk. Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, p. 737.

With complete disintegration the Annona chalk breaks down into a black waxy soil similar to that of adjacent formations. As a rule, however, owing to its greater hardness, the soil is thin and less productive than adjoining areas. Over the area where it constitutes the surface formation its outcrops are conspicuous in all the slopes and drainage ways by reason of their glaring white color.

The Austin chalk is characterized by many fossils, of which large specimens of *Inoceramus cripsi* var. *barabini* Morton and *Exogyra ponderosa* Roemer are conspicuous from the base to the top. As these fossils occur also in the formations above the Austin, they do not constitute a reliable means of discrimination. Hill has given several other forms as occurring in the Austin, such as *Exogyra læviuscula* Roemer, *Gryphæa aucella* Roemer, and *Hemiaster texanus* Roemer.[1]

The thickness of the Austin group as revealed by the Clarksville wells corresponds closely with the estimate given by Taff for the

[1] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 336.

central Texas region (p. 21). In the Clarksville wells the water-bearing sands (Blossom sand member) were reached at a depth of about 600 feet. The drill is reported to have passed through "white rock" all the way, the lower portion being softer. As the wells are located very near the top of the Annona chalk, these figures may be considered a close approximation of the thickness of the Austin group in this locality.

TAYLOR MARL AND NAVARRO FORMATION.

Attempted differentiations.—Above the Austin group occurs a series of beds of calcareous clays, chalky marls, and greensands, the differentiation of which is rendered extremely difficult by reason of the unindurated character of the material and the consequent lack of good exposures.

Numerous efforts have been made by Hill and others to classify these beds, but the results have been unsatisfactory. Taff [1] divided the Cretaceous rocks above the Austin chalk in central Texas into (1) Greensand marl; (2) Marly flags, 100 feet; (3) *Ponderosa* marl, 1,000 feet; and (4) Chalk marl, 100 feet. In his latest report on the Texas Cretaceous, Hill divided the Upper Cretaceous into two divisions, the lower of which he called the Taylor marl and the upper the Navarro formation, a name originally proposed by Shumard. In northeastern Texas he divides [2] the Navarro into Arkadelphia beds, Washington beds, Annona chalk, Roxton beds, and Brownstown beds. As it is now clear that the Annona and the Brownstown represent the Austin, the overlying Taylor marl must be represented in part at least by the marls overlying the Annona, to which Hill originally applied [3] the name "Kickapoo." He states that the formation bears a growth of hardwood, including Bois d'Arc, and adds "this is the only marly terrane in the entire range of Cretaceous formations in Texas which is covered by arborescent vegetation."

In Arkansas the equivalents of the Navarro and Taylor formations, as made out by Hill and Veatch, are as follows:

Arkansas equivalents of the Navarro formation and Taylor marl.

3. Arkadelphia clay: Dark laminated clays; 200 to 500 feet.

2. Nacatoch sand: Glauconitic sands and thin ledges of calcareous sandstones; 60 to 160 feet.

1. Marlbrook marl: Blue chalky glauconitic marls; in places, impure chalk. A chalky layer, 20 to 50 feet thick, which occurs 200 to 300 feet above the base, is called the "Saratoga" chalk member. Thickness, 50 to 750 feet.

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[1] Third Ann. Rept. Texas Geol. Survey, 1891, pp. 354-359.

[2] Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 340. In describing the "Washington beds" the author states that they "surmount the Brownstown marls," evidently an error carried over from his earlier descriptions wherein the Brownstown marl was considered as being above the Annona chalk.

[3] Hill, R. T., Bull. Geol. Soc. America, vol. 5, p. 308, 1893.

Hill recognizes two lithologic phases of the upper part of the Navarro in the region north of the Brazos. The lower division, called by him the "Corsicana beds," consists of brown sandy marl with an occasional bed of hard, calcareous sandstone. Limestone concretions and a few bands of limestone occurring in these beds suggest the formations occurring in the vicinity of Cooper, Delta County. The upper division, which he called the "Kemp beds," consists of a yellow clay with nodules which apparently corresponds to the beds observed one-half mile north of Sulphur Bluff. However, very little information is available concerning the relation of these beds.

Character and thickness.—No satisfactory data bearing on the thickness of the Navarro and Taylor formations in this region are available. They are estimated to have a combined thickness of about 1,000 to 1,200 feet. The Sulphur Springs well shows 381 feet of blue shale with some sand, which evidently represent in part the Arkadelphia clay and Nacatoch sand.

Although well-marked correspondence with the Arkansas section can be made out in the character and sequence of the formations in Delta and adjoining counties, the lack of good exposures due to the unconsolidated character of the beds renders the definition of formation boundaries impracticable, and the whole is mapped as a unit.

At the base of the section in southern Lamar County a clay marl containing varying proportions of sand, and having an estimated thickness of 100 to 150 feet, forms a deep black soil in which no outcrops appear. This marl grades upward into fine marly sands containing thin ledges of limestone or chalk. These beds are exposed at Ladonia (Pl. II, *A*), Wolfe City, and elsewhere along a narrow belt extending from the northeast part of Delta County westward along the south side of North Fork as far west as Ladonia and thence southwestward through Wolfe City. Above the sands lies a highly calcareous marl or impure chalk, 20 to 50 feet thick, corresponding in position and character to the "Saratoga" chalk member of the Arkansas section. These beds are exposed in the slopes of North Fork about 2 miles north of Enloe, south of Ladonia, and in the vicinity of Fairlie in Hunt County.

The chalky beds grade upward into unconsolidated arenaceous marls in which occur concretionary masses of dense blue fossiliferous limestone. These marls constitute much of the surface of Delta County, but owing to the readiness with which they succumb to the weather exposures of unaltered material are rare. The estimated thickness of the marls is 350 to 500 feet, but as no wells extend through them in this region the data on which to base an estimate are very imperfect. Toward the south the black lands representing the outcrop of the marls give place to sands the exact relations of which are not clear, but which represent apparently the horizon of the

A. RAILROAD CUT AT LADONIA STATION.

Exposures of fine, marly sands containing thin ledges of limestone or chalk representing a part of undifferentiated Navarro-Taylor marl division. (See p. 26.)

B. RAILROAD CUT AT AVINGER STATION.

Exposure of sands and clays of Wilcox ("Sabine") formation.

Nacatoch sand, though some doubt exists owing to the near proximity of the Wilcox ("Sabine") formation.

In the vicinity of Commerce, Hunt County, green sands occur bearing *Crassatellites subplanus* (Conrad)?, *Cardium* sp., and *Fusus* sp.

Above the glauconitic sands are beds of blue bituminous sandy shale and dark laminated clays, which are exposed only near Sulphur Bluff and 3 miles north of that place on the south side of South Fork, where a bluff 50 feet high is composed of black laminated clay with thin laminations of ferruginous sand grading downward into blue bituminous sandy shale. The blue sandy shales contain characteristic Cretaceous fossils which are best preserved in a hard, chalky ledge near the middle. The dark laminated clays and associated beds are thought to represent the horizon of the Arkadelphia clay, the larger part of which in this region is covered by the overlap of the Eocene.

Fossils.—Arenaceous and chalky beds 2 miles north of Enloe yielded the following fossils, as determined by Dr. T. W. Stanton, of the Survey:

Exogyra ponderosa Roemer.
Cucullæa sp.
Cinulia sp.
Mosasaurus, weathered centrum of a caudal vertebra and a fragmentary element of the skull.
Ostrea sp.
Inoceramus cripsi var. barabini Morton.
Baculites asper Morton?

From the chalk 1½ miles south of Ladonia in the southern part of Fannin County the following were obtained:

Gryphæa vesicularis Lamarck.
Gyrodes sp.
Avellana sp.
Baculites anceps Lamarck.
Cucullæa sp.
Anchura? sp.
Nautilus sp.

In a railway cut near Cooper the overlying marls yielded the following in considerable numbers:

Exogyra costata Say.
Inoceramus cripsi var. barabini Morton.
Trigonia.
Morea sp.
Gryphæa vesicularis Lamarck.

In the greensands 1½ miles west of Commerce the following were obtained:

Crassatellites subplanus (Conrad)?.
Cardium sp.
Fusus sp.

The following were obtained in the blue sandy shale at Sulphur Bluff, 3 miles north of the town of that name in Hopkins County:

Inoceramus proximus Tuomey.
Crassatellites subplanus (Conrad)?.
Lunatia sp.
Cucullæa tippana Conrad.
Turritella trilira Conrad.

Clays occurring one-half mile north of the town of Sulphur Bluff gave the following:

Ostrea sp.
Veniella conradi Morton.
Exogyra costata Say.
Anchura? sp.

All the above are considered by Dr. Stanton as belonging to the Navarro and Taylor formations, but there are no distinctive species that fix the exact horizon. In fact, as pointed out by Dr. Stanton, the paleontology of the Upper Cretaceous in northern Texas has not as yet received sufficient study to make fine discriminations practicable with only the small collections submitted.

TERTIARY SYSTEM.

EOCENE SERIES.

MAJOR DIVISIONS OF THE EOCENE.

The Eocene underlies all the area south of Sulphur Fork, as well as a small isolated area on the north side of that stream extending west from Texarkana south of New Boston nearly to the west boundary of Bowie County. In the eastern part of the area along Sulphur Fork the Eocene is covered by a wide belt of deposits of later age.

As developed in eastern Texas and the adjoining portions of Louisiana, the Eocene comprises the following subdivisions:

4. Jackson formation. Calcareous clays containing marine fossils in abundance.

3. Claiborne group. Lower portion: Fossiliferous, calcareous clay, argillaceous limestone, greensand, limonitic iron ore, etc., upper portion lignitiferous sands and clays.

2. Wilcox ("Sabine") formation. Lignitiferous sands and clays, with marine fossils in the seaward or southern portions.

1. Midway formation. Dark-colored calcareous clays and fossiliferous limestones.

MIDWAY FORMATION.

The Midway formation, called the "Basal" or "Wills Point clays" in the Texas reports,[1] consists of calcareous clays with more or less sand and closely resembles the underlying Cretaceous clays and marls. The chief differences noted are the more distinctly stratified structure of the Eocene beds with laminations of sand and the presence of concretionary masses of limestone, which toward the east in Arkansas appear to become regularly bedded limestones. Large quantities of gypsum are also found in the clays, but the lignitic material so prevalent in the overlying Wilcox is wanting. The surface exposure of the Midway is limited to the extreme western por-

[1] Penrose, R. A. F., jr., First Ann. Rept. Geol. Survey Texas. Kennedy, William, Third Ann. Rept. Geol. Survey Texas, 1891, p. 47.

tion of the Eocene area and is marked by a belt of clay prairie lands extending with interruptions from Wills Point northward to Cumby and thence curving eastward past Ridgeway to South Fork.

The characteristic fossils of the formation are:

Enclimatoceras ulrichi White.
Ostrea crenulimarginata Gabb.
Ostrea pulaskansas Harris.
Volutilithes limopsis Conrad.

In common with other beds of the Eocene it contains:

Venericardia planicosta.
Pseudoliva vetusta.
Calyptraphorus velatus.
Turritella mortoni.[1]

The thickness of the Midway formation at Texarkana is about 214 feet and in Texas is from 260 to 300 feet.[2] The beds lie in a horizontal position, dipping slightly toward the southeast. These clays underlie a belt of prairie land with scattered belts and groves of hardwood timber, consisting mostly of post oak, black jack, and hickory.

WILCOX ("SABINE") FORMATION

The Midway formation grades upward into a series of siliceous and glauconitic sands, variously colored from white through yellow, red, and brown to black, interstratified with clays, which are generally dark blue or black. The sands that constitute the major part of the formation are laminated, thinly stratified, massive, and cross-bedded and are frequently interlaminated with clay. Many beds of lignite occur, varying in thickness from a few inches to several feet, and the sands and clays generally are impregnated with vegetal matter to such an extent that they burn white or buff on being exposed to heat. The sands contain more or less carbonate of lime, in places in sufficient amount to cement the sands into a calacareous sandstone or arenaceous limestone. Some of these indurated portions occur in somewhat even beds and some of them in concretionary masses of various sizes and shapes. When met in wells, these indurated masses are usually designated "rock" or "bowlders" by the driller.

According to previously published reports the Wilcox formation has an aggregate thickness of about 900 feet. In the well at Sulphur Springs (p. 61) the drill penetrated 1,317 feet of sand and clay that apparently represent the Wilcox and Midway formations, combined. Of this thickness 810 feet is assigned to the Wilcox.

[1] For a detailed discussion of the paleontology of the Midway formation see Harris, G. D., The Midway stage: Bull. Am. Paleontology, vol. 1, 1896, pp. 117-270.

[2] Penrose places the thickness at 250 to 300 feet (First Ann. Rept. Geol. Survey Texas, p. 23); and Kennedy (Third Ann. Rept. Geol. Survey Texas, 1892, p. 49) assigns them a thickness of 260 feet. In the Sulphur Springs well (p. 61) 324 feet of clays and sands have been referred to this formation.

CLAIBORNE GROUP.

The Claiborne group overlies the Wilcox and is said to contain "the most persistent and widely spread marine beds of the Coastal Plain." (See Veatch's map, fig. 2.) In northeastern Texas and northern Louisiana the group is divisible into a lower fossiliferous formation which has been called "Lower Claiborne," but for which Harris [1] has recently introduced the name St. Maurice formation, and an upper lignitiferous formation to which the name Cockfield has been given.

The upper portion of the Claiborne group consists of lignitiferous sands and clays, in which no marine fossils have been found except at the very top at Robertson Ferry, on Sabine River, and is known as the Cockfield formation. The bed exposed at Robertson Ferry containing marine fossils is included in the Cockfield formation.

The lower portion of the Claiborne is more calcareous, glauconitic, and clayey than the Wilcox and contains no lignitic matter. The thickness of the lower formation (St. Maurice) varies from 250 to 700 feet. The upper formation (Cockfield) consists of 400 to 500 feet of lignitiferous sands and clays, which are evidently of near-shore origin.

In southern Texas the "Lower Claiborne" was included by Kennedy in his "Marine beds" [2] and was subdivided into a lower division called Mount Selman and an upper division called Cook Mountain.[3] The "Marine beds" of Kennedy, however, included also a portion of the Wilcox which contains marine fossils.[4]

In southern Cass County and westward the Wilcox formation merges upward in places into brown and blue sands and clays, and glauconitic beds containing deposits of iron ore which may belong to the Claiborne.

Beds of this character occur in isolated areas and if of Claiborne age evidently represent outliers left in the general process of erosion. The fossils reported from these localities are not stratigraphically distinctive and the correlation with the Mount Selman formation is made chiefly on the presence of the iron ore and the general lithological character.

In the lower beds the iron exists in the form of carbonate of iron or clay ironstone, as scattered masses and nodules inclosed in the sand, in places coalescing into a bed continuous for several hundred yards. These layers are usually only a few inches in thickness and rusty from oxidation. In the southern part of Morris County, and

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[1] Science, April 1, 1910, p. 502.

[2] Kennedy, William, Third Ann. Rept. Geol. Survey Texas, 1891, p. 52.

[3] Hayes, C. W., and Kennedy, William, Bull. U. S. Geol. Survey No. 212, 1903

[4] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 36.

in the southwestern part of Cass County, and extending thence west into Morris, Camp, Upshur, and the counties lying to the west, occur deposits of brown iron ore, lying horizontally near the tops of the hills, in some places at the surface and in others overlain by 1 foot to 30 feet of sand. The ore occurs in a variety of forms, botryoidal, stalactitic, mammillary masses, etc., but its characteristic form is that of loose nodules and geodes in a ferruginous sandy matrix or consolidated into irregular beds varying in thickness from 1 foot to 10 feet. The ores were termed "nodular or geode ores" by Penrose[1] who considers them to have been formed by the alteration of clay ironstone.

LATER TERTIARY DEPOSITS.

No marine deposits of Tertiary age later than Claiborne have been recognized in this part of northeastern Texas. Until near the close of the period the region appears to have been above sea level, or if temporarily depressed and subjected to sedimentation the deposits were subsequently removed by erosion. During Oligocene, Miocene, and early Pliocene times a general uplift caused the seacoast to recede toward the south to near the present coast. As a result of this elevation the region was subjected to more or less profound erosion and reduced to a level estimated by Veatch [2] to have been 500 to 700 feet above the present sea level.

In late Pliocene time there was deposited over the worn land surface a sheet of silts, sands, and gravels to which the name Lafayette was given by Hilgard.[3] In this part of northeastern Texas these deposits appear to have been removed by subsequent erosion. Redeposited remnants, however, occur as high-level terraces along the valleys and also as a thin gravel veneer over the rolling uplands.

QUATERNARY SYSTEM.

PLEISTOCENE SERIES.

PORT HUDSON FORMATION.

During the long interval of erosion which succeeded the deposition of the Lafayette formation the gravels derived from that formation were concentrated in many places by stream action. Then came a slow subsidence, which converted the bottom lands into swamps and caused the deposition of the Port Hudson formation of sand, silts, and clays containing remains of animals and plants characteristic of

[1] Penrose, R. A. F., jr., First Ann. Rept. Geol. Survey Texas, 1890, pp. 76–81.
[2] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 44.
[3] Hilgard, E. W., Am. Geologist, vol. 8, 1891, p. 130. See also McGee, W J, Twelfth Ann. Rept. U. S. Geol. Survey, pt. 1, 1891, pp. 347–521. Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 44–46.

swamp conditions. In these old valley deposits the streams cut newer valleys of moderate extent, remnants of the Port Hudson now occurring as flat-topped terraces along the principal streams, at no great depth below the present flood plains. The distribution of these terrace deposits in northeastern Texas is shown approximately on Plate I (p. 16). In western Bowie and eastern Red River counties, as will be seen, the terraces belonging to the Red River and Sulphur Fork valleys, respectively, coalesce over the intervening areas. Moreover, over most of the area north of Sulphur Fork a mantle of gravel occurs with some patches of gravel which are possibly due to the augmentation of the rivers by glacial flood waters.

Along Red River, in Bowie and Red River counties, the height of the outer terrace is about 70 to 75 feet above the present flood plain; while about 35 or 40 feet below this another well-marked terrace was noted in places.

RECENT.

EROSION.

A slight elevation following the Port Hudson period of deposition caused a renewal of stream activity with the excavation of the present valleys and the formation of the present topography. The amount of erosion accomplished in this later period, however, is small as compared with that which was effected in late Tertiary and early Quaternary times. The chief changes consisted in the alluviation of river bottoms, the destruction of river banks, and the formation of cut-offs by the wandering of the rivers. In northeastern Texas the topographic and geologic changes have been slight.

NATURAL MOUNDS.

Scattered over the sandy areas in this ana adjoining regions are innumerable small mounds varying from 20 to 100 feet in diameter and from 2 to 5 feet in height. They are especially well developed over the Port Hudson terrace plains, but occur also to some extent over the hill lands. In the Cretaceous area, outside the limits of the Port Hudson deposits, they are confined to the sandy belts representing the outcropping of the Blossom and Woodbine sands. In general, these mounds are rudely circular in outline, but in some localities they show a well-marked tendency toward a northeast-southwest elongation.

Mounds of similar character have a wide distribution and their origin has been a subject of much discussion. The problem is a perplexing one and remains as yet without satisfactory solution. Veatch, in a very complete review, groups the possible agencies of formation as human, animal, water erosion, eruptions, and wind.[1] Of the theories

[1] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 55-59.

included under these heads he concludes that those relating to the dune and the ant hill are the best supported. In a later paper, Campbell [1] summarizes the various hypotheses as (1) human; (2) animal, such as ground squirrels, gophers, and prairie dogs' burrows; (3) ant hills; (4) water erosion; (5) chemical solution; (6) wind action; (7) physical or chemical segregation; (8) glacial action; (9) uprooted trees; (10) spring and gas vents; and (11) fish nests. In his discussion he disposes of all of these hypotheses except that which ascribes the origin to burrowing animals, and adds, "but whether the mounds are due to ants or to small rodents the writer is unable to say." He admits that many mounds may have been produced by wind action, and that probably many others of an entirely different origin may have been modified by the wind, but maintains that "the great number of natural mounds are far too symmetrical in profile and in plan to have been formed by wind-blown material."

In view of the wide distribution of natural mounds and their occurrence in regions widely separated, some doubt may reasonably be entertained as to all having been formed by the same agency. The writer's observations in northeastern Texas has led him to favor the theory which ascribes the mounds in this region to wind action. The fact that they are not uniformly circular but are at times elongated, and that the position of the longer axis is parallel with the direction of the prevailing winds, seems to offer some support to this theory. However, the time at the disposal of the writer did not allow full opportunity to determine satisfactorily the extent to which the linear arrangement prevails and further observations are needed to settle the matter.

STRUCTURE.

The warping of the old Jurassic land surface, which preceded and accompanied the deposition of later formations, gave the beds a gentle slope toward the Gulf, amounting, in Lamar County, to about 55 feet per mile.[2] This dip was estimated by taking the elevation by barometer of the base of the Goodland limestone north of Hugo, Okla. (475 feet above tide), and comparing it with the elevation as shown in the Paris well, 1,125 feet. The distance is about 29.1 miles, in which the rocks are carried down 1,600 feet, or about 55 feet per mile.

As to the attitude of the beds south of Sulphur Fork, no definite data are obtainable. If, however, this region has been affected by

[1] Campbell, M. R., Jour. Geology, vol. 14, 1906, pp. 708-717. Contains a fairly complete list of papers relating to the subject.

[2] Using the observed dips of the Goodland limestone, Taff estimated the dip at about 50 feet per mile, and predicted that the water-bearing Trinity sand would be found at Paris at a depth of 1,500 feet. In the well subsequently drilled there, however, these sands were reached at a depth of 1,635 feet, to which 91 feet must be added for the difference in elevation between the bench mark on the post-office building (601 feet) and the top of the well.

the Red River-Alabama Landing fault, as indicated by Hill [1] and Veatch,[2] the strata south of Sulphur Fork must lie nearly horizontal.

If, as suggested by Veatch, the Red River fault and the Alabama Landing fault constitute parts of the same general displacement, the fault line would occupy approximately the position of the Sulphur Fork, including North Fork. Owing to the covering of alluvial deposits, however, no traces of the existence of this fault can be observed except a disturbed condition of the Austin chalk beds noted by Hill [3] in the cut north of Pecan Gap station.

According to Hill and Veatch the displacement of this fault is about 600 feet, with the downthrow to the north. It is scarcely conceivable that a displacement of 600 feet could escape recognition in the vicinity of North Fork, as it would be sufficient to bring the Austin chalk to the surface in Delta County. The writer was at first inclined to think that the chalk near Enloe might be the Austin brought up by faulting, but his further study of the stratigraphic relations and faunal contents of these beds did not support this conclusion. It seems probable, therefore, that if any displacement has occurred here its extent is much less than 600 feet.

UNDERGROUND WATER.

SOURCE.

All underground water is derived from rainfall. A considerable part of the rainfall runs off the surface and is carried away by streams; a part is removed by evaporation or consumed by living organisms and in chemical work; and the remainder sinks into the soil and unites with the underground waters, to reappear in part as springs at more or less distant points.

The proportion of the rainfall disposed of by evaporation and run-off and by percolation and absorption into the rocks, varies with climatic, topographic, geologic, and other conditions. The portion which sinks into the ground furnishes the entire supply for both deep and shallow wells, and it is this alone that need be considered so far as underground waters are concerned.

The percentage of the rainfall which sinks into the earth is determined by (1) the character of the rains, whether slow and steady or of a torrential nature; (2) the topography of the country, whether flat or with many steep slopes; (3) the character and amount of vegetation covering the surface; and (4) the porosity of the soil and the physical character and state of saturation of the underlying beds.[4] The surface of the zone of saturation varies with climatic conditions,

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[1] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, p. 384.
[2] Veatch, A. C., op. cit., pp. 68-69.
[3] Hill, R. T., op. cit., p. 342.
[4] Veatch, A. C., op. cit., p. 70.

rising in periods of long continued rains and sinking during periods of drouth. In regions of excessive rainfall and limited evaporation its upper limit usually coincides with the surface, whereas in arid regions it may be several hundred feet below the surface. Moreover, the upper line or limit of saturation—the water table—conforms in a general way to the surface, rising somewhat higher under elevations than under depressions.

AVAILABILITY OF UNDERGROUND WATER.

The availability of the water that sinks into the soil depends on (1) the adequacy of the supply and the quality of the water contained in the rock formations, and (2) the depth at which it may be encountered and the height to which it will rise in wells. The permanency of the supply depends on the capacity of the rocks for absorbing and transmitting water, and the quality of the soluble minerals contained in the beds through which it passes. The feasibility of obtaining water at any locality depends on the position and elevation of the rock strata and the structural relations which control the arrangement of the rock masses. It is evident, therefore, that the controlling factors in the utilization of underground water are the composition of the rocks and their arrangement in sheets and masses, or, in other words, the geologic structure.

CAPACITY OF ROCKS FOR IMBIBING WATER.

The capacity of rocks to imbibe moisture varies with their physical structure. Most of the water in rocks occurs in pores and interstices, the larger part of the world's well-water supply being derived from saturated porous beds, only a small part of it being obtained from caverns or large cavities. Practically all rocks, however compact they may appear to the eye, have interstices and small cavities in which water may be stored. The degree of porosity of rocks, however, differs greatly in different rocks, being highest in open-textured loose sands, sandstones, gravels, and chalks, all of which have great capacity for imbibing water, and lowest in close-textured clays, slates, marbles, and granites, which have very small capacity for absorbing and transmitting water. Some rocks, however, such as granite, which in their original condition are almost impervious, become water bearing through the development of fractures and crevices.

The capacity of rocks for transmitting water is different from their capacity for imbibition. In certain fine-grained rocks the pore spaces are so small that they will not readily transmit water. Hence rocks like chalk or brick, which absorb water freely, transmit it slowly, whereas others with no greater total pore space transmit it readily. Sandstones, for instance, vary greatly in texture and consequently in their capacity for carrying water.

ARTESIAN WATERS DEFINED.

Underground waters which under the influence of hydrostatic pressure tend to rise to the level of the water surface at the highest point from which the pressure is transmitted are known as artesian waters. Hence an artesian well is any well in which the water rises under artesian pressure. If the water rises to the surface the well is known as a flowing artesian well; if the water fails to rise to the surface it is known as a nonflowing artesian well. An artesian system is any combination of geologic structural features—such as basins, planes, joints, or faults—in which waters are confined under artesian pressure and will rise if an outlet is afforded by a well or other perforation. An artesian basin is a basin of porous-bedded rock in which, as a result of synclinal structure, the water is confined under artesian pressure. An artesian slope is a monoclinal slope of bedded rocks in which water is confined beneath relatively impervious covers owing to the obstruction to its downward passage by the pinching out of porous beds, by a change in character from pervious to impervious, by internal friction, or by dikes or other obstructions. An artesian area is an area underlain by water under artesian pressure.

CONDITIONS THAT DETERMINE ARTESIAN WELLS.

The distribution of underground water depends on the arrangement of the rocks in sheets and masses. If the strata are horizontal they constitute storage systems in which the water is under little or no artesian pressure and will escape only laterally as seepage springs where the beds are cut by valleys of erosion. If the water bearing beds are inclined and are included between impervious sheets, the water absorbed over the outcropping area will sink under the influence of gravity and if reached by a well at any point beyonp the limit of its outcrop will tend to rise therein to the level of complete saturation.

The water pressure and, therefore, the height to wnich water will rise depend on several conditions: (1) On the elevation of the groundwater table at the outcrop or source, which in turn depends on the uneven elevation and surface conformation of the catchment area; (2) on the loss by friction in transmission, a factor which depends on the size of the spaces between the grains and is not by any means uniform even in the most even-textured beds; and (3) on the loss by leakage resulting from increases in porosity of the inclosing beds from faults, joints, and other natural breaks, and, locally, from the multiplication of wells within a restricted area. Hence the level to which water will rise in wells is always somewhat lower than the lowest point of the outcrop of the containing beds and becomes lower and lower with increasing distance from the catchment area.

The factors controlling the occurrence of flowing wells may be briefly stated as follows: (1) There should be relatively porous beds suitably situated to collect and transmit the water; (2) the water-bearing beds should be inclosed between other relatively impervious layers to confine the water; and (3) the level of the ground-water table at the source should be enough higher than the surface at the point where the well is located to compensate for the loss of head due to resistance and leakage. As these conditions vary from point to point it is evident that both flowing and nonflowing artesian wells

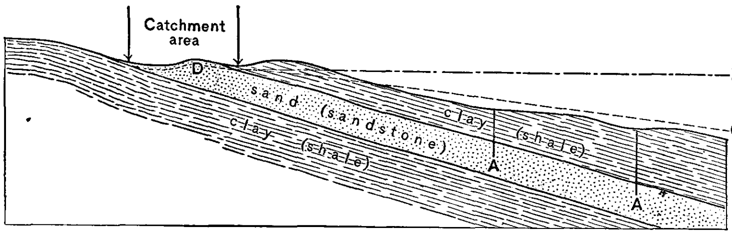

FIGURE 3.—Diagram showing the common arrangement of factors producing artesian wells. *A*, artesian wells; *B*, head of water if there were no loss by resistance or leakage; *C*, actual head of hydraulic gradient; *D*, ground-water table at outcrop.

may occur within the same artesian area. The accompanying diagram (fig. 3) illustrates the most common arrangement of factors producing artesian wells.

ARTESIAN WATERS IN NORTHEASTERN TEXAS.

GENERAL GEOLOGIC RELATIONS OF THE WATER-BEARING BEDS.

Within the area here considered the known water horizons occur in the Cretaceous and Tertiary and may be represented as follows:

Water-bearing formations in northeastern Texas.

System.	Formation.	Character.
Tertiary (Eocene).	Wilcox ("Sabine") formation.	Sands and clays. Certain beds water bearing. No correlation possible.
	Midway formation.	Mostly clays, some thin beds of limestone in places. No water. Some sandy beds slightly water bearing.
Upper Cretaceous (Gulf series).	Navarro formation and Taylor marl.	Clay marls, not water bearing. Glauconitic sands. An important water horizon in Arkansas; of doubtful utility in Texas.
		Clay and chalk marls in places sandy. Near the base a bed of sand appears to be water bearing, but it has not been developed.
	Austin group.	Chalk (Annona) and chalk marl (Brownstown). Not available as a source of water. Contains hard water where porous.
	Eagle Ford clay.	Blossom sand member. Water bearing. Clays. No water, or limited supplies of highly mineralized water.
	Woodbine sand.	Sands and shales. The sands are usually water bearing. Several water horizons.

Water-bearing formations in northeastern Texas—Continued.

System.	Formation.	Character.
Lower Cretaceous (Comanche series).	Washita group.	Impure limestones and usually nonwater-bearing marls; 35 feet of sand [a] with water occurring in the Paris well.
	Fredericksburg group (Goodland limestone).	Massive white limestone. No water.
	Trinity sand.	Sands and clays with thin beds of limestone. Important water horizon in Texas; becomes of less importance eastward.

[a] According to Mr. J. A. Porter (p. 46), the seventh water horizon occurred under a limestone "cap-rock" at 1,635 feet. The sandstone is evidently the one mentioned by Hill (p. 46) as occurring at 1,650–1,685 feet, but Hill does not state that it is water bearing. The discrepancy as to the lower portion of the Paris record is not easily reconcilable, there being no reliable data available for that part of the hole.

CRETACEOUS SYSTEM.

TRINITY SAND.

The Trinity sand is an important water-bearing horizon, supplying a large number of wells in central Texas, where it is divisible into several formations, known as the Trinity group. In the main the beds consist of fine, clean, white sand pressed compactly together and popularly known as "packsand." The group includes some calcareous beds, which increase in thickness toward the southern part of the State, and are there known as the Glen Rose limestone.

The outcrop of the Trinity sand occurs in Oklahoma several miles north of Red River. This catchment area constitutes a belt from 5 to 10 miles in width, extending nearly due east into Arkansas. From this line of exposure the southward dip of the beds carries them beneath all this part of northeastern Texas to depths proportionate to the distance from the outcrop. The only available record of the depth to the Trinity sand in northeastern Texas is that of the well at Paris (p. 45), where it was reached at about 1,735 feet. From this record and from the depth of the sands as shown by a well at Hugo the dip of the formations is estimated at about 56 feet per mile.

Sands being near-shore formations they gradually give place seaward to contemporaneous clays and limestones formed in deeper and quieter waters. This change consists both in an increase in the argillaceous and calcareous constituents of the rocks and in a wedging out of the sands. This imbrication of the strata is shown in the ideal diagrammatic section of the Cretaceous rocks in northern Texas and southwestern Arkansas given by Taff [1] (fig. 4, p. 39).

Water falling upon the outcrop of the Trinity sand or carried over it by rivers sinks into it readily, and for a certain distance from the outcrop these sands furnish an abundant supply of water of excellent quality. Farther away, however, the water becomes affected by

[1] Taff, J. A., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, p. 697.

mineral constituents taken up in its underground passage, and is likely to be too highly mineralized for ordinary use.

The conditions which control the height to which water will rise in wells has been explained (p. 37). Within the main zone of saturation water pressures in a formation are likely to be unequal, owing to differences in the coarseness of the strata, leakage through springs, and local irregularities in the additions supplied by rainfall. Hence there is a gradual decline in the pressure head with increase of distance from the line of outcrop. In the absence of accurate relief maps of northeastern Texas any statement of the areas in which flowing wells may be expected from any particular horizon can be approximate only. At its outcrop north of Hugo the Trinity sand stands about 500 feet above sea level. The elevation of the top of the well at Paris is 510 feet. Water from the Trinity would therefore lack 10 feet of rising to the top even if it sustained no loss of pressure. The amount of such loss is unknown, but assuming it to be 30 or 40 feet the water from the Trinity sand would lack 40 or 50 feet of reaching the surface at Paris. The area in which flowing wells may be expected from the Trinity sand in the vicinity of Paris or at points equally distant from the outcrop must therefore have an altitude of less than 450 or 460 feet above sea level, hence these wells would be confined to the valley of Red River.

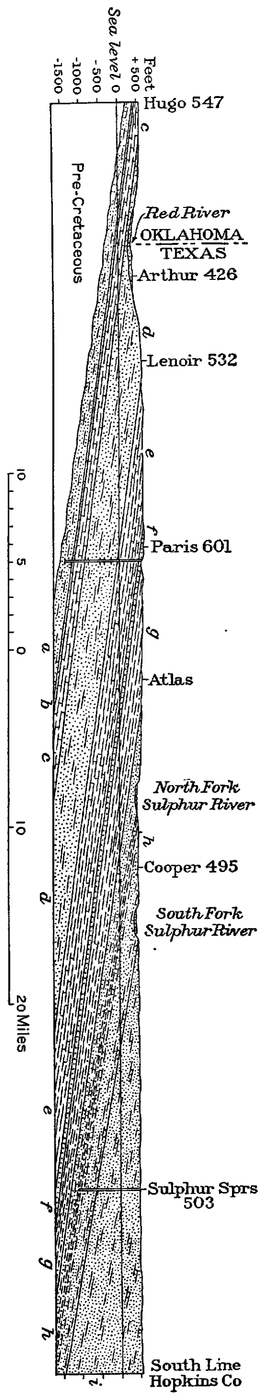

FIGURE 4.—Profile section showing water horizons. *a*, Sands and interlaminated clays; *b*, limestones; *c*, limestones and shales; *d*, mostly sands with some clays; *e*, clays with thin limestones; *f*, Blossom sand member of Eagle Ford clay; *g*, Annona chalk and Brownstown marl; *h*, sandy and clay marl, some chalk; *i*, sands, clays, and sandstones.

WASHITA GROUP.

The Washita group has not hitherto been recognized as including water-bearing beds. Its mention here is based on the somewhat doubtful assignment to it of the seventh water horizon in the

Paris well (p. 45). Even if the seventh horizon belongs to the Washita, some doubt exists as to whether the water came from that level (sandstone No. 24 of the section) or from some lower horizon. Hill in his section (p. 46) gives a sandstone at 1,650 to 1,685 feet, but does not credit it with having water. Mr. Porter's log shows the seventh water horizon at 1,635 feet just below a limestone, a depth very close to that of the bed (24) shown in Hill's section.

A point in favor of assigning the bed to the Washita group is the statement of Mr. Porter that the water from it rose to within 2 feet of the surface. The evidence available does not support the view that water from the Trinity would rise so high. The Washita, on the other hand, outcrops in the vicinity of Hugo at a higher level than the Trinity and can reasonably be expected to furnish flowing wells at a level of 500 to 510 feet in Lamar County. In general the Washita group consists of shales and limestones, but it contains some arenaceous beds in the upper part (Denison formation; the Pawpaw beds of Hill), and these may contain water in some places.

Flowing wells may be expected from the Washita group, if water bearing, along the south side of Red River in Lamar County at altitudes of 500 feet and under. Toward the east the pressure evidently declines because of the gradual lowering of the surface of the outcropping beds in the territory. The area in which flowing wells may be had from this horizon is probably confined to Lamar County and the extreme northern part of Red River County.

WOODBINE SAND.

The Woodbine formation consists of alternations of sands, sandstones, clays, and marls, commonly lignitiferous and glauconitic and containing iron pyrite. The character of the waters also indicates that some of the beds contain more or less iron and salt. The lower portion of the formation, called by Taff and Hill the Dexter sand, has layers of considerable thickness, which are free from mineral matter and rather porous. The water from this horizon (sixth) in the Paris well (p. 45) rose to within 6 feet of the surface. Its character was not adequately tested, however, as it was allowed to mingle with the more mineralized waters from the higher beds. The upper portion of the Woodbine includes several beds of sand which are water bearing, but they contain quantities of vegetable and animal remains which, together with soluble salts, so impregnate the water as to render it useless.

North of Paris Red River flows upon the outcrop of the Woodbine formation, the sands appearing on both sides of the river in the bluffs bordering the alluvial bottoms. On the south side of the river the sands outcrop in a belt several miles wide, extending through the northern part of Fannin, Lamar, and Red River counties, except where covered by Recent alluvial formations.

EAGLE FORD CLAY.

Lower clays.—The lower portion of the Eagle Ford consists of blue marly clays containing hard concretions, with occasional layers of sandy shale. The sandy constituents increase downward and the formation gradually passes into the Woodbine sand below. This part of the formation is for the most part dry, but in places it contains small quantities of water, which, however, is too highly charged with deleterious substances to be used.

Blossom sand member.—The upper 50 to 80 feet of the Eagle Ford clay consists of glauconitic sands irregularly interlaminated with clays. On exposure the sands become red from the oxidation of the contained iron. These sands outcrop in a narrow band from 1 mile to 2 miles wide, extending east and west across Red River, Lamar, and Fannin counties and adjoining on the south the Eagle Ford black prairies or clay belt. The towns of Blossom, Paris, and Detroit are located on the outcrop of these sands, the first named giving the name to the beds. The shallow wells along the outcrop commonly range from 25 to 75 feet in depth and yield an abundant supply of soft water, which in some wells is of good quality, but which in most is impregnated with variable amounts of mineral matter. The quality of the water from the embedded portion of this sand seems to be good, as shown by the Clarksville waterworks wells, which derive their supply from it.

The sands appear to have a thickness of more than 60 feet generally, but only a small part of the member is water bearing—a fact that must be taken into account in sinking wells to this horizon.

AUSTIN GROUP.

The Austin group consists chiefly of chalks (Annona chalk) and chalk marls (Brownstown marl) and is in the main destitute of water. In places, however, the beds are somewhat porous and may then furnish limited supplies of very hard water.

NAVARRO FORMATION AND TAYLOR MARL.

The Navarro formation and Taylor marl consist of clay and sandy marl, with some sand and chalk. Near the base is a bed of chalk, which outcrops near Enloe and southwestward in the vicinity of Pecan Gap and Ladonia. Underneath the chalk is a soft yellow sand, which outcrops at Ladonia. The thickness of this sand is nowhere clearly shown, but probably does not exceed 50 or 60 feet. At Pecan Gap 30 feet of sand underlie the chalk, the base of the sand not being exposed. Portions of the sand become notably calcareous, with occasional thin chalky layers. Downward the sands grade into sandy yellow clay containing many *Exogyra*.

The outcrop of this sand constitutes a narrow band through the northern part of Delta County and southwestward in Hunt County through Wolf City. Its water-bearing character has not been tested underground, but its character and outcrop indicate that it may constitute a source of supply in a belt a few miles wide along its south border. As the catchment area is not extensive it is not likely to prove a very important horizon and will probably not be available for wells except in a comparatively small area.

In Arkansas the Nacatoch sand (see p. 25) constitutes an extensively exploited water horizon. At Texarkana it contains no less than eight water-bearing beds, two of which (at 1,020 and 1,174 feet, respectively) showed strong pressure. In Texas these beds show a diminution in their porous sandy character, and though still water bearing to some extent are of less importance in this respect than in southern Arkansas. In southern Delta County a narrow belt of glauconitic sandy shales and sands, which apparently represent this formation, outcrops along the north side of South Fork and just west of Commerce. The outcrops are meager, however, and the character and relations of the beds are not clearly shown. In a well 100 feet deep at Sulphur Bluff these sands were reached at 30 feet and were found to contain water, which, however, was not used. The overlap of the Eocene south of Sulphur Fork has covered the higher portions of the Cretaceous and nothing can be said of these beds here.

TERTIARY SYSTEM.

WILCOX ("SABINE") FORMATION.

The Wilcox ("Sabine") formation in this region consists of ferruginous and lignitiferous sands, ferruginous sandstones, and blue and brown clays, with one or more beds of lignite and local beds of iron ore. The formation is generally water bearing, but as its character changes from place to place no definite correlation can be made between the water sands in different localities. Owing to the lenticular character of the bedding it is probable that the water sands are of local extent only and occur in different positions within the formation.

Underground-water conditions in the Wilcox formation differ materially from those in the Cretaceous. In the Cretaceous the sandy beds lie between more impervious strata, thus permitting the water to enter only at the outcrop. In the Tertiary (Eocene) no such definite relationship exists between the clays and sands, there being no well-defined persistent clay layers. The whole series being predominantly sandy the water is relatively free to penetrate the beds at any point. Hence the head in any case is dependent not on the height of the ground water table at the outcrop of the horizon tapped, but on its height near the well.[1]

[1] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 81–82.

From the evidence supplied by the Sulphur Springs well (see p. 61) it would appear that below a depth of 50 feet in that vicinity the beds of the Wilcox are largely barren. At Mount Vernon, however, 20 to 25 miles farther east and about 25 feet lower, an abundant supply of water is found at about 400 feet. At Mount Pleasant no water was found below the surface sands to a depth of 300 feet, but at Pittsburg, 12 miles south, 33 feet of water sand occurs at 151 to 184 feet. At Daingerfield, 15 miles east of Pittsburg and at about the same level (400 feet above tide), the gin well is apparently supplied from the same bed at a depth of 186 feet, the water rising to within 20 feet of the surface. This sand probably has its outcrop somewhere between Mount Pleasant and Pittsburg. At Jefferson a well whose top is 196 feet above tide obtains water at a depth of 830 feet.[1]

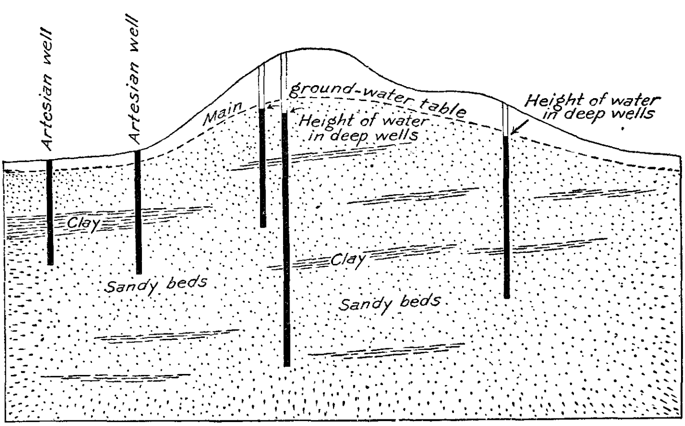

FIGURE 5.—Diagram showing water conditions in the lower Eocene strata in northwestern Louisiana and southern Arkansas. The beds are predominantly sandy, with irregular discontinuous clay masses; water is relatively free to pass to any part of the beds, and the hydraulic head depends on the local position of the ground-water table rather than on its position at the outcrop of the water-bearing beds.

At Hawkins, in the valley of the Sabine River, in Wood County, a flowing well is reported at a depth of 200 feet. The elevation of the town is 394 feet.

In general the water-bearing character of the Wilcox formation beds is controlled by the variation in the porosity of the beds from place to place, and hence the successful development of a well depends on finding a bed coarse enough to act as a natural horizontal strainer and so aid in removing the water in the adjoining finer beds. Although the sand beds vary greatly in physical character and thickness within short distances, there are, nevertheless, certain beds in which the chances of developing a satisfactory well are greater than in others. Of these the most important are located toward the top of the formation and are represented in the Pittsburg and Daingerfield wells.

[1] The authority for the depth of this well is Mr. J. M. De Ware, of Jefferson. In Hill's report (Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 414) the depth of this well is given as 802 feet.

SURFICIAL SANDS AND GRAVELS.

The irregular deposits of sand and gravel of late Tertiary and Quaternary age, which in places overlie the older Tertiary and Cretaceous beds, are of varying value as water carriers. Wells in these beds situated on the hills are likely to be of some slight local importance. In the larger river valleys, however, they may yield large supplies.

REVIEW BY COUNTIES.

LAMAR COUNTY.

Geographic relations.—Lamar County adjoins Red River, in the extreme northwestern part of the area included in this report. It comprises an area of 903 square miles and in 1910 had a population of 46,544. Its county seat and chief town is Paris, with a population of 11,269. The county is traversed by the Texas & Pacific, St. Louis & Southwestern, and Texas Midland railways.

The drainage of the county is divided about equally between Red River and North Fork of Sulphur River, the divide between the two systems passing east and west across the county near the middle. The general slope is toward the southeast. The surface is rolling, without pronounced relief, the drainage ways being but moderately incised below the general plain level.

Geology.—The south half of the county is underlain by light to dark-brown and jet-black clay or clay loam designated Houston clay and Houston black clay by the Bureau of Soils; these, constituting what is locally known as black waxy land, are residual soils derived from the weathering of the clay and chalk marls of the Austin group. Northward from Paris the gray sandy clay loam derived from the Eagle Ford clay extends to the vicinity of Lenoir, from which point north to the river a strip of sandy soil 2 to 10 miles wide represents the outcrop of the Woodbine sand.

Lamar County lies upon the outcrop of the lower half of the upper Cretaceous, comprising within its boundaries the Woodbine, Eagle Ford, Brownstown, and Annona formations and the Taylor marl, which outcrop in successive belts extending east and west across the county. North of the Brownstown area is a strip of sandy soil 1 to 2 miles wide which represents the outcrop of the upper arenaceous layers of the Eagle Ford, to which in this report the name Blossom sand member is given. The approximate distribution of the outcrops of the different formations will be seen on the map (Pl. I). Within the area of the Eagle Ford clay a number of isolated patches or outliers of overlying formations have not been entirely removed by erosion. No attempt has been made to map these areas. The strata have a dip of 50 to 60 feet per mile toward the south-southeast.

Water resources.—Throughout the clay-land area cisterns and tanks constitute practically the sole source of water supply in Lamar County. Paris derives its supply from a rain reservoir about 6 miles west of town. In 1896 the city made a determined effort to develop an underground supply, but without satisfactory results. Shallow wells and springs are common in the area of the Woodbine sand, the supply for the most part being ample and the quality good.

Although the Trinity sand underlies the whole county (see fig. 4) only in the northern part is it near enough to the surface to be practically available. Its catchment area northward in Oklahoma is lower than the surface of most of Lamar County, hence flowing wells from this horizon can be expected only in the low-lying districts, notably along the valley of Red River.

A well put down by S. J. Wright on the banks of Red River opposite the mouth of Kiamichi River is reported to have found an abundant flow of water in these beds at a depth of 301 feet, the water having sufficient force to rise to a considerable height above the surface. Owing to the caving of the well, the drill was lost and the well abandoned.

The Woodbine sand outcrops in the northern part of the county and over its area the ground-water table can be reached by wells at depths of 20 to 50 feet. Southward from the outcrop the sands lie at constantly increasing depths. At Paris the first water sand of this formation was found at 600 feet.

A detailed section of the Paris well has been kindly furnished by Mr. John A. Porter, the superintendent. The boring, which was made by the city waterworks, is located 2½ miles east of the city square. The elevation is 510 feet above tide (91 feet lower than the United States Geological Survey bench mark on the Government building, which reads 601 feet). The well was completed December 19, 1906.

Record of the Paris well.

Formation.[a]		No.	Character.	Thickness.	Depth.
				Feet.	*Feet.*
Eagle Ford clay.	Blossom sand member.	1	Sand with thin soil on top	60	60
		2	"Packsand;" first water	20	80
		3	Blue marl	100	180
		4	Blue marl with trace of sand at top	320	500
		5	Marl of lighter color; second water at 570; rose to within 110 feet of surface.	100	600
Woodbine sand.		6	Gray sandrock	50	650
		7	Marl	125	775
		8	Sandrock; third water; rose to within 100 feet of the surface	8	783
		9	Marl	175	958
		10	Gray sandrock; fourth water; rose to 75 feet from surface	25	983
		11	Marl	66	1,049
		12	Gray sandrock; fifth water; rose to 30 feet from surface	31	1,080
		13	Marl	33	1,113

[a] Identifications by the writer.

Record of the Paris well—Continued.

Formation.	No.	Character.	Thick-ness.	Depth.
			Feet.	*Feet.*
Woodbine sand.	14	Red sandrock	52	1,165
	15	Sandrock and clay	6	1,171
	16	Sandrock with indications of lime; sand almost white	105	1,276
	17	Unrecorded; "was drilled while sand bucket was being drilled out."	39	1,315
	18	Marly lime and sand } Sixth water; rose to within 6 feet of the surface.	33	1,348
	19	Sandrock	39	1,387
	20	Loose sand	25	1,412
	21	Gravel	8	1,420
Washita group and Trinity sand.	22	Sand, followed in succession by shell rock (8 to 10 inches) and alternating layers of limestone and marl darker below.	130	1,550
	23	Unrecorded; said to penetrate limestone at the bottom	85	1.635
	24	Unrecorded; sand at top; seventh water, which rose to within 2 feet of the surface.	360	1,965

The above record to a depth of 1,550 feet (Nos. 1 to 22) corresponds with that published by Hill.[1] The remaining portion of Hill's record, which stops at 1,726 feet, is as follows:

Record of lower part of Paris well (by Hill).

Formation.	No.	Character.	Thick-ness.	Depth.
			Feet.	*Feet.*
Washita group.	23	Unrecorded	100	1,650
	24	Grayish friable sandstone	35	1,685
	25	Impure argillaceous limestone with fossils	15	1,700
	26	Impure limestone with *Gryphæa washitaensis*	10	1,710
Goodland limestone.	27	White limestone resembling Goodland limestone	15	1,725
	28	Hard arenaceous limestone with *Pecten* and *Anomia*	+1	1,726

According to Porter, water was found in sand at 1,635 feet. This is evidently the sand noted in Hill's section at 1,650 to 1,685 feet (No. 24). Hill makes no mention of water at this horizon. From the greater detail given by Hill from 1,550 to 1,726 feet it is probable he had before him the drillings from the well. Later the well was extended to 1,965 feet, but no record is available for this portion. The Trinity must have been reached at about 1,735 feet, but nothing is known of its water-bearing character.

The Paris well is located on the outcrop of the Blossom sand member, which constitutes the upper part of the Eagle Ford clay, in which five small water reservoirs were encountered within the first 100 feet. In the Woodbine, aggregating about 800 feet in thickness, are six beds of sand, five of which are water bearing. The first yielded at 570 feet a strong flow of briny water, which rose to within 110 feet of the surface; it may represent a water sand within No. 5, not otherwise noted. The second (No. 8) also yielded salty water,

[1] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 629.

which rose 10 feet higher than that from No. 5. The third at 958 feet yielded water that rose to within 75 feet of the surface, and the fourth at 1,049 feet water that rose to within 30 feet of the surface. All of the waters were briny and unfit for use. In the fifth sand (No. 19) a strong flow was reached at 1,350 feet and rose to within 6 feet of the surface. The quality of this water is unknown, as the waters from above were allowed to mingle with it. This sand is inferred to be the basement reservoir of the Woodbine, which is so prolific of wells in regions to the southward. The next water, the seventh, according to Porter, came from beneath a bed of limestone at 1,635 feet and rose to within 2 feet of the top. The failure to exclude the higher waters throws doubt on the character of those from the two lowest flows. The height to which the water rises indicates that flowing wells may be obtained from these horizons in Lamar County at localities having elevations under 500 feet.

In the area of outcrop of the Blossom sand member water is found in shallow wells at depths ranging from 15 to 50 feet. The water from many of these wells is strongly mineralized, but a notable difference is manifested by the waters of wells which are near together. The well of the Texas Midland Railway at Paris is located in these sands at an altitude of about 566 feet. The following record, which has been published by Hill,[1] was supplied by the president of the company, E. H. R. Green.

Well of the Texas Midland Railway, Paris, Lamar County, Tex.

No.	Character.	Thickness.	Depth.
		Feet.	*Feet.*
1	Residual soil grading into sand and clay	18	18
2	Black sand, water bearing, yielding 1,200 gallons per day	15	33
3	Hard barren pack sand	12	45
4	Top portion of barren joint clays	28	73

At Blossom, a station on the Texas & Pacific Railway 12 miles east of Paris, a number of wells have been sunk to depths of 15 to 40 feet. W. E. Moore's well, located near the edge of the Black Prairie, in the south part of the town, gave the following record:

Well of W. E. Moore, Blossom, Tex.

No.	Character.	Thickness.		Depth.	
		Ft.	*in.*	*Ft.*	*in.*
1	Top soil and clay	6		6	
2	Sand and clay mixed	25		31	
3	Red sand rock		10	31	10
4	Dark sand	4		35	10
5	Dark clay or slate	110		145	10

[1] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 631.

Water, doubtless coming from the sand of No. 2, rose in this well to within 30 feet of the surface. The water is not used.

A well 117 feet deep put down near the depot several years ago yields a small supply of mineralized water which is regarded locally as having valuable medicinal properties. The only soft-water well in town is that of John Carter, on the north side of the village. It is about 30 feet deep. (See analyses of water of the Blossom wells, p. 74.)

In the south part of the county the Blossom sand member apparently underlies all the black-land area and can be reached at gradually increasing depths up to 1,400 or 1,500 feet. Wells located on the Annona chalk belt will reach the sands at depths of from 300 to 600 feet. The water-bearing character of these sands underground in Lamar County has not been tested and their availability is largely a matter of conjecture. At Clarksville, in Red River County, however, they yield an ample supply of good water for the use of the city and it is quite probable tnat similar supplies may be found in them in Lamar County. In the absence of well records no definite statement can be made as to the height to which water from the Blossom sand member will rise in the county. At Clarksville the wells have an elevation of about 450 feet and the water rises to within 55 feet of the top. At their outcrop 4 miles north of town t e sands have an elevation of about 400 feet. Westward there is a rise in the surface outcrop with a corresponding rise in the water table to about 550 feet at Paris. From this it will appear that flowing wells can not be expected from the Blossom sand member in Lamar County at elevations greater than 500 to 525 feet.

DELTA COUNTY.

Geographic relations.—Delta County borders Lamar County on the south and occupies the triangular-shaped area between North and South forks of Sulphur River. It has an area of 266 square miles, with a population of 14,566; the county seat is Cooper. The county is traversed from northeast to southwest by the Texas Midland Railroad and is intersected for short distances in the northwest and southwest corners by the Gulf, Colorado & Santa Fe and St. Louis & Southwestern railroads, respectively.

The county is an eastward-dipping plain, grading from the rolling black prairie on the north and west to an almost flat surface on the east. Elevations are: Enloe, 495; Cooper, 495; Klondike, 478; and Ben Franklin, 465 feet, above sea level. It is drained entirely by North and South forks of Sulphur, the larger part going to the latter on account of the general slope. None of the drainage ways are conspicuous.

Geology.—The county is situated on the outcrop of the uppermost beds of the Upper Cretaceous as represented in Texas, South Fork following approximately the boundary between the Cretaceous and the overlying Eocene Tertiary. A single small area of Cretaceous in the form of an inlier occurs south of South Fork at Sulphur Bluff in northeast Hopkins County. Outside a narrow belt bordering South Fork the soils of Delta County are of the black waxy type characteristic of the black-prairie region of Texas.

Water resources.—In the black-land areas the water for domestic use is derived almost entirely from cisterns and tanks. In the rather small sandy areas both wells and cisterns are in use. A boring made by Mr. E. H. Bond 3 miles southwest of Cooper to a depth of 263 feet was wholly in clay marl. The section is as follows:

Record of E. H. Bond's well 3 miles southwest of Cooper, Tex.

No.	Character.	Thickness.	Depth.
		Feet.	*Feet.*
1	Black soil	5	5
2	Yellow sandy clay marl	45	50
3	Blue clay marl	213	263

No water was found except a "slow seep" from No. 2. This is the source from which the water of the shallow wells is derived, but the water is hard and brackish and little used except for stock.

In the sandy areas in the south part of the county the wells range in depth from 10 to 100 feet. The water is reported to be fairly good and the supply ample, but cisterns are coming into general use. Throughout the county rain reservoirs and tanks are relied upon mainly for stock supplies.

No effort has been made to exploit the underground waters of Delta County. A study of the geology shows that although the Trinity and Woodbine reservoirs undoubtedly extend beneath the county, they are at too great depth to be available even if they were likely to furnish a desirable quality of water, which is improbable. The estimated depth of the Trinity at Cooper is about 3,000 feet. The depth to the first water sands of the Woodbine is 1,800 to 2,000 feet and to the lowest, the only one concerning whose quality doubt exists, is 800 to 900 feet deeper. The Blossom sand member can be reached at a probable depth of from 1,200 to 1,300 feet. In the absence of any test well in the region, however, no safe prediction can be made as to its availability as a source of water supply so far from the outcrop.

The only other apparent source of underground water over the larger portion of the county is the sand bed which outcrops along the south side of North Fork. This sand evidently extends beneath the larger part of the county. From its outcrop it appears to dip south by southeast, and can be reached at increasing depths according to the elevation of the surface and the distance from the outcrop. At Commerce, Hunt County, it lies at a depth of 600 feet and, as shown by the Midland Railway well (see below), is water bearing. At Cooper the sand is estimated to lie at a depth of 500 to 600 feet. As the surface is 30 to 50 feet higher at Cooper than at the outcrop of the sand, flowing wells could not be expected, but the water would probably rise to within 50 feet of the top of the well. The width of the outcrop or catchment area of the sand is from 1 to 2 miles.

The upper sands (Nacatoch?) outcrop in a narrow belt along the south side of the county through Klondike and to the north of Commerce just over the line in Hunt County. These sands would be available for wells only in a restricted area bordering South Fork. At Horton, 4 miles south of Klondike, these sands were reached at 315 feet:

Record of well at Horton, Delta County, Tex.

No.	Character.	Thickness.	Depth.
		Feet.	*Feet.*
1	Surface sand	30	30
2	Blue "slate"	60	90
3	Black clay	225	315
4	Water sand	(?)	

At Commerce, Hunt County, which is located at about the same geologic horizon, the same sands occur at a depth of 370 to 385 feet, according to the somewhat imperfect records available.

Record of Capt. Ander's well; elevation, 548 feet, approximate.

No.	Character.	Thickness.	Depth.
		Feet.	*Feet.*
1	Soil	10	10
2	Joint clay	30	40
3	Blue shale	330	370
4	Water sand beneath a hard ledge		

Record of Texas Midland Railroad well; elevation, 548 feet, approximate.

No.	Character.	Thickness.	Depth.
		Feet.	*Feet.*
1	Blue and yellow clay	20	20
2	Thin stratum of flowing sand with 6 inches of limestone		
3	Blue sandy shale	365	385
4	White water saud	4	389
5	Hard limestone	4	393
6	Blue sandy shale	195	588
7	Hard sandstone	6	594
8	White sand with water	6	600
9	Blue sandy shale	55	655
10	Unrecorded	25	685

The depth of this well is given on the authority of Mr. L. W. Wells, assistant to the general manager of the Texas Midland Railroad, who states that the upper horizon has been cased off. The upper sands (No. 4) apparently represent the Nacatoch. The lower sands (No. 8) apparently represent the sands which outcrop near Ladonia. The statement by Hill[1] that a well 2,390 feet deep had been put down by H. G. Johnston at Commerce is an error, as Mr. Johnston writes that he has never put down a well at Commerce.

RED RIVER COUNTY.

Geographic relations.—Red River County adjoins Lamar County on the east and, like Lamar, lies between Red River on the north and Sulphur River on the south. It has an area of 1,061 square miles and a population of 28,564. The county seat is Clarksville. It is traversed from east to west by the Texas & Pacific Railway, which follows the crest of the divide between Red and Sulphur rivers.

The general slope to the southeast has the effect of throwing the principal part of the drainage into the Sulphur. The surface is rolling without marked relief and the drainage ways are for the most part inconspicuous. The most important tributaries are Pecan Bayou on the north and Cuthand Creek on the south. The plateau level ranges from about 530 feet above sea on the west to 390 feet above on the east. Detroit has an elevation of 482 feet; Bagwell, 476; Clarksville, 442; and Annona, 370.

Geology.—The geologic conditions in the northern and western parts of Red River County present essentially the same features as are found in Lamar County on the west. The outcrop of the Upper Cretaceous formations constitute a series of belts extending northeast two-thirds of the way across the county, where they disappear under a covering of Quaternary sands and gravels. In the northern part of the county the Woodbine sand appears along the south side of the Red River valley, bordered on the south by the clays of the Eagle Ford formation. Then comes the Blossom sand member of the Eagle Ford in a strip a mile or two wide extending from Blossom eastward nearly across the county to where the formation disappears beneath the alluvium of the Red River valley about 10 miles north of Annona. South of this comes the black-land area representing the outcrop of the chalk marls (Brownstown), chalk (Annona), and clay marls (Navarro and Taylor), each constituting a belt 5 to 6 miles in width, disappearing under the Quaternary deposits a short distance east of Annona. In the southern and eastern parts of the county the Cretaceous formations are entirely hidden from view by the early Quaternary (Port Hudson) deposits, which cover the higher areas,

[1] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 637.

and by the flood-plain deposits which occupy the valleys. Moreover, the Quaternary sands and gravels occur in broad, shallow depressions eroded in the Cretaceous area. A case in point is that of Cuthand Creek, the headwaters of which west of Clarksville are engaged in removing the filling of sand and gravel, occupying a depression in the surface of the chalk and chalk marls. The Annona chalk makes its appearance on the east side of this valley 6 or 8 miles southwest of Clarksville and extending northeastward constitutes the broad ridge on which the town is situated.

Water resources.—The areas in which shallow wells constitute a source of water supply are confined chiefly to the valleys of the main streams. Outside the valleys a few shallow wells, sunk in areas covered by the Quaternary sands and gravels, in places furnish an abundance of fairly good water, but not uncommonly are found to be too highly charged with deleterious substances to be used. Wells located in the northern part of the county on the outcrop of the Woodbine sand find water at depths varying from 20 to 40 feet. In general the water is good and the supply ample. The outcrop of the Blossom sand member constitutes a third but less important area of shallow wells. Water is found at a depth of 10 to 30 feet in this area, but it is likely to contain a large amount of mineral substances in solution. Wells differ greatly in the character of the water they furnish, those located near together often showing wide discrepancy.

Few surface wells have been dug in the Eagle Ford prairie or black-land areas; and such as have been attempted secure but a limited supply of water of poor quality in the seepage that finds its way along the joints of the clays and chalk.

The artesian conditions in Red River County are similar to those in Lamar County. The southward dip of the Trinity sand carries it too far below the surface to be available for wells located anywhere outside of the valley of Red River. It seems possible that flowing wells may be obtained in this formation in the lowlands bordering Red River, but in the absence of a suitable topographic map no definite prediction as to this can be made.

The Woodbine sand contains plenty of water, which when tapped by wells in the area to the south of the outcrop will tend to rise to the surface. The uncertainty of finding good water in the upper beds, however, makes these horizons of doubtful utility in this county. In an effort made some years ago to find artesian water the city of Clarksville drilled to the Woodbine sand, finding water at a depth of about 1,100 feet. The water, which was too salty for use, is reported to have been accompanied by natural gas and to have spouted out at the surface when first struck, but quickly subsided to 10 feet below the top. The elevation of the top of the well is about 430 feet, which indicates that flowing wells may be expected from this horizon in locations having an altitude less than 420 feet. In 1902 the Clarksville Ice Co. put down a well to a depth of 1,800 feet, passing two water horizons, both in the Woodbine, one at 1,000 feet and one at 1,600 feet. The water from both these horizons was too strongly charged with salt for use. It appears that no attention was paid in either of these attempts to the horizon from which the present water supply of the city is obtained.

In 1902 the city of Clarksville[1] completed two wells, finding water in sand immediately underlying the chalk and chalk marl on which the city is located. This bed, to which the name Blossom sand member has been given, was reached at a depth of about 600 feet. The water, which rises to within 55 feet of the surface, is soft but rather high in alkalies, and the supply is apparently ample. The sands from which this supply comes outcrop along Pecan Bayou about 4 miles north of town. The elevation of the outcrop is about 400 feet, as determined by the aneroid, and the top of the well 450 feet, indicating that the Blossom sand member has a southward dip here of about 130 feet per mile. Assuming this rate of dip to continue it is evident the member will not be available as a source of water supply south of a line drawn east and west 7 or 8 miles south of Clarksville. Between this line and the outcrop of the member on the north the indications are favorable for good wells in this sand, but flowing wells can be expected only in those localities whose elevations are under 400 feet.

Indications of oil and gas are reported to have been found in a well 100 feet deep on the farm of Mr. Cox, about a mile north of Detroit. If correctly reported, these evidently came from sandstone lenses in the Eagle Ford clay.

BOWIE COUNTY.

Geographic relations.—Bowie constitutes the third and most easterly of the three counties occupying the narrow divide between Red River and Sulphur Fork. Its population is 4,827. Its width from north to south varies from 25 miles at the west end to 20 at the east. The relief is low and the crest of the divide, which is occupied by the Texas & Pacific Railway, is located north of the center line of the county. The divide slopes gradually eastward, as shown by the following list of elevations taken in order from west to east: DeKalb, 407; New Boston, 352; State line, 282.

Geology.—As shown on the map (Pl. I, p. 16), the larger portion of the area included between the flood plains of the two rivers is occupied by sands and gravels of Quaternary age. A considerable area in the southern and eastern part of the county is of Eocene (Wilcox) age, the north boundary of the formation extending through Old Boston

[1] For information concerning the Clarksville wells indebtedness is acknowledged to Mayor F. B. Mason.

and crossing the railroad track in the vicinity of Whaley station. New Boston is situated in a plain underlain by clay apparently representing the outcrop of the Midway formation (Eocene).

Three miles north of Malta station, on the Freeze place, is a small outcrop of the fossiliferous clay marl belonging to the undifferentiated Navarro and Taylor. The exposure occurs on the edge of a river terrace and has an area of about 2 square miles. Calcareous clay and greensand about 25 feet in thickness are here overlain by a thin capping of Quaternary sand and gravel. The locality is noted throughout the surrounding region for the Cretaceous shells found in the clays.

Water resources.—Throughout the county water is usually found in shallow wells varying in depth from 20 to 60 feet. The quality is in general good and the supply ample except in certain elevated localities where the water-bearing sands have been dissected by erosion. Instances are noted where wells when first drilled supplied good water, but after a time became highly charged with deleterious substances, especially hydrogen sulphide (HS_2). This is probably due to the entrance of low forms of plant life or to the decomposition of iron sulphide in the sand through the accession of air.

In the area covered by the Port Hudson (Pleistocene) deposits water is found in packsand or quicksand underlying clay near the middle or base of the formation, which does not usually exceed 60 feet in thickness. In the deeper wells the water is said to occur in a black sand immediately below a sandy clay "rock." Most wells are from 20 to 30 feet in depth. A few have been extended through the Port Hudson into the underlying clays of the Midway or the Cretaceous formations, but the results generally have not been satisfactory.

Where erosion has dissected the formation, exposing a bed of clay, springs are likely to occur at the top of the clay. Such a case is seen at De Kalb, where a fine spring occurs in a ravine about one-half mile southwest of the railroad station. The water, which is of good quality, flows out at the top of a dark-brown tough sandy clay.

In the Eocene area water is found in shallow wells at varying depths, from 20 to 50 feet, according to locality. The soils of this area are chiefly red and yellow sands, grading downward into partly consolidated sands and sandy shales, portions of which consist of hard ferruginous sandstone. The water from this horizon is usually more or less strongly mineralized. Dalby Springs, four in number, derive their supply from these beds; the water from them varies somewhat, but in all is rather strongly mineralized. (See p. 74 for analyses.)

In the eastern part of the county the Wilcox formation is more or less obscured by the later deposit of the Port Hudson. In this part of the county the water occurs in the surficial sands and gravels at depths varying from 15 to 45 feet. The supply of the Texarkana Water Co. is obtained from 52 wells located in a branch valley in the northeastern part of the city. The supply comes mainly from the surficial sands at from 15 to 45 feet below the surface.

Deep wells.—While several deep wells are known to have been put down in this county, only very meager information concerning them is at present obtainable. In 1905 a boring was completed a mile south of De Kalb to a depth of 1,833 feet in the search for oil and gas. The top of the well is about 350 feet above sea level, or 50 feet lower than the station. The only record obtainable of this hole is the following, given from memory by Mr. N. E. McKinney, the president of the company:

Record of well 1 mile south of De Kalb, Tex.

No.	Character.	Thickness.	Depth.
		Feet.	*Feet.*
1	Sand and sandy clay	93	93
2	Compact bed of clay with water below	7	100
3	Unrecorded	400	500
4	White rock	530	1,030
5	Blue clay. (Showing of oil and gas at 1,503)		

Water was encountered which at first overflowed and at the time of visit stood a little below the surface. No attention was paid to the water horizons nor to the character of the water. It is probable the water which rose to the surface came from the Blossom sand member, which was evidently penetrated at a depth of about 1,030 to 1,050 feet.

In 1898 a well was put down on the public square of New Boston to a depth of 1,270 feet, according to Mr. Paul G. Ruff. The drill is said to have passed through alternate strata of blue shale and sand rock, finding at about 500 feet one flow which rose to within 40 feet of the surface and another at about 700 feet; both flows were strongly salt. Mr. C. A. Berkshire states that the drill passed through about 450 feet of blue shale and then sand and sandy shale, with a number of beds of hard rock, to a depth of 1,200 feet. The water, which occurs in the sandy beds at a depth of about 500 feet, is highly mineralized and is not used except to some extent for watering stock. It is evidently from the Nacatoch sand. The elevation of the top of the well is 350 feet.

In 1906 a test well for oil and gas was drilled at Redwater to a depth of 2,000 feet. The well, which is located 450 yards west of the station, was completed April 30, 1906. It was drilled by

J. J. Boynton, who furnishes the record. The elevation of the collar is about 286 feet above sea level.

Well of the Redwater Oil & Mineral Co., Redwater, Tex.

Formation.		Character.	Thickness.	Depth.
			Feet.	*Feet.*
Wilcox ("Sabine").		1. Soil and clay	15	15
		2. Sand and water	2	17
		3. Lignite	4	21
		4. Sand	3	24
		5. Lignitiferous sand	4	28
		6. Light colored shale	4	32
		7. Black shale	8	40
		8. Gumbo	25	65
		9. Gray sands	2	67
		10. Yellow clay	13	80
		11. Lignitiferous sand	33	83
		12. Soft gray sand	2	85
		13. Yellow clay	20	105
		14. Soft brown shale	60	165
		15. Soft light shale	17	182
		16. Gray sand	36	218
Midway 269.		17. Black shale or gumbo	47	265
		18. Blue shale	67	332
		19. Hard sand	1	333
		20. Black shale	154	487
Navarro formation and Taylor marl.	Arkadelphia 565.	21. Shale and shells; some water in shell bed at 500	113	500
		22. Blue shale	40	540
		23. Black shale	240	780
		24. Hard dark-brown sand	1	781
		25. Soft black shale	79	860
		26. Shale with shells	40	900
		27. Black shale	80	980
		28. Hard lime	28	1,008
		29. Gumbo	4	1,012
		30. Lime	5	1,017
		31. Blue shale	35	1,052
	Nacatoch (?) 232.	32. Sandy shale	21	1,073
		33. Blue shale	67	1,140
		34. Lime (or sand?)	10	1,150
		35. Blue shale	20	1,170
		36. Brown sand	11	1,181
		37. Hard packsand	2	1,183
		38. Blue shale	97	1,280
		39. Sand and clay mixed	4	1,284
		40. Hard blue shale	10	1,294
	Marlbrook (?) 716.	41. Gumbo	24	1,318
		42. Black shale	12	1,330
		43. Gumbo	8	1,338
		44. Shale	40	1,378
		45. Sand rock	3	1,381
		46. Shale	34	1,415
		47. Gumbo	70	1,485
		48. Shale and shells	5	1,490
		49. Blue shale	16	1,506
		50. Black shale	494	2,000

No record was kept of any of the water sands except Nos. 2 and 21. No. 2 (15 to 17 feet) is the source of supply for the surface wells of the neighborhood. The beds believed to represent the Nacatoch horizon (1052 to 1294) are probably water bearing. This well did not reach the Austin group, under which lies the water-bearing Blossom sand member of the Eagle Ford, but it evidently stopped not far short of it.

A comparison of this record with that at New Boston indicates that the southward dip of the formations in this locality is about 60 feet per mile.

Several wells put down in Texarkana reach the water-bearing Nacatoch sand at a depth of 800 to 850 feet. According to the superintendent, Mr. R. A. Munson,[1] the well of the waterworks company has the following record:

Record of well of Texarkana Waterworks Co.

Formation.	No.	Character.	Thickness.	Depth.
			Feet.	*Feet.*
Quaternary or Lafayette	1	Dirt, sand, and gravel	50	50
Sabine (Wilcox)	2	White sand and clay, with water	45	95
Midway (?) and Arkadelphia.	3	Dark blue clay, no water	730	825
Nacatoch	4	Sand and sand rock, water bearing	100	925
Marlbrook[a]	5	Blue clay	5	930

[a] Veatch assigns No. 5 to the Marlbrook, but the more complete record of the Oil Prospect well shows it to be evidently Nacatoch.

Analysis[1] shows the water to be highly mineralized. It is used only occasionally to supplement the supply from the shallow wells.

A well put down by the American Well & Prospecting Co. for the Home Ice Co.[2] was drilled to a depth of 1,900 feet, with the following results:

Record of well of Home Ice Co., Texarkana, Tex.

Formation.	No.	Character.	Thickness.	Depth.
			Feet.	*Feet.*
Lafayette (?)	1	Coarse gravel	6	6
Lower Eocene (?)	2	Yellow clay	29	35
Lower Eocene and Arkadelphia.	3	Blue clay	845	880
	4	Sand containing brackish water which rose within 15 feet of the surface.	20	900
Nacatoch	5	Hard sandstone	11	911
	6	Sand containing brackish water which rose within 5 feet of surface.	30	941
Marlbrook	7	Blue clay	759	1,700
Annona	8	White chalky limestone	125	1,825
Brownstown	9	Blue clay	75	1,900

A similar record is shown by a well (No. 480) which was drilled in 1907 by J. J. Boynton, as an oil prospect, 1 mile northeast of the city, and was abandoned at 1,390 feet.

The Texarkana oil prospect well is located in the creek bottom at an elevation about 305 feet. The record was furnished by Mr. J. D. Cook. The well is cased with 11⅝-inch pipe to 145 feet, with 9-inch pipe to 860 feet, and with 6-inch pipe to 1,360 feet.

[1] Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 180, 261.

[2] Idem, pp. 180, 265.

Record of well of Texarkana Oil Prospect Co.

Formation.	No.	Character.	Thickness.	Depth.	Remarks.
			Feet.	*Feet.*	
	1	Soil and clay	5	5	
	2	"Packsand"	40	45	
Recent.	3	Quicksand	10	55	
Wilcox, 145 feet.	4	"Packsand"	55	60	
	5	Hard bowlders	2	62	
	6	"Packsand"	43	105	
	7	Quicksand	5	110	
	8	"Packsand"	35	145	
	9	"Hard rock"	3	148	
	10	Blue shale	27	175	
	11	"Hard rock"	44	179	
	12	Black shale	10	189	
	13	Gravel	20	209	
	14	"Hard rock"	1	210	
	15	Blue shale	8	218	
	16	"Packsand"	2	220	
	17	"Gumbo shale"	26	246	
	18	Gravel	4	250	
	19	Shell rock	4	254	
	20	Blue shale	3	257	
	21	Gumbo	24	281	
	22	Rock	4	285	
	23	Gumbo	18	303	
Midway, 289 feet.	24	Rock	5	308	
	25	Blue shale	10	318	
	26	Gravel	3	321	
	27	Shale	15	336	
	28	Sand	4	340	
	29	Gravel	8	348	
	30	Gumbo shale	20	368	
	31	"Rock"	6	374	
	32	Shale	2	376	
	33	Soft black shale	5	381	
	34	Hard shale	3	384	
	35	"Rock"	4	388	
	36	Shale	7	395	
	37	Gravel	2	397	
	38	"Gumbo shale"	35	432	
	39	Gravel	2	434	
	40	Gumbo	38	472	
	41	Blue shale	30	502	
	42	"Bowlders"	3	505	
	43	Blue shale	37	542	
	44	"Bowlders"	2	544	
	45	Gumbo	16	560	
Arkadelphia, 408 feet.	46	"Bowlders"	4	564	
	47	Shale	108	672	
	48	Lime	18	690	
	49	Blue shale	10	700	
	50	Gumbo	14	714	
	51	Blue shale	20	734	
	52	Gumbo	102	836	
	53	"Rock and bowlders"	6	842	
	54	Gray sand	2	844	
	55	Gravel	2	846	
	56	Blue shale	4	850	
	57	"Hard sand" (sandstone)	20	870	9-inch casing to 860 feet.
	58	"Packsand"	8	878	
	59	Gray sand, water	35	913	
	60	"Hard rock"	4	917	
	61	"Hard sand," water	10	927	
	62	Shale	30	957	
	63	Loose sand, water	13	970	
	64	"Rock"	6	976	
	65	Shale	44	1,020	
Nacatoch, 347 feet.	66	Black sand, water	20	1,040	Strong flow, came
	67	Shale	10	1,050	almost to top.
	68	"Rock"	1	1,051	
	69	Shale	16	1,067	
	70	"Rock"	6	1,073	
	71	Hard sand, water	25	1,098	
	72	"Rock"	3	1,101	
	73	Gray sand, water	38	1,139	
	74	"Rock"	3	1,142	Water comes within
	75	Blue shale	10	1,152	25 feet of the top.
	76	"Hard rock"	4	1,156	
	77	Soft sand, water	14	1,170	
	78	"Crevice rock"	4	1,174	
	79	Black sand, water	15	1,189	Strong pressure water.

Record of well of Texarkana Oil Prospect Co.—Continued.

Formation.	No.	Character.	Thickness.	Depth.	Remarks.
			Feet.	*Feet.*	
Marlbrook, 441 feet.	80	Shale	2	1,191	
	81	Gumbo	30	1,221	
	82	Blue shale	8	1,229	
	83	Gumbo	21	1,250	
	84	Black shale	16	1,266	
	85	Gumbo	6	1,272	
	86	Shale	8	1,280	
	87	"Crevice rock"	12	1,292	
	88	Gumbo	20	1,312	
	89	Shale	10	1,322	
	90	Gumbo	16	1,338	
	91	Shale	12	1,350	
	92	White chalk rock	50	1,400	6-inch casing to 1,360 feet.
	93	Blue and black shale	97	1,497	
	94	Hard shell rock	13	1,510	
	95	Blue shale	75	1,585	
	96	Hard shell rock	15	1,600	
	97	Black shale	30	1,630	
Austin, 459 feet.	98	White chalky lime	35	1,665	
	99	Black shale	10	1,675	
	100	White chalky lime	80	1,755	
	101	Lime with shells	15	1,770	
	102	Black shale	70	1,840	
	103	Gumbo	30	1,870	
	104	Black shale	35	1,905	
	105	Gumbo	63	1,968	
	106	Sand with shells	12	1,980	
	107	Black shale	16	1,996	
	108	Gumbo shale	18	2,014	
	109	Soft black shale	27	2,041	
	110	Gumbo	6	2,047	
	111	Black shale	15	2,062	
	112	Gumbo	18	2,080	
	113	"Rock" (concretion?)	2	2,082	
	114	Gumbo	7	2,089	
Blossom sand member of Eagle Ford clay, 42 feet.	115	Hard sand	7	2,096	
	116	Gray sand, water	17	2,113	Water salty. Rose rapidly to 1,500 feet, then slowly to top.
	117	Hard sand rock	18	2,131	
Lower clays of Eagle Ford clay and Woodbine sand, 174 feet.	118	Dark blue or black shale	79	2,210	
	119	"Emery rock" (hard rock cut drill badly.)	5	2,215	
	120	Hard sand	15	2,230	
	121	Sand, softer	4	2,234	Water lost here.
	122	Hard sand	11	2,245	
	123	Black shale	10	2,255	
	124	Hard sand	23	2,278	
	125	Light blue shale	14	2,292	
	126	Hard rock	10	2,302	
	127	Rock softer	3	2,305	

A comparison of the foregoing record with records published by Veatch[1] shows some discrepancies in the thicknesses of the different formations. These discrepancies may be attributed doubtless to the incompleteness of the earlier records, together with the varying character of some of the formations. In the ice company's well one chalk bed only is noted, and this is found at a depth of 1,700 feet. In the oil prospect well three chalk beds are penetrated, one at 1,350, one at 1,630, and one 1,665 feet. It is evident that the 125 feet of chalky limestone in the ice company's well represents the two lower beds with their associated marls or shales (Nos. 98, 99, and 100), and that the upper bed of chalk No. 92 evidently grades horizontally into blue

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 261-265.

marly clays which are included in the blue clays assigned to the Marlbrook in the ice company's well. Likewise, the greater thickness of the Nacatoch (347 feet) is probably to be accounted for by local variation in the character of the beds assigned to the lower part of the Arkadelphia or the upper part of the Marlbrook, or perhaps to lack of care in keeping the record.

From the data furnished by the above records it is shown that although the Nacatoch sand furnishes an abundance of water, its quality is such as to make it unfit for domestic use. The water found in the Blossom sand (Nos. 115–117) is too highly charged with saline constituents for use. The bed was not reached in the Redwater well. The only locality in which the Blossom sand member seems likely to constitute a possible source of water supply is in the western part of the county. From DeKalb westward this sand should be reached at from 1,000 to 1,300 feet, according to locality, and in some places the water will doubtless flow out at the surface. The quality of this water differs greatly from point to point, and no reliable statement can be made as to what its quality may be at any place. At Clarksville it is of good quality and this is likely to be true of it in some other places.

HOPKINS AND FRANKLIN COUNTIES.

Topographic relations.—Hopkins and Franklin counties lie just within the northern boundary of the Eocene and have the general relief of an eastward (coastward) sloping plain dissected by the branching tributaries of South Fork of Sulphur River on the north (mainly through White Oak Creek), and of Sabine River through Lake Fork on the south. The drainage of the region is divided about equally between the two systems. On the south and east the surface is diversified by many low eminences mostly rounded out of the unconsolidated sands, but in the extreme southern part of the area the interstream areas present a flat-topped, mesalike appearance, due to the capping of a more resistant layer of hard iron conglomerate. In the north and west a narrow strip of high-rolling prairie constitutes the eastward continuation of the prairie region of the adjoining county and has the White Oak bottom as its eastern limit. Cumby and Ridgeway, the two highest points in the district, are located on this prairie. The drainage ways are for most part broad and shallow and are occupied by insignificant streams, which in the summer or dry season consist merely of a chain of pools. White Oak bottom has an average width of about 3 miles. All the smaller streams are completely dry during the summer season. The population of Franklin County is 9,331, and that of Hopkins County is 31,038.

Geology.—Hopkins and Franklin counties lie on the northern edge of the eastern timber belt, which represents the outcrop of the Eocene

Tertiary. The formations consist for the most part of unconsolidated sands and clays, with local beds of lignite and ferruginous sandstones and iron ore. Owing to the nonpersistent character of the stratification and the lack of fossils, no general sequence can be worked out in the stratigraphy of the region. It is clear, however that South Fork of Sulphur River marks the northern boundary of the Eocene in this region and that the beds belong to the Wilcox formation.

In prospecting for water at Sulphur Springs the city corporation put down, to a depth of 1,515 feet, a well, the record of which has been kindly furnished by Mr. W. B. Baxter. This section is instructive as showing the thickness and character of the formations constituting the lower Eocene in this region. The collar of the well is 500 feet above tide.

Record of city well, Sulphur Springs, Tex.

Formation.	No.	Character rock.	Thickness.	Depth.
			Feet.	*Feet.*
Wilcox.	1	Surface soil	1	1
	2	Red clay	8	9
	3	Lignite	2	11
	4	White sand with water; source of supply for most of the wells of the region.	4	15
	5	Blue sandy shale	18	33
	6	Buff sandstone	2	35
	7	"Pipe clay"	2	37
	8	Black shale with mica	15	52
	9	Sand with water; furnishes city supply	16	68
	10	Shale	59	117
	11	Limestone	1	118
	12	Black shale interlaminated with lighter colored shale; contains iron concretions, iron pyrites, and mica.	565	683
	13	Hard limestone	1	684
	14	Black shale in thin layers with fossils	20	704
	15	Light-colored shale	8	712
	16	Blue shale	88	800
	17	Black shale with iron concretions; and fossils; *Venericardia planicosta.*	10	810
Midway, 324½.	18	Blue shale	90	900
	19	White clay	20	920
	20	Blue shale	80	1,000
	21	Hard sandstone	4	1,004
	22	Blue shale	30	1,034
	23	Fine sand; some water	2	1,036
	24	Soft white clay	15	1,051
	25	Gray sandstone	40	1,091
	26	White "pipe" clay	2	1,093
	27	Sandstone	15	1,108
	28	Hard blue shale	2	1,110
	29	Soft sandstone	15	1,125
	30	Hard sandstone	2½	1,127½
	31	Hard blue shale	5	1,132½
	32	Fine gray sand	1	1,133½
	33	Very hard sandstone	1	1,134½
Navarro and Taylor, 381.	34	Hard blue shale	171	1,305½
	35	Sand with some water	14	1,319½
	36	Blue shale and sand	95	1,414½
	37	Blue shale; some sand with mica	101	1,515½

The upper 1,134 feet of this section are assigned to the Wilcox and Midway, the division between these being placed tentatively at the base of No. 17. The beds below No. 33 apparently represent the Navarro formation and Taylor marl.

Ridgeway and Cumby are located on a prairie composed of dark soil underlain by yellow calcareous clay in some instances showing the presence of greensand. Some fossils obtained from this clay a few miles north of Cumby are reported by Dr. T. W. Stanton to be "probably of Tertiary age, but they contain no distinctive forms that fix the exact horizon." The stratigraphic relations indicate that the narrow strip of prairie extending from Cumby past Ridgeway represents the outcrop of the Midway clay and shale beds (Nos. 18–22). North of Sulphur Bluff, in the northeastern part of the county, a narrow prairie of black soil overlies yellow calcareous clay over blue chalky sand. Three miles north of this, on the south side of South Fork, 42 feet of blue and black sandy shales and shaly sands, which is strongly bituminous and contains many Cretaceous fossils (pp. 27, 28), outcrops in a bluff, where it apparently represents the lowermost beds of the Sulphur Springs well. This strip of black land is said to extend down the river as far as Goolesboro, in Titus County, where it disappears beneath the alluvium of the valley.

In the vicinity and south and east of Mount Vernon the higher elevations are capped by a deposit of unconsolidated yellow and red sand, white clays, and gravels which rest upon the apparently eroded surface of the Wilcox formation. Both sands and clays are usually distinctly cross-bedded and the contact with the underlying formation is frequently marked by a layer of ferruginous sandstone or iron ore, sometimes in broken blocks irregularly distributed along the plane of contact. These overlying beds are probably of late Tertiary age, though no evidence that would fix their age is at hand.

Deposits of lignite are reported from different localities, but the beds are usually thin and of small horizontal extent. A bed 2 feet thick is reported in the Sulphur Springs well at a depth of 9 feet and similar occurrences are reported in the vicinity of Mount Vernon in Franklin County. At Como, 10 miles south of Sulphur Springs, a bed of lignite 7 feet thick, found at a depth of 75 feet, has been successfully worked for the past six years. The lower 2 feet of the deposit is unavailable on account of impurities. The roof is composed of compact sand and the mine is entirely free from water. This bed comes to the surface 1½ miles north and borings do not indicate workable thickness outside a very small area. Fifteen feet above the Como vein is another bed 2½ feet thick, and 45 feet above is one 2 feet thick. The following record of a shaft put down a number of years ago somewhere in this vicinity is published in the Texas reports.[1]

[1] Dumble, E. T., Report on brown coal and lignite of Texas, 1892, p. 161.

Record of shaft near Como, Tex.

	Feet.
1. Clay	6
2. Sandrock	10
3. Slaty clay	4
4. Brown coal	16
5. Sands and clays	9
6. Plastic clay	30
	75

In places the sands are indurated to form ferruginous sandstones, which weather out in irregular masses and have some use for building and paving, and by the railroads for ballast. No workable deposits of iron ore are reported in this district.

Water conditions.—In the prairie areas cisterns are the sole reliance for water for domestic use. In the remaining areas shallow wells are abundant, the surface sand overlying a clay being a good reservoir. The water is, however, at times mineralized and many persons residing on the sandy lands have cisterns; some have both wells and cisterns. Sulphur Springs is now supplied by a rain reservoir, but for a long time, until it outgrew them, it was amply supplied by three wells.

In the sandy wooded region, the larger portion of which drains southward through Lake Fork and Big Cypress Creek, an abundant supply of water is found in the surface sands at depths varying from 20 to 40 feet. Along the slopes springs are of frequent occurrence. In localities underlain by formations in which clay predominates some difficulty is found in obtaining sufficient supplies of water. The character of the water is quite variable, in some localities being soft and agreeable and in others more or less strongly mineralized. At Mount Vernon, Franklin County, the supply for domestic use is drawn chiefly from shallow wells and cisterns.

Deep wells.—Very few attempts have been made to exploit the deep-lying water beds and the information concerning their extent, character, or location is very meager. The most serious attempt made was that at Sulphur Springs by the city authorities, who drilled to a depth of 1,515 feet without satisfactory results. The record of this well (p. 61) shows that below the upper "veins," Nos. 4 and 9, the only water encountered was a small flow at a depth of 1,034 feet and another at 1,303 feet. At Mount Vernon, Franklin County, the railroad has a 400-foot well which yields a large supply by pumping.[1] No information is available as to the horizon from which the water is derived. At Cumby, wells 300 feet deep fail to find water below the surface supply.

As to the Cretaceous horizons, very few data are available. The record of the Sulphur Springs well indicates, however, that owing

[1] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 230–231.

to the thickness of the post-Cretaceous deposits over most of this region the possibility of exploiting the underlying water horizons is exceedingly remote. The only district in which there is any possibility of obtaining water from the Cretaceous beds is in the extreme northern part of Hopkins County, and the lack of knowledge of the extent and water-bearing character of these beds makes hazardous any prediction concerning them. The conclusion seems warranted, however, that in the valley of the Sulphur Fork, and for 4 or 5 miles to the south, the Nacatoch sand may be reached at depths varying from 500 to 1,000 feet. At Commerce, in Hunt County, which is 9 miles northwest of Ridgeway, these sands were reached at 370 feet. They outcrop between Commerce and Fairlie, 6 miles northwest of Commerce, giving an estimated dip of 50 feet per mile. From this it would appear that these beds may be reached at Ridgeway at a depth of 800 to 1,000 feet and the lower sands about 200 feet deeper. No prediction can be made as to the water-bearing character of the latter beds; the upper or Nacatoch sand is water-bearing at Commerce, but the water is not used because of its mineralized character.

CASS COUNTY.

Topography.—Cass County is in the northeastern part of the State, adjoining the Louisiana State line; it is bounded on the north by Sulphur Fork, and on the south and west by the counties of Marion and Morris, respectively. Its area is 945 square miles and its population 27,587. Linden is the county seat. The county is traversed by two railroads—the Missouri, Kansas & Texas and the Texas & Pacific.

The region constitutes the eastern extension of the general coastward-sloping plain of the eastern timber belt and differs from the counties to the west only in the greater degree to which the original plain level has been dissected by erosion. The drainage is principally to the southeast through small streams emptying into Caddo Lake, Sulphur Fork on the north receiving but a small part of the run-off through a few short tributaries. The surface is decidedly rolling and is characterized in the main by long ridges extending from northeast to southwest, or in a direction at right angles to this. These ridges are separated by steep-sided, narrow, deep ravines, the bottoms of which are generally occupied by narrow streams fed by the numerous springs found everywhere along the sides of the ridges.[1] In some of the ridges deposits of laminated iron ore occur in thin seams at depths of 20 to 40 feet below the summits. Such ridges usually present a terraced appearance due in part to the differential erosion of the hard and soft layers and in part, doubtless,

[1] Kennedy, William, Second Ann. Rept. Geol. Survey Texas, 1890, pp. 67-68.

to landslides brought about by the undermining action of springs which find their way out of the greensands that underlie the ore beds.[1]

The following elevations are shown by the railroad profiles: Alamo, 242; Atlanta, 264; Avinger, 393; Bivens, 314; Hughes Springs, 373; Kildare, 311; Queen City, 349.

The tops of the hills are from 50 to 100 feet above the level of the flood plains of the principal streams and have a general elevation of between 500 and 600 feet above tide level. On the north the wide flood plain of Sulphur Fork is bounded by a relatively narrow northward-facing drainage slope intersected by few and short tributaries.

Geology.—The county lies entirely upon the outcrop of the Wilcox formation and, like the district on the west, is characterized by timber-covered slopes and sandy soils. The deposits exposed within the limits of the county present the twofold division noted in the counties farther west, viz, an upper unstratified deposit of sand with local deposits of iron ore and a lower division of stratified sands, sandy clays, and clays with local deposits of lignites.

The upper part of the lower division consists of thinly laminated red, yellow, and white sands and sandy clays, blending horizontally and vertically in places into unstratified mottled red and white sands. The clays are usually dark blue, gray, or black, or in places red, yellow, or white; they occur interstratified and interlaminated with the sands and are generally sandy, though in places fairly free from sand. These beds are well exposed in the vicinity of Queen City, where they have a thickness of 65 feet or more, for which reason they have been given the name Queen City in the Texas reports.

Below these beds is a series of black, blue, and gray micaceous sands, blue, brown, and gray clays, and beds of lignites of varying thickness and generally of local extent. In places the sands are said to contain thin strata of sandstones and limestones.

Deposits of brown coal appear in different parts of the county, the best occurrences being reported from the northeastern portion, at Alamo and Stone Coal Bluff. At the former locality a bed of brown coal, 4 feet 7 inches thick, was found at a depth of 52 feet and another bed, 1 foot 8 inches thick, 11 feet higher. At Stone Coal Bluff a bed of coal 12 feet thick is said to occur at the bottom of the river.[2]

Resting on the irregular worn surface of the stratified lignitiferous sands and clays constituting the lower division are yellow, brown, and red pebbly sands, for the most part unstratified, ranging from a few feet to 100 feet in thickness. These sands contain the iron-ore deposits of the region, which appear as a kind of pavement

[1] Penrose, R. A. F., First Ann. Rept. Geol. Survey Texas, 1889, pp. 84-86. Kennedy, William, Second Ann. Rept. Geol. Survey Texas, 1890, pp. 68-70.

[2] Shumard, B. F., First Rept. Progress Geol. Survey Texas, p. 12.

under the sands capping the ridges or as aggregations of bowlders accumulated along the slopes.

According to Kennedy, with the exception of some small deposits of laminated ore, no continuously bedded ores occur within the county. For the most part the ores consist of rounded, oval, or lenticular concretionary masses, which in places have the appearance of a regular bed, but which change horizontally into ferruginous sandstone or into the irregular or rudely rectangular blocks of conglomeratic ore usually found along the valley sides or capping the lower hills. The ore deposits vary in thickness from a few inches to a maximum of 10 feet,[1] and for the most part are limited to the surface. Parties who have worked and prospected the ores for years state that on following them into the hills the ore is replaced by dark ferruginous sand. The best deposits are reported to occur southwest of Hughes and east of Linden.

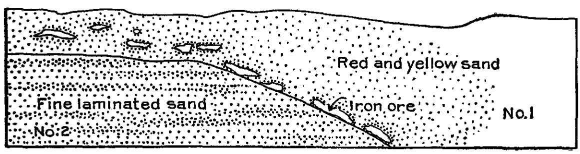

FIGURE 6.—Diagrammatic section of strata near Atlanta, Cass County.

In a railroad cut one-half mile north of Atlanta the beds have the relations shown in figure 6.

Here 4 to 12 feet of red and yellow sand containing irregular masses of low-grade iron ore, blocks of which occur distributed along the plane of contact, rest unconformably upon laminated sand or sandy clay, with little appearance of grit.

The relations of the formations on the western side of the county are shown in the accompanying section, compiled from a series of exposures in railroad cuts north of Hughes:

Composite section in railroad cuts north of Hughes, Tex.

	Ft.	in.
1. Soil and reddish-brown sand with pebbles	4 to	2
2. Yellow and red sand, containing concretionary masses of low-grade iron ore. Portions of the beds are indurated to a hard ferruginous sandstone	8	
3. Laminated red and white sand, sandy clay, locally white mottled clays, containing nodular, concretionary iron ore	4	
4. Brown lignitic sands and sandy clays, and laminated black clay	8	
5. Brownish-red sand interlaminated with fine white sandy clay	25	
6. Lignite		3
7. White sand mottled with red; exposed	3	
	68	3

The age of this upper deposit of sand with its concretionary and conglomerate ores has not been clearly determined. In the Texas

[1] Penrose, R. A. F., First Ann. Rept. Geol. Survey Texas, 1889, pp. 35–65. Kennedy, William, Second Ann. Rept. Geol. Survey Texas, 1890, pp. 65–95.

reports the areas in which the iron ores occurred were regarded as outliers of the lower (Mount Selman) division of the lower Claiborne (St. Maurice). That the ores had their source in the Claiborne beds may be admitted, but their present condition may be due to rearrangement by erosion during late Tertiary time.

Water resources.—The supply of water for domestic and stock purposes in Cass County is obtained almost entirely from shallow wells 20 to 50 feet deep, the most common depth being 30 to 40 feet. The supplies are derived mostly from surficial sands, but in some places come from the lower sand horizons. The water from the surficial sands is usually soft and of good quality, but locally becomes mineralized to a greater or less extent.

Springs are of frequent occurrence wherever the base of the surficial sands has been reached by erosion, but in general are small and are but little used. They are frequently chalybeate in character, that at Hughes having for a long time sustained an excellent reputation for its medicinal properties. Another spring, owned by Mr. Charles Thrasher, 5 miles east of Linden, is also worthy of note. Analyses made in the laboratories of the Survey (p. 74) of the waters of these two springs show them to be very much alike.

The supply of water derived from the surficial sands is in the main ample for present requirements for domestic and stock purposes, but it is not sufficient to meet manufacturing or city needs, to supply which resort is had to rain tanks.

So far as can be learned no attempts have been made to exploit any of the deeper water horizons in Cass County. At Jefferson, in Marion County, 10 miles south of the boundary of Cass, a well put down many years ago to a depth of 802 feet in the search for coal struck a strong flow of water with sufficient pressure, according to reports, to rise 35 or 40 feet above the surface when piped. At first the flow is said to have been very strong, but caving at the bottom resulting from drawing the pipe back 80 feet has greatly diminished the pressure. At present the flow is about a gallon a minute. Kennedy reports as follows concerning this well: "The drill passed through alternate strata of sands, clays, and lignites to a depth of 802 feet. Three heavy beds of lignite and a number of smaller ones are said to have been passed through in the boring." [1]

According to Mr. J. M. De Ware, corroborated by Mr. W. T. Atkins, this well is about 830 feet deep. The elevation at the top is about 196 feet. The water is rather strongly mineralized and has a high reputation locally. (See analysis, p. 74.)

Veatch states [2] that this water comes from the Nacatoch sand. In the absence of satisfactory data no definite statement can be made,

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[1] Proc. Acad. Nat. Sci., Philadelphia, for 1895, 1896, pp. 136-137.
[2] Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 233.

but it seems probable that the source is the lower portion of the Wilcox formation.

If this water horizon is persistent it will undoubtedly be found underlying the whole of Cass County at depths varying from 800 to 1,200 feet, according to locality. In some places the water would no doubt be too strongly mineralized to be of general use, but from the variable character of the water from the Wilcox formation it is not improbable that good wells might be developed in localities 10 to 20 miles away.

Nothing is known of the Cretaceous horizons in this region, but the inference is that they are not practically available, owing to their excessive depth and to the highly mineralized character of the water they yield.

DATA CONCERNING WELLS.

The following table gives the obtainable data in regard to the wells of the region:

Data concerning wells in northeastern Texas.

No.	Locality.	Owner.	Driller.	Authority.	Diameter of well.	Depth of well.	Elevation of surface. (Approximate.)
	Bowie County:				*Inches.*	*Feet.*	*Feet.*
1	De Kalb, 13 miles north	S. L. Moore	Hudson and Cornelius	Hudson and Cornelius	2	425	
2	De Kalb, 1 mile south	N. E. McKinney		N. E. McKinney		1,833	350
3	New Boston	Town of New Boston	John Lowdermilk	John Lowdermilk	3¾	536	352
4	Do			C. K. Berkshire	5	1,200	352
5	Pope post office	Cass Pope		Cass Pope	6	196.5	
6	Rolyat, 4 miles north			Postmaster		247	
7	Rolyat, 3 miles west	I. N. Phillips		I. N. Phillips	6	165	
8	Rolyat	Postmaster		Postmaster	8	119	
9	Redwater	Redwater Oil & Mineral Co	J. J. Boynton	J. J. Boynton		2,000	286
10	Texarkana (Tex.)	Taxarkana Ice Co		R. A. Munson		63	
11	Do	Jack Weed	John Lowdermilk	John Lowdermilk		550	
12	Texarkana (Ark.) [1]	J. D. Cook et al	J. J. Boynton	J. J. Boynton, J.D. Cook	11⅝–6	2,305	305
	Cass County:						
13	Hughes Spring [2]	Hughes Spring					
14	Linden, 5 miles east	Chas. Thrasher		W. H. Crow			
	Camp County:						
15	Pittsburg	W. C. Hargrove et al		W. C. Hargrove	6–4	1,860	395
16	Do	Arkansas & Texas Consolidated Ice & Coal Co. (No. 1.).		E. L. Wells, jr., manager	6	263	395
17	Do	Arkansas & Texas Consolidated Ice & Coal Co. (No. 2)		do	6	273¾	395
	Delta County:						
18	Cooper, 3 miles west	E. H. Bond		E. H. Bond		263	495
19	Horton					315	
20	Klondike					160	478
	Fannin County:						
21	Honey Grove	Honey Grove		Postmaster		1,700	
22	Ladonia [3]					1,035	625
	Franklin County:						
23	Mount Vernon	St. Louis Southwestern Ry		A. J. Patton, county clerk		400	476
	Hopkins County:						
24	Cumby	Cumby				300	649
25	Sulphur Springs	Sulphur Springs		W. B. Baxter	6–4	1,514	503

[1] For records of other wells at Texarkana see Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 180.
[2] Analyzed by A. C. Peale, Bull. U. S. Geol. Survey No. 32, 1886, p. 135.

Data concerning wells in northeastern Texas—Continued.

No.	Locality.	Owner.	Driller.	Authority.	Diameter of well.	Depth of well.	Elevation of surface. (Approximate.)
					Inches.	*Feet.*	*Feet.*
	Hunt County:						
26	Commerce *a*			H. G. Johnston		2,390	548
27	Do	Capt. Anders				370	548
28	Do	Texas Midland R. R				900	548
	Lamar County:						
29	Blossom	W. E. Moore		W. E. Moore		146	530
30	Do	Blossom				117	530
31	Paris, 2½ miles east	Paris Waterworks Co	H. G. Johnson	J. A. Porter, W. F. Gill		1,965	510
32	Paris	Texas Midland Ry		E. H. R. Green, president		73	566
	Marion County:						
33	Jefferson, 400 yards north of post office	J. M. De Ware		J. M. De Ware		830	196
	Morris County:						
34	Daingerfield	Joseph Bradfield		Joseph Bradfield		186	400
35	Omaha, 4 miles from	M. C. McCollum		M. C. McCollum		100	
	Red River County:						
36	Clarksville (public square)	Corporation Clarksville		Frank B. Mason, Mayor		1,100	410
37	Clarksville, ¼ mile west of station	do			8–6	600	450
38	Clarksville	Ice factory		Frank B. Mason, Mayor		1,800	
39	Lydia, 4 miles south	W. S. Perkins		Postmaster		200	260
40	Towson, 3 miles above, on bank of Red River.	S. J. Wright		S. J. Wright	6	300	
	Titus County:						
41	Mount Pleasant	H. W. Cheney et al		H. W. Cheney	7–6¼	300	

[1] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 636.

Data concerning wells in northeastern Texas—Continued.

No.	Locality.	Height of water above (+) or below (–) ground.	Depths of principal water-bearing strata.	Yield per minute.		Geologic horizon of water-bearing strata.	Quality.	Remarks.
				Flow.	Pump.			
		Feet.	*Feet.*	*Gallons.*	*Gallons.*			
	Bowie County:							
1	De Kalb, 13 miles north		–2		Very small.			Abandoned.
2	De Kalb, 1 mile south	– 0	(?)	Small.		(?)	Salty	Trace of oil and gas at 1,503.
3	New Boston		500–536			Navarro	do	
4	Do	–60	±500			do	do	Casing 200. Used somewhat for watering stock.
5	Pope post office	+60	145–196			do	Soft	
6	Rolyat, 4 miles north				None.			
7	Rolyat, 3 miles west	–60				Navarro	Hard, alkaline	Drilled in 1900.
8	Rolyat	–49				do	Soft	Drilled in 1902.
9	Redwater		500 1,170?			Navarro-Taylor.		Drilled in 1906.
10	Texarkana (Tex.)	–20	33–63		Large.	Wilcox	Soft	
11	Do	– 0	136 550			Navarro		Lower horizon doubtful.
12	Texarkana (Ark.)	–25 – 0	878–1,190 2,096			Navarro Woodbine.	Soft	Water found down to 888 salty and sulphureted. Cased off. Well completed in 1907.
	Cass County:							
13	Hughes Spring	Spring.		Moderate.		Wilcox	Chalybeate	Local resort.
14	Linden, 5 miles east	Spring.		Moderate.		do	do	
	Camp County:							
15	Pittsburg	*a* –8	220 750 1,700			Wilcox do Navarro	Soft	Cased to 400; drilled in 1900.
16	Do	–20	150–200		50	Wilcox	do	
17	Do	–20	160–200		50	do	do	
	Delta County:							
18	Cooper, 3 miles west							No water, except seep from clays.
19	Horton		315					
20	Klondike							No water; abandoned.
	Fannin County:							
21	Honey Grove				Plenty.		Mineral	Can not be used even for stock without mixing with pure water.
22	Ladonia							Abandoned.
	Franklin County:							
23	Mount Vernon	No flow.			Large.	Wilcox		

a Lowers to 70 feet when pumped.

Data concerning wells in northeastern Texas—Continued.

No.	Locality.	Height of water above (+) or below (−) ground.	Depths of principal water-bearing strata.	Yield per minute.		Geologic horizon of water-bearing strata.	Quality.	Remarks.
				Flow.	Pump.			
		Feet.	*Feet.*	*Gallons.*	*Gallons.*			
	Hopkins County:							
24	Cumby							No water below 40 feet.
25	Sulphur Springs				Small.	Wilcox		Drilled 1900. "Found no sand worth developing."
	Hunt County:							
26	Commerce							"Well was a failure."
27	Do	−90	370			Navarro	Soft	
28	Do		385 900			do	do	"Not good for boilers."
	Lamar County:							
29	Blossom	−25	25–35			Blossom	Hard	Used occasionally.
30	Do	−25	25–35		Small.	do	Hard, mineralized.	
31	Paris, 2½ miles east	− 2	0–80 570–1,412 1,635			do Woodbine Washita	Mineralized	Drilled in 1896.
32	Paris		18–33		8	Blossom		
	Marion County:							
33	Jefferson, 400 yards north of post office	+35±	300 500 800			Wilcox	Mineral	"Now clogged by caving.'
	Morris County:							
34	Daingerfield	−20	186		"Inexhaustible."	do	Some mineral	
35	Omaha, 4 miles from				Large.		Mineral	Not used.
	Red River County:							
36	Clarksville (public square)	−10	550 ±1,050		Large.	Blossom Woodbine	Brine	Water accompanied with natural gas.
37	Clarksville, ¼ mile west station	−55	550–600		Large.	Blossom	Good, soft	2 wells drilled in 1902.
38	Clarksville		1,000 1,600?		Large.	Woodbine	Brine	Drilled in 1902.
39	Lydia, 4 miles south				Not any.			
40	Towson, 3 miles above, on bank of Red River.	*a* Flow.	300	Large.		Trinity	Soft	Drilled in 1892.
	Titus County:							
41	Mount Pleasant							Test for oil, incomplete.

a Would flow if piped. Drill lost by caving and well abandoned.

CHEMICAL COMPOSITION OF THE WATERS.

The available information regarding the chemical composition of the waters of northeastern Texas is given in the following table. The number of analyses is too small to permit much generalization regarding the mineralization of the waters. Those tested from the Sabine formation seem to be much superior in quality to those from other underground sources. The waters from the Blossom sand member at Blossom are very high in calcium, magnesium, alkalies, and sulphates, being similar in these respects to the waters tested from the Eagle Ford clay. The single well tested drawing its supply from the Nacatoch sand yields a brine. The analyses are stated in parts per million in ionic form. Most of them were made especially for this report, and the few obtained from other sources have been recomputed to ionic form in order to facilitate comparison.

Chemical composition of underground waters of northeastern Texas.

[Parts per million unless otherwise stated.]

	County.	Town.	Source.	Owner, name, location, etc.	Water-bearing formation.	Date of collection.	Analyst.
1	Bowie	Dalby Springs	Springs		Wilcox		
2	do	New Boston	Well	City supply	Nacatoch	Sept. 10, 1907	R. B. Dole and M. G. Roberts.
3	do	do	do	do	do	do	Do.
4	Cass	Hughes Springs	Springs	H. R. Hughes	Wilcox	Sept. 12, 1907	B. L. Glascock.
5	do	Linden	Well	W. H. Coon	do	Nov. 15, 1907	J. R. Bailey and A. M. McAfee.
6	Delta	Ben Franklin	Creek			Jan. 9, 1902	W. A. Powers.
7	do	do	do			Sept. 30, 1902	Kennicott Water Softener Co.
8	Harrison	Marshall	Well		Wilcox	Sept. 19, 1907	B. L. Glascock.
9	do	do	do		do	do	Do.
10	do	do	Springs	Hynson Springs	do	Feb. 3, 1908	J. R. Bailey and A. M. McAfee.
11	Lamar	Blossom	Salt well	Well on Main Street	Eagle Ford	Apr. 7, 1908	R. B. Dole and M. G. Roberts.
12	do	do	Well	Dr. A. J. B. Beauchamp	Blossom	Feb. 9, 1907	Do.
13	do	do	do	Well on Main Street	Eagle Ford	do	Do.
14	do	do	Black well		do	Feb. 14, 1907	Do.
15	do	do	Well	J. C. Thompson	Blossom	Feb. 11, 1907	Do.
16	do	do	do	Ed. Arnold	do	Apr. 7, 1908	Do.
17	do	do	do	W. J. Wallace	do	Feb. 9, 1907	Do.
18	do	do	do	T. F. Hefner	do	Apr. 7, 1908	Do.
19	do	do	do	Cotton-yard well	do	do	Do.
20	do	do	do	J. W. Williams	do	do	Do.
21	do	do	do	A. P. Ball	do	do	Do.
22	do	Paris	Artificial Lake	City supply		Dec. 1, 1902	Kennicott Water Softener Co.
23	do	do	Wells	Frisco Plant	Blossom	Nov. 29, 1902	Do.
24	Marion	Jefferson	Well	J. M. DeWare	Wilcox	Sept. 19, 1907	B. L. Glascock.
25	Morris	Daingerfield	do	Joseph Bradfield	do	do	Do.
26	Red River	Clarksville	Seep cistern	B. F. Mason	Annona	Mar. 5, 1907	H. S. Spaulding.
27	do	do	Well	600-ft. well	Blossom	Mar. 5, 1907	Do.
28	Wood	Mineola	do	Mineola Light & Ice Co	Wilcox	Feb. 3, 1908	J. R. Bailey and A. M. McAfee.
29	do	do	do	City supply	do	do	Do.

	County.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
1	Bowie	78	9.1	1.0	7.1	3.8	38	2.3		41	31		39	230
2	....do	16	.5		11	.8	862		24	717	1.6		1,134	2,271
3	....do	48	2.3		14	1.6	882		26	706	3.6		1,152	2,333
4	Cass	21	12	4.9	4.9	4.4	3.4	2.7	.0	18	25	.0	5.2	86
5	....do	23	12		11	8.5	13			41	1.9	1.0	5.5	112
6	Delta				38	3.5	57		8.5		17		8.5	161
7	....do	16	a 2.7		36	4.5	11		60		20		9.1	
8	Harrison	24	.51	1.3	5.4	2.0	15		.0	6.1	24	.44	7.0	86
9	....do	26	.26	1.7	32	11	33	4.3	4.8	171	86	4.9	20	347
10	....do	78	40	10	9.8	16	11	5.4			239	.06	14	435
11	Lamar	49	.21		542	91	542		.0	175	1,670		703	3,788
12	....do	48	.15		510	88	530	35	.0	38	2,485	1.8	151	4,112
13	....do	50	.2		660	110	965	35	.0	78	1,935	.0	1,872	5,558
14	....do	75	.6	8.3	485	113	720	42	.0	11	2,695	.2	328	4,694
15	....do	18	.2		265	28	208	61	.0	227	465	10	499	1,693
16	....do	31	.08		304	24	214		.0	179	767		237	1,932
17	....do	49	3.8		460	128	890	27	.0	146	3,180	.3	79	5,078
18	....do	84	.12	4.0	474	109	892		.0	3.5	3,247		99	5,185
19	....do	42	.04		492	114	960		.0	106	3,241		88	5,089
20	....do	48	2.4		472	44	660		.0	38	2,585		40	3,984
21	....do	16	.44		44	2.9	55		.0	179	55	5.0	31	324
22	....do	45	a 2.7		31	5.1	55		35		57		70	
23	....do	43	a 1.5		25	4.0	85		35		108		66	
24	Marion	31	18	6.4	32	14	25		.0	80	79	1.3	20	297
25	Morris	18	.68	.7	62	1.5	394	1.0	17	518	2.1	2.6	319	1,032
26	Red River	11	Tr.		80	9.2	98		.0	194	96	16	103	5,288
27	....do	9.6	.2		6.4	3.5	304		37	387	147	3.3	122	835
28	Wood	17	3	1.9	2.6	4.2	49	2.8	2.4	102	19	1.8	7.0	154
29	....do	26	.40	.42	8.0	8.6	404	33	31	485	10	.01	310	1,069

a Iron and aluminum oxides.

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CONTENTS.

ILLUSTRATIONS.

GEOLOGY AND UNDERGROUND WATERS OF NORTHEASTERN TEXAS.

By C. H. Gordon.

INTRODUCTION.

GEOGRAPHY.

The area considered in this report embraces 5,989 square miles in the extreme northeast part of Texas, comprising the counties of Bowie, Red River, Lamar, Delta, Hopkins, Franklin, Titus, Morris, Camp, and Cass.

The mean annual rainfall of the region is about 48 inches, ranging from 45 inches in the west to a little more than 50 inches along the Arkansas State line. The mean annual temperature is from 64° to 65° F. The district is traversed from east to west by three lines of railroads, the Texas & Pacific (Sherman branch), the St. Louis & Southwestern, and the Missouri, Kansas & Texas. The Marshall branch of the Texas & Pacific crosses the eastern part of the region and the Texas Midland, the Gulf, Colorado & Santa Fe, and the St. Louis & San Francisco all have their termini at Paris in the northwestern part of the region.

The rich soil of the black prairie lands early attracted settlers. According to the census of 1910 the population of the 10 counties named was 198,869, or an average of 33.7 to the square mile. The western part of the region is the most thickly settled, the two blackland counties, Lamar and Delta, leading, with an average of 51.5 and 54.7 per square mile, respectively. The average for the timber-belt counties is 28.3, Hopkins and Camp leading with 46.6 and 44, respectively.

PHYSIOGRAPHY.

Lying near the outer border of the Gulf Coastal Plain, the surface of the district has in general the low rounded relief and gentle seaward slope characteristic of that physiographic province. The elevation ranges from 237 feet above sea level at Sulphur, in the northeast corner of Cass County, to 649 feet above sea level at Cumby, near the western border of Hopkins County. The crest of the divide between

Red and Sulphur Rivers has an average eastward slope of about 3½ feet per mile, descending from an altitude of 601 feet at Paris to 295 feet at Texarkana, or a total of 306 feet. South of Sulphur River the reconstructed plain surface coincident with the tops of the present hills would slope toward the southeast, and within the limits of the district would range from 649 feet at Cumby to about 320 feet near the eastern boundary of Cass County.

The region is underlain by relatively soft strata which dip gently toward the coast, and in which the present relief has been developed by the dissection of the plain surface which characterized the region on its emergence from the sea. Degradation has left few if any traces of this old land surface, the chief topographic features now presented being the rolling and hilly uplands and the flood-plain and terrace areas, the former due largely to the differential erosion of the older beds of the coastal plain and the latter represented by the flat lowlands and adjoining terrace areas composed of redeposited sediments of comparatively recent fluviatile origin.

The upland areas, which rise from 100 to 200 feet above the flat-bottomed drainage ways, present an irregular rolling topography due entirely to differences in the adjustment of erosion to the different geologic formations. The northwest portion, comprising all of Lamar and Delta counties and most of Red River County, is underlain by Cretaceous strata consisting of marls, glauconitic sands, clays, and chalk, which have been carved by erosion into an undulating surface of low relief called rolling prairie, which constitutes an integral part of the black-prairie belt of Texas. The interior of this belt is marked by a low range of hills that extends across Lamar and Red River counties, due to the greater resistance to erosion offered by the chalk formation. This range apparently constitutes an extension of the Locksburg Wold in Arkansas, described by Veatch.[1] The Saratoga Wold, also mentioned by Veatch, is somewhat obscurely represented in Delta County near Enloe. In places the chalk ridge in Lamar and Red River counties presents a low northward-facing escarpment, due chiefly to a single hard layer 4 to 6 feet thick near the top.

The upland region south of a line extending a little north of east from Commerce through Boston, the county seat of Bowie County, lies within the province known as the east Texas timber belt. This region is characterized by a range of hills which constitutes the extension into Texas of the range known as the Sulphur Wold in Arkansas. It is essentially a deeply dissected dip plain, the substructure of which consists of the sandy beds of the lower Eocene. Over a considerable part of the region the slopes are still covered with timber.

The streams have comparatively wide, flat flood plains, bounded by terraces, the highest of which has an elevation of about 90 feet

[1] Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 14-16.

above the present flood plain. These high-level terraces cover considerable areas adjoining Red and Sulphur rivers in the eastern part of the district. Between Annona and New Boston nearly all of the country between the two rivers is of this type.

A marked feature of this and adjoining parts of the Coastal Plain is the presence of low mounds composed of sand, which occur over all the region except that covered by the most recent fluviatile deposits. These mounds are commonly from 2 to 3 feet high, though a few attain a maximum height of 6 feet. Some are elliptical; most of them are circular and are from 20 to 100 feet in diameter. The tendency toward elongation appears to be more marked in some places than in others, the longer axis usually extending in a northeast-southwest direction. As remarked by Veatch, they are particularly abundant in the terrace areas, where in wet weather they form low sandy islands in the midst of a water-covered clay country.

DRAINAGE.

The drainage of the region is effected mainly by Sulphur River, which flows from west to east entirely across the district. A feature of the drainage is the greater development of the southeastward-flowing system of tributaries, those flowing to the northeast being relatively few and for the most part unimportant. From this it follows that the divides are located much nearer the main streams on the south side than on the north, and the northward-facing slopes are shorter and steeper, a feature consequent upon the general coastward slope of the original plain surface and the effort of the streams to adjust themselves to the rock structure of the region. A small area in the southern part of Hopkins County is drained by tributaries of Sabine River, and the larger part of the region lying to the east is drained into Ferry Lake through Big Cypress and other creeks. Ferry Lake connects with Sodo and Cross lakes in Caddo Parish, La., these together constituting one body of water which occupies the lower portion of the valley of Big Cypress Creek. This body of water belongs to the class of lakes in the Red River Valley whose origin is attributed to log jams.[1]

The main streams and their tributaries that have cut to the level of ground water flow throughout the year, but many of the branches are wet-weather streams only. The soft rocks over which the streams flow yield to them an abundance of fine material, which is carried in suspension for long distances, discoloring the water and forming in quieter stretches of the streams grayish or brownish red deposits.

[1] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 60–62.

LITERATURE.

Most of the published accounts of investigations heretofore made in northeastern Texas are found in the reports of the Texas Geological Survey and of the United States Geological Survey. In two reports only are the waters of the region specially considered. Hill [1] in his exhaustive report on the geography and geology of the Black and Grand prairies of Texas gives detailed descriptions of the Cretaceous formations with special reference to the underground waters and all information available concerning the counties adjoining Red River. Veatch, in his report on the geology and underground water resources of northern Louisiana and southern Arkansas, has included some data bearing on the eastern part of the region. With these exceptions, the publications relating to the region, a fairly complete list of which follows, deal chiefly with questions of stratigraphy and natural resources other than water.

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——— The age of the iron ores of eastern Texas: Science, vol. 23, 1894, pp. 22–25. Notes greater development of the nodular iron ore in Cass, Marion, Morris, Upshur, and Harrison counties, asserts that their age is "Lower Claiborne" or later.

——— The iron ores of eastern Texas: Trans. Am. Inst. Min. Eng., vol. 24, 1894, pp. 258–288, 862–863.

——— The Eocene Tertiary of Texas east of the Brazos River: Proc. Acad. Nat. Sci. Phila., 1895, pt. 1, pp. 89–160. Discusses the stratigraphy of the region and compares it with that east of the Mississippi as noted by Hilgard, Smith, and Johnson.

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

JOHNSON, LAWRENCE C., The iron regions of northern Louisiana and eastern Texas: House Doc. No. 195, 50th Cong., 1st. sess., 54 pp., 1 map, Washington, 1888.

TAFF, J. A., Report on the Cretaceous area north of the Colorado River: Third Ann. Rept. Geol. Survey Texas, 1891, pp. 269–379; map by J. A. Taff and S. Leverett. Descriptions of the Texas Cretaceous in this paper relate chiefly to regions in the central part of the State. Contains brief discussion of estimates of depths of artesian wells in Lamar and Fannin counties (pp. 371–373).

——— and S. LEVERETT, Report on the Cretaceous area north of the Colorado River: Fourth Ann. Rept. Geol. Survey Texas, 1892, pt. 1, pp. 239–354. Continues discussion in the Third Annual Report (1891) and describes with considerable detail the occurrence and extent of the subterranean artesian basins.

——— Chalk of southwestern Arkansas: Twenty-second Ann. Rept. U. S. Geol. Survey, 1900–1901, pt. 3, pp. 685–742. Discusses the stratigraphy of southwestern Arkansas and its relation to that of Texas. Correlates the "White Cliffs" chalk with the Austin chalk of the Texas region.

VEATCH, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: Prof. Paper U. S. Geol. Survey No. 46, 1906. Includes many facts bearing on the geology and underground waters of northeastern Texas. Follows Hill in assigning the "White Cliffs," or Annona, chalk to a higher horizon than the Austin chalk.

GORDON, C. H., The chalk formations of northern Texas: Am. Jour. Sci., 4th ser., vol. 27, 1909, pp. 369–373. Correlates "White Cliffs" and Annona chalk with the upper part of the Austin group, the lower part being represented by the Brownstown marl.

GEOLOGIC HISTORY.

PRE-CRETACEOUS.

In the mountains of eastern Oklahoma, as shown by Taff,[1] the rock exposures appear to indicate that deposition was continuous from very early geologic time down to the close of the Pennsylvanian ("Coal Measures") epoch. Similar conditions prevailed in central Texas, where rocks representing all the divisions of the Paleozoic, with the possible exception of the Devonian, occur in conformable sequence resting upon the beveled edges of an older series of sedimentary rocks, the pre-Cambrian Llano series.[2] In western Texas and western Oklahoma these rocks grade upward without a break into deposits with Permian and Triassic affinities.

Throughout this area and to the northwest a sea existed, over whose bottom a vast thickness of sediments was laid down. The thickness of the Cambro-Ordovician in Oklahoma is estimated by Taff[1] at 12,000 feet and of the Devonian at 600 feet. Drake[3] estimates the thickness of the Carboniferous at 24,500 feet. The land mass from which these sediments were derived lay to the south and southeast, the relative positions of the land and ocean areas being thus in a sense the reverse of those now existing.[4]

[1] Taff, J. A., Atoka folio (No. 79) and Tishomingo folio (No. 98), Geol. Atlas U. S., U. S. Geol. Survey, 1902 and 1903.

[2] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 89.

[3] Drake, N. F., Proc. Am. Philos. Soc., vol. 36, 1898, p. 361.

[4] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 17.

Near the close of the Carboniferous the offshore belt of greatest sedimentation, extending from central Texas around through Oklahoma and Arkansas across the Mississippi Valley and connecting with the great trough now represented in the Appalachian chain, was subjected to profound folding and was elevated into a mountain range overlooking a sea extending to the west and to the north. Following this came a long period representing Triassic and Jurassic time, during which the elevations were worn down and the materials deposited in the adjacent seas. The lapse of time represented in the truncated edges of the folded and faulted strata was evidently very great. Then came a southward tilting of the region whereby land and water conditions were reversed and the sea transgressed northward over a relatively smooth base-leveled plain.

CRETACEOUS.

With the advent of the Cretaceous, ushered in by the northward transgression of the sea, marine sedimentation took place, the materials being derived from the land areas on the north and west. These deposits consist of alternations of sands, clays, marls, and limestones, and their character and relations show that many changes took place in the position of the shore lines and that the depth of the sea over the depressed land areas varied greatly from time to time.

If the prevailing doctrine that limestones and marls indicate deep-water conditions be strictly held, the alternations of sands, chalks, and marls of the Upper Cretaceous indicate a complex series of movements in the Texas-Arkansas region, but to interpret in terms of crustal oscillation the alternations of formations indicating quiet conditions of deposition—such as limestones, shales, and clays—seems to the writer untenable. Although the accepted doctrine may be broadly admitted, it seems probable that beds corresponding to those usually classed as deep-sea deposits may be locally formed by causes other than the lowering of the sea bottom; for instance, the shifting of currents or the extension of barriers, however produced, will be registered in the character of the formations, and such changes as these may take place locally without change of elevation. Fluctuations of level did occur, however, irregularly over the whole region, the result being a warping which caused one shore line to cut obliquely across that of a preceding period, giving rise to the present wedge-shaped outcrops with the point of the wedge directed northeast in the direction of greatest depression. These relations are well shown in the map (fig. 2, p. 18),[1] indicating the position of the shore line at different stages in the process of adjustment to the warping surface. In the early stages of advance the sea transgressed far to the west

[1] Veatch, A. C., Geology and underground-water resources of northern Louisiana and southern Arkansas: Prof. Paper U. S. Geol. Survey No. 46, 1906, fig. 3, p. 18.

over western Texas into New Mexico. At the close of the Cretaceous it had withdrawn on the west, but continued depression toward the northeast had marked out the Mississippi embayment, the submergence of which continued into late Oligocene time. Owing to the transgression of the shore line in the Mississippi embayment, accompanied by the withdrawal of the sea on the west, the earlier formations are overlapped by the later, and in consequence the outcrops wedge out toward the northeast, in Arkansas.

POST-CRETACEOUS.

Upon the Upper Cretaceous beds in the south half of the district lie sands, clays, and ferruginous sandstones belonging to the Eocene. No stratigraphic break has been recognized between the two systems. Originally, the Eocene doubtless extended much farther north, covering the whole of the area here considered, the present exposures of the lower formations being due to the removal of the Eocene sediments by erosion.

At the beginning of the Eocene there was evidently a slight warping of the surface which allowed the ocean to advance farther up the Mississippi embayment than before. As a result the early Eocene beds slightly overlap upon the Cretaceous, though no stratigraphic break marks the close of the Cretaceous in the Gulf region. A marked change appears in the animal life, however, an entirely new fauna making its appearance. Dana suggests [1] that this abrupt change in animal life is perhaps due to an alteration in the direction and character of the ocean currents, with the consequent change in temperature and food supply, and to the destructive effects of earthquake waves resulting from the gigantic disturbances which produced the Rocky Mountains rather than to a time lapse.

Throughout the region in the epoch succeeding the Midway—that is, in the interval represented by the Wilcox formation, of the Eocene series—near-shore or swampy conditions prevailed with an occasional submergence by the ocean.

No Oligocene or Miocene deposits have been recognized in this part of northeastern Texas. The Miocene was essentially a period of erosion in this region, and if deposits of Oligocene age were laid down here they were largely removed during the Miocene epoch.

During the succeeding epoch (Pliocene) a mantle of sand, silt, and gravel was spread over the eroded surface. Again erosion followed, during which much of the material previously deposited was carried away or rearranged at lower levels. Pleistocene deposition succeeded, giving rise to marine sedimentation along the coasts and fluviatile deposits on the land (Port Hudson formation). This was

[1] Manual of Geology, 4th ed., 1895, pp. 877-878.

followed by another period of erosion, in which the present flood plains and principal terraces were formed, this constituting the closing stage of the Pleistocene. The present cycle is represented in the surficial flood-plain deposition and hill-land erosion now in progress.

GEOLOGY.

The geologic formations that outcrop in the district may be classed as (1) Upper Cretaceous, (2) lower Tertiary, and (3) surficial deposits. The Cretaceous includes the Comanche series (Lower Cretaceous) as well as the Gulf series (Upper Cretaceous), but only the latter appears at the surface in the district.

CRETACEOUS SYSTEM.

COMANCHE SERIES (LOWER CRETACEOUS).

Lower Cretaceous beds do not appear at the surface in northeastern Texas, but outcrop in eastern Oklahoma on the north side of Red

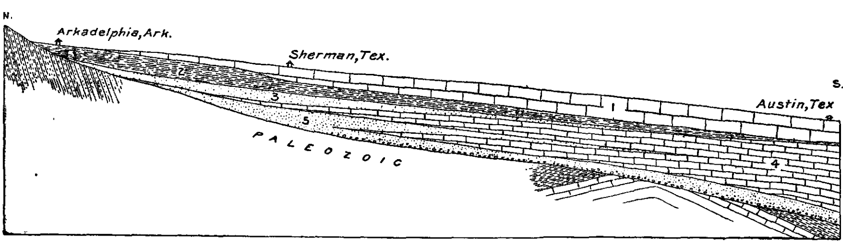

FIGURE 1.—Diagrammatic section of the Cretaceous rocks in northern Texas and southwestern Arkansas. (After Taff.) 1, White chalk; 2, blue marl; 3, sands at base of Upper Cretaceous; 4, Lower Cretaceous limestone; 5, sand at base of Lower Cretaceous. Reproduced from Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, p. 697.

River and farther northeast, in Arkansas. The lowest formation, known as the Trinity sand, is composed of fine, clean sand with occasional pebbles and bowlders of white quartz and other crystalline rock derived from the old Paleozoic land surface. In some places the sands are interlaminated with thin layers and lenses of clay; in other places they contain vegetal remains and brackish-water shells. Throughout a large portion of the Black and Grand prairie region in Texas this formation constitutes an important water-bearing stratum, which supplies thousands of artesian wells, many of which flow. In northeastern Texas, however, the southward dip of the strata has carried these sands too far below the surface to be conveniently reached by the drill except in a relatively narrow belt along the south side of Red River in Lamar and Red River counties.

The Trinity sand, which represents near-shore deposits, is succeeded upward by the limestones and marls of the Fredericksburg and Washita groups, a change indicative of deeper water. The Fredericksburg group is represented by the Goodland limestone and the Washita group by the Denison formation, Fort Worth limestone, and Preston formation. As the sea in which these sediments were deposited progressed northwestward upon the sinking land surface the lime formations lapped upon and graded into the sandy shore formations and hence are much thinner in this region than in the southern part of the State.

The stratigraphic relations are shown in figure 1 (p. 14).

GULF SERIES (UPPER CRETACEOUS).

CLASSIFICATION.

The sequence and lithologic character of the formations composing the Upper Cretaceous in northeastern Texas is shown in the accompanying table, which includes also Veatch's table for western Arkansas. The correlations are suggested by the author. Veatch considers the Annona and Brownstown to be equivalent to the lower part of the Navarro and Taylor, and the Bingen to be the littoral equivalent of the Woodbine, Eagle Ford, and Austin.

Classification of the Upper Cretaceous in northeastern Texas and southwestern Arkansas.

Northeastern Texas (Gordon).			Southwestern Arkansas (Veatch).		
Formations.		Character of rocks.	Formations.		Character of rocks.
Navarro formation and Taylor marl.	Arkadelphia clay.	Dark-blue to black laminated clays. Sulphur Bluff.	Arkadelphia clay.		Black laminated clays.
	Nacatoch sand.	Green sands grading into marls below. Delta County.	Nacatoch sand.		Sand with occasional quartzitic layers.
	Marlbrook marl.	Sandy and clay marls. Chalk at Enloe Sands near Ladonia. Blue marly clay.	Marlbrook marl.		Very calcareous clay with marine fossils.
Austin group.	Annona chalk.	White chalk.	Annona chalk.		White chalk.
	Brownstown marl.	Blue clay marl.	Brownstown marl.		Blue calcareous clay.
Eagle Ford clay.	Blossom sand member.	Sands and sandy clays interlaminated.	Sub-Clarksville sand.	Bingen sand.	Water-bearing sand.
	....	Dark laminated clays.	Eagle Ford clay.		Blue calcareous clay.
Woodbine sand.	....	Lignitiferous sands, sandy clays, and sandstones.	Woodbine sand.		Lignitiferous sands and clays with plant remains.

With the exception of the chalks, the rocks are characterized for the most part by a general lack of consolidation. The marls and clays especially disintegrate readily, yielding a thick mantle of black soil through which the underlying formations rarely protrude. No stratigraphic breaks occur within the Upper Cretaceous, and the gradations between its different formations is so gradual that these can be mapped in most places only with the greatest difficulty, if at all.

The chief exposures of the rocks of the gulf series occur in the northwestern part of the area between South Fork of Sulphur River and Red River. Farther east, in Texas, these formations are covered by surficial deposits which consist largely of unconsolidated sands, clays, and marls, and some indurated beds of sandstone and chalk. The beds dip southeastward at a low angle, at a rate of about 50 to 55 feet per mile, in the district north of North Fork. In their eastward extension and also where they lie under cover toward the south, as indicated by the few well records available, they appear to have a steeper dip.

WOODBINE SAND.

The Woodbine consists of ferruginous and argillaceous sands accompanied by bituminous laminated clays. The sands are for the most part unconsolidated and contain many remains of plants, a feature which distinguishes them from other Upper Cretaceous formations. When unweathered the sands appear white and friable, but contain more or less iron in the form of pyrite and glauconite as well as other ingredients, which on decomposing materially affect the character of the waters derived from them. In places solutions of the oxidized iron minerals have consolidated the sands into dark-brown ferruginous sandstone or siliceous iron ore. In large part the sands break down into deep loose soils. The clays are laminated and are for the most part impure, sandy, and lignitic. In northeast Texas the formation is characterized by the presence of argillaceous and calcareous layers interlaminated with the sand and by the occurrence of plant remains in considerable numbers, together with a peculiar molluscan fauna. A large part of the plant collection noted by Hill was obtained by Vaughan at Arthurs Bluff on Red River in Lamar County.

The Woodbine sand underlies the area adjacent to Red River in the northern part of Lamar and Red River counties and as far west as Dexter in Cooke County. From Red River it extends southward coextensively with the lower cross-timber country, but has not been recognized south of Brazos River. The region of its outcrop is generally characterized by a loose sandy soil, mostly covered with coarse post-oak and black-jack timber, here and there broken by small prairies where the beds contain an increased proportion of clay. From Red River to the Brazos the western boundary of the belt is marked by a range of low hills and knobs whose existence is due to the greater resistance to erosion offered by the more consolidated ferruginous beds of the lower part of the formation (called Dexter sand by Taff and Hill). The Woodbine is traversed for miles by Red River, but owing to its unconsolidated character and its covering of timber and alluvial deposits exposures of it are infre-

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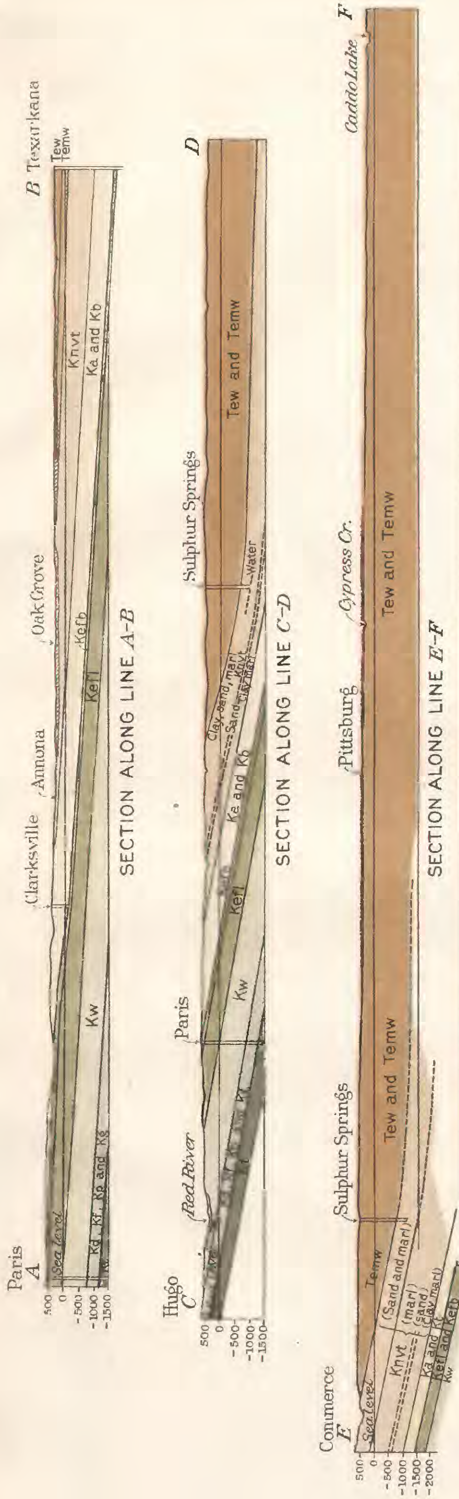

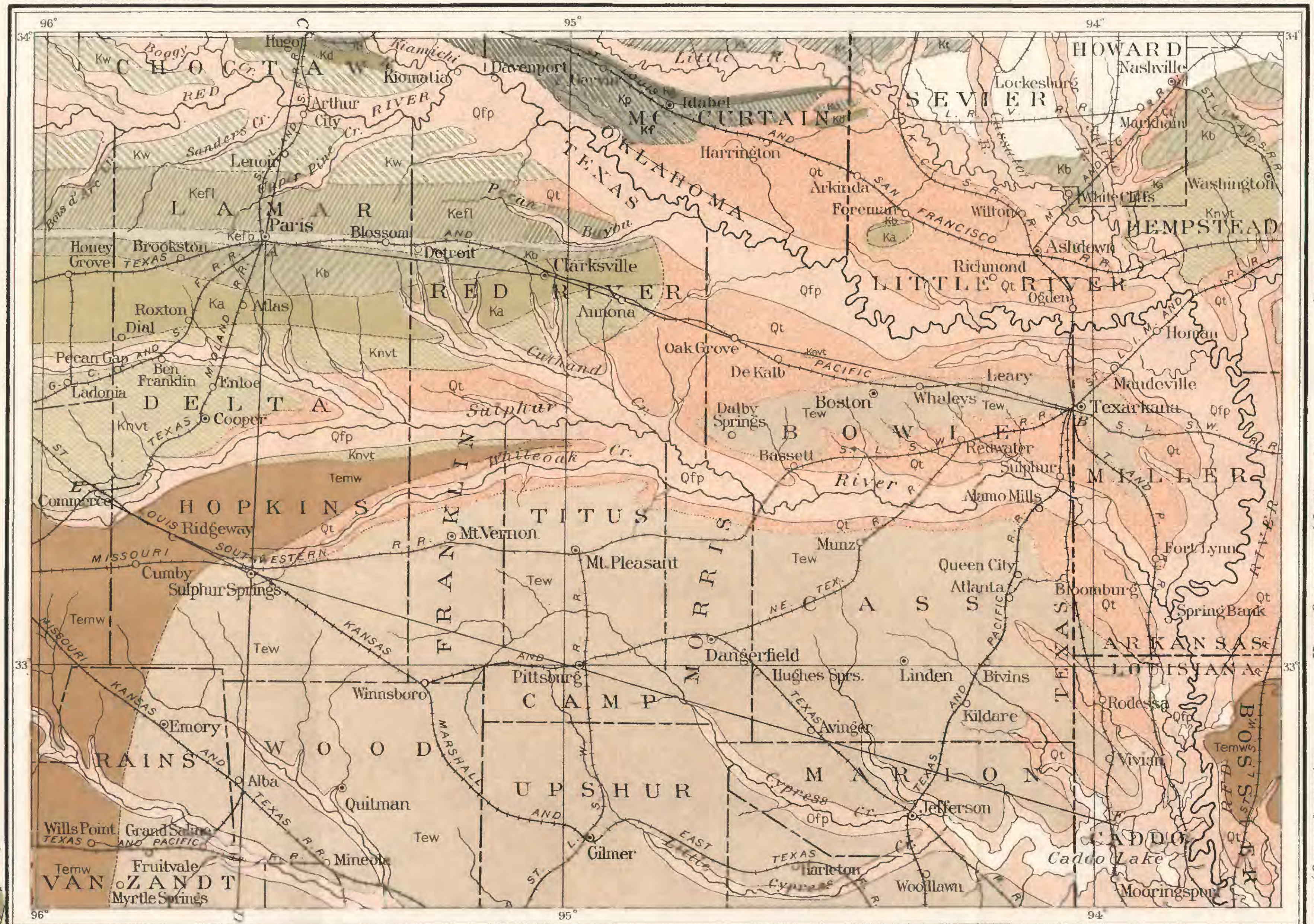

Base drawn mainly from post-route map of Texas, 1910. Survey of Cypress Bayou and Caddo Lake by the War Department, 1892, and other sources

GEOLOGIC MAP OF NORTHEAST TEXAS

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

10 0 10 20 30 40 Miles

1911

Geology by C. H. Gordon

JULIUS BIEN CO. LITH N.Y.

LEGEND

SURFICIAL DEPOSITS

QUATERNARY

- Recent — Qfp — Flood-plain deposits (recent silts and clays)
- Pleistocene — Qt — Port Hudson formation (Sands, silts, and clays)

CONSOLIDATED SEDIMENTS

TERTIARY

- Eocene — Tew — Wilcox (Sabine) formation (lignitiferous sands and clays)
- Eocene — Temw — Midway and Wilcox formations undifferentiated (clays with some sand and limestone)

CRETACEOUS

Upper Cretaceous (Gulf series)

- Knvt — Navarro formation and Taylor marl undifferentiated (Clay, glauconitic sands, calcareous marls with some chalk) [Arkadelphia clay, Nacatoch sand, and Marlbrook marl in southwestern Arkansas]
- Austin group — Ka — Annona chalk
- Austin group — Kb — Brownstown marl
- Kefb / Kefl — Eagle Ford clay (clay with lenses of limestone and at top Blossom sand member (Kefb)) [Bingen sand in southwestern Arkansas]
- Kw — Woodbine sand (with lentils of clay)

Lower Cretaceous (Comanche series)

- Washita group — Kd — Denison formation (limestone and shales)
- Washita group — Kf — Fort Worth limestone (limestone with some shales)
- Washita group — Kp — Preston formation (limestones and shales)
- Fredericksburg group — Kg — Goodland limestone
- Kt — Trinity sand (sands and laminated clays)

quent, occurring only in undermining bluffs, as at Arthurs Bluff north of Paris and at Pine Bluff in the northeast part of Lamar County. At Rock Ford, in Red River County, sand, in part glauconitic, occurs in the bluffs, which also show near the top several layers of white fossiliferous limestone. The area in which the Woodbine outcrops in northeastern Texas is shown approximately on the map (Pl. I).

In this region the formation has an estimated thickness of 600 to 800 feet. In the Paris well the drill penetrated 820 feet of sand and clay beds which have been assigned to the Woodbine; some of the lower beds, however, may belong to the underlying Denison formation. Southward it diminishes in thickness until it disappears by overlap in the vicinity of the Brazos. Eastward in Arkansas the Woodbine, there called the Bingen sand, coalesces, according to Veatch,[1] with the sands at the top of the Eagle Ford (Blossom sand member) by the thinning out of the intervening Eagle Ford clay. According to Veatch, therefore, the Bingen sand, which is the lithological counterpart of the Woodbine sand in Texas, is the time equivalent of all the beds of the Upper[2] Cretaceous below the Brownstown marl. (See fig. 2.)

As the Brownstown was considered by Veatch to lie immediately above the Austin chalk, the conclusion was drawn that the Bingen sand contained the littoral equivalents of the Austin and the Eagle Ford.[3]

EAGLE FORD CLAY.

Character.—The lower two-thirds of the Eagle Ford formation in northeastern Texas consists chiefly of dark, laminated clays, and the upper 50 to 75 feet is made up of brown, ferruginous, glauconitic sands interlaminated with clay. Inasmuch as the upper sandy beds constitute a water horizon of some value, a subdivision of the formation based on lithological distinctions seems warranted. To the upper sandy portion, therefore, the term Blossom sand member is applied, from the town of Blossom, which is located in eastern Lamar County upon the outcrop of the beds.[4]

Thickness.—The total thickness of the Eagle Ford clay in this region, as recognized in the Paris well section (p. 45), is 600 feet. This well is located directly upon the outcrop of the Blossom sand member and it doubtless includes very nearly the full thickness of the beds. Eighty feet of the sands was penetrated, the whole of

[1] Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 23–24.
[2] Veatch says "Lower" Cretaceous, but this is evidently a typographical error.
[3] Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 18.
[4] Am. Jour. Sci., 4th ser., vol. 27, 1902, pp. 371, 373.

which with the exception of a few feet of soil is regarded as representing the Blossom. The formation thins rapidly eastward, there being but 174 feet of hard sands that can be referred to this formation in the Texarkana well (p. 59), east of which it is not known.

Fossils.—As a whole the Eagle Ford is not very fossiliferous except in the upper arenaceous division (Blossom sand member). A few

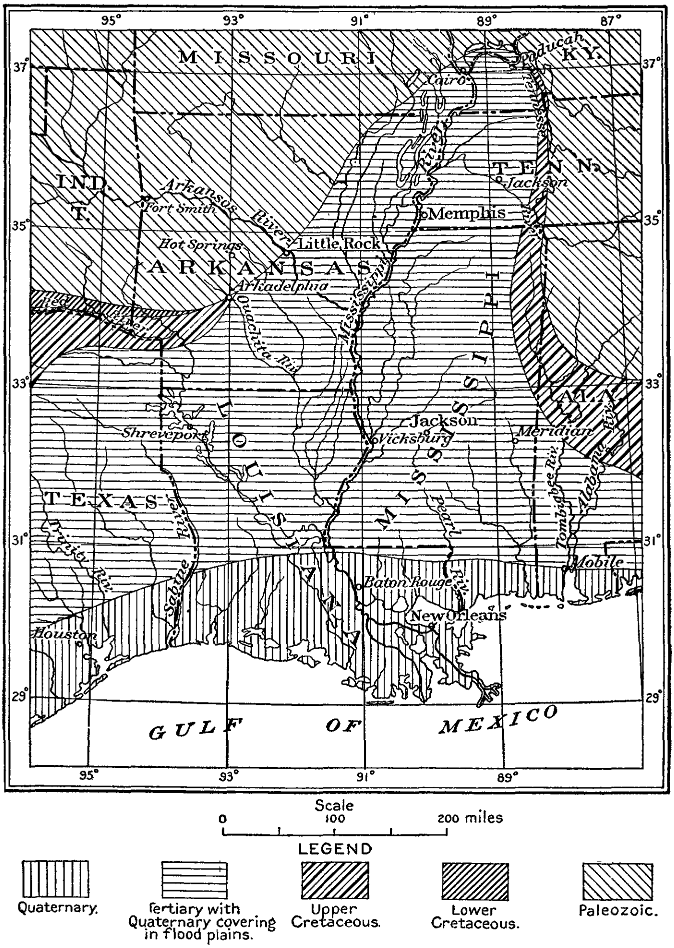

FIGURE 2.—Map showing overlap of Upper Cretaceous on Lower Cretaceous and of Tertiary on Cretaceous in the Mississippi Valley. (After Veatch.)

forms of Ammonites preserved with their nacreous shell coloring occur sparingly throughout the formation, and the blue limestone concretions are generally filled with the remains of certain invertebrate forms. In addition to an abundance of fish remains, chiefly teeth, the Blossom sand member contains an abundance of the characteristic forms *Ostrea lugubris* = *O. belliplicata*, *Inoceramus fragilis*, *I. labiatus*, and a small form like *O. congesta*. Hill[1] gives the following list of fossils obtained from the Eagle Ford formation:

Planticeras syrtalis Mort. var. cumminsi Cragin.
Ammonites woolgari Mort.
Sphenodiscus dumblei Cragin.
Buchiceras inequiplicatus Shumard.
B. swallowi Shum.
Tapes hilgardi Shum.
Anchura modesta Cragin.
Fusus graysonensis Cragin.
Natica striatacostata Cragin.
Neritopsis biangulatus Shumard.
Ostrea lugubris Conrad=O. belliplicata Shum.
Ostrea sp. (like O. congesta).
Inoceramus fragilis Hall and Meek.
I. labiatus Schlotheim.
Fish teeth.

Lower clays.—The lower part of the formation consists essentially of blue and black laminated bituminous clays accompanied by thin laminated clay limestones and nodular septaria of blue limestone; thin laminæ of sand occur in this portion, showing a gradual transition from the Woodbine sand below. The central and larger part of the formation is made up of blue and black marly clays, which include thin beds of arenaceous limestone and numerous hard nodular septaria, some of which attain a diameter of 3 feet; these septaria are composed of dense blue limestone with cross fissures filled with calcite and selenite. Selenite in minute crystals is disseminated generally through the clays, in places in considerable quantities, and the water flowing through these beds is generally bitter and disagreeable to the taste.

The clays constitute a belt of prairie extending east and west across Lamar and Red River counties north of the Texas Pacific Railway, and bounded on the north by the Woodbine sand and on the south by a narrow strip of sandy land representing the outcrop of the Blossom sand member. The outcrops of the clay make the black waxy land north of Paris.

Blossom sand member.[2]—The clays of the Eagle Ford grade upward into brown sandy ferruginous glauconitic beds interlaminated with thin beds of clay. The clays are filled with fossiliferous concretionary masses of limestone similar to those in the middle part of the formation; in places these weather out as bowlders. Locally the sands are highly fossiliferous, some layers being composed in large part of the casts of shells. The full thickness of these beds was not observed in the area to which this report relates, but at Sherman (2 miles west of the area) the following succession occurs.[3]

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[1] Hill, R. T., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 7, p. 328.

[2] Blossom sand member = "sub-Clarksville" sand of Veatch, Prof. Paper U. S. Geol. Survey No. 46. "Fish beds" of Taff and Hill=Blossom sand member (in part). *Ostrea belliplicata* bed of Taff=Blossom sand member (in part).

[3] Hill, R. T., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 7, 1899–1900, p. 326.

Section of Blossom sand member at Sherman, Tex.

	Feet.
6. Sandy clay shales with *Ostrea lugubris*	10
5. Thin slabs of brown sandstone with rounded conglomerate of jasper pebble. *Ostrea lugubris* and fish teeth	5
4. Blue laminated clay, weathering into limonitic colors	10
3. Massive agglomerate of shells of *Ostrea lugubris*	2
2. Sandy clay shale in thin alternations of clay and sand; clay efflorescent and drab colored on drying; contains *Ostrea lugubris*.	40
	67

The description given in the section of the beds at Sherman corresponds well with the character of the strata as they appear in Lamar and Red River counties.

The outcrop of the Blossom sand member extends in a band approximately a mile in width from a point nearly north of Annona, where Pecan Bayou intersects the bluff of Red River, to the western limit of the area, except where interrupted by overlying Quaternary formations. Outcrops occur at different places along the south side of Pecan Bayou, which flows for the greater part of its course on the formation; and in Lamar County they appear almost continuous along a line through Blossom and Paris, both of which places are located upon these beds. On the south the sands are bounded by the black waxy soils derived from the marly clays of the Brownstown marl, the lower formation of the Austin group. Four miles north of Clarksville the contact of the Blossom sand member with the overlying Brownstown marl was observed in a ravine. The section obtained here was as follows:

Section in ravine 4 miles north of Clarksville.

	Feet.
Brownstown marl:	
7. Clay marl with an abundance of *Exogyra ponderosa* in the lower 12 inches	6
Blossom sand member of Eagle Ford clay:	
6. Sand, in places mixed with marly clay	3
5. Blue marly clay (exposed)	6
4. Covered (about)	10
3. Yellow sand with fossil impressions	10
2. Drab fissile clay	2
1. Yellow sand above, grading into drab arenaceous clay below. Contains iron concretions showing impressions of fossils	20
	57

From 10 to 20 feet below the top of these beds in Grayson County, as described by Taff,[1] is a bed of coarse sand or grit, in places a conglomerate, called the "Fish bed," from the large number of fish teeth contained in it. This bed was not definitely recognized in Lamar and Red River counties. The beds are generally highly fos-

[1] Taff, J. A., Fourth Ann. Rept. Geol. Survey Texas, p. 303.

siliferous, though in general the material is in a friable condition, owing to weathering and oxidation. Ostreas (*Ostrea lugubris* = *O. belliplicata*) are numerous and in places farther west make up most of certain beds to which the term "shell bed" very appropriately applies.

The Blossom sand member, though comparatively insignificant stratigraphically, is important, because it constitutes the only available water-bearing horizon over a considerable portion of south Lamar and Red River counties. It is from this sand that the water supply at Clarksville is obtained, a fact which, in the absence of known outcrops, led Veatch [1] to give it the name "sub-Clarksville" sand. At Paris, according to the well record given on page 45, these sands have a thickness of 80 feet.

AUSTIN GROUP.

General character and relations.—From Sherman in Grayson County southward to the Colorado in Travis County the Austin chalk constitutes the most persistent and characteristic formation of the Cretaceous in Texas. Throughout this area its thickness is estimated by Taff to be about 600 feet. From the base to the top the rock consists for the most part of soft bluish-white chalk, chiefly in beds from 2 to 6 feet thick, interspersed here and there by a succession of thinner layers. The beds are generally separated by very thin sheets of calcareous marl, which in places thicken to 3 to 12 inches. Toward the top the beds become more massive, being from 4 to 6 feet thick, with very little separating marl between them.

Interstratified with the soft layers in places are nonpersistent harder arenaceous layers, which on weathering project in rounded subangular surfaces.

On weathering, the chalk loses the bluish cast seen in fresh exposures and becomes white or cream colored. It usually has an earthy texture and when fresh can be readily cut with a handsaw. Here and there nests of pyrites and crevices filled with calcite appear. Under the microscope [2] the material shows calcite crystals, minute amorphous calcite, and the shells of foraminifers, mollusks, echinoids, and other marine organic débris such as usually constitute chalk formations.

From Sherman eastward the basal portion of the Austin becomes more argillaceous and assumes the character of clay marl or marly clay. Beginning at the base in the vicinity of Sherman this change in character reaches higher and higher as the formation extends eastward until at Atlas, Clarksville, and White Rock north of Annona in Texas and at White Cliffs in Arkansas only the uppermost beds pre-

[1] Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 25.

[2] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1899–1900, p. 329.

sent the character of true chalk. Among previous writers Taff[1] seems to be the only one who recognized the true relations of the chalk deposits of northeastern Texas and southwestern Arkansas. The statements by this author accord so well with the independent conclusions of the writer that they are given entire:

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

The fossils of the main chalk which are not found below the chalk in northern Texas south of Sherman occur in the chalky marl beneath the chalk from the vicinity of Paris, Tex., eastward. The fauna, including the characteristic species of fossils, such as *Exogyra ponderosa*, *Gryphæa vesicularis*, *Astrea larva*, and others which occur only in the upper beds of the chalk in central Texas, are found in great abundance in the marl at the base of and beneath the white chalk in southwestern Arkansas.[2]

This chalk grows thinner in outcrop northeastward as it approaches the Paleozoic border and elevated mountain districts until it ends in chalky marl near the center of the Cretaceous area of southwestern Arkansas.

Hill[3] considered the chalk near Annona and westward as representing a higher horizon than the Austin chalk, which he describes as having largely thinned out east of Paris, but says that its exact relationship is subject to later determination. To the marls underlying the chalk at White Cliffs, Ark., which he rightly considered the equivalent of the lower part of the Annona chalk, he gave the name Brownstown. Veatch[4] appears to have accepted Hill's conclusions in assigning the Annona chalk to a higher horizon than the Austin, which he states does not appear east of Paris, Tex. In this he differs, however, from Hill, who states that "the most eastern outcrop of this chalk [Austin] is in Little River County, in the southwest corner of Arkansas."[5]

The field work of 1906 and 1907 having settled conclusively that the Annona chalk corresponds to the upper beds of the Austin, and that the underlying Brownstown marl is the eastern equivalent of the lower portion of the same formation, it seems appropriate to include both of these under the term Austin group.

Brownstown marl.—In Red River and Lamar counties and west to Sherman the Blossom sand member, constituting the uppermost beds of the Eagle Ford clay, grades rather abruptly into the light-blue calcareous and sandy clay or marl (Brownstown) representing the lower formation of the Austin group. Toward the top the proportion of lime increases, so that the upper beds are decidedly chalky and in places

[1] Taff, J. A., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1900-1901, pp. 698-700.

[2] The writer's observations show these fossils to be present in northeastern Texas from the marls at the base of the chalk up to the marls of the Navarro formation.

[3] Hill, R. T., op. cit., p. 341.

[4] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 19.

[5] Hill, R. T., op. cit., p. 330.

grade horizontally into true chalk. This variation in the composition of the Austin group gives rise to variation in the relative thickness of the chalk and marl divisions and in the relative width of their outcrops, the one varying inversely as the other. Four miles south of Paris the marls appear on fresh exposure bluish-white and chalky, much resembling chalk, but softer. On weathering they become drab to yellowish-brown, grading upward into a black waxy soil. The lower portions are more arenaceous, forming along the northern border of the formation outcrop a strip of soil called "mixed land" or "tallow-ridge land." The width of the outcrop of the marls south of Paris is from 5 to 6 miles, indicating a thickness of about 300 feet, while that of the overlying chalk on the south is correspondingly lessened. The chalk belt widens toward the east and west, the marl belt narrowing to a mile or less north of Annona. The marls here pass under the later Quaternary deposits along with the overlying Annona and higher beds, but they evidently thicken rapidly eastward, for according to Veatch they have a thickness in southwestern Arkansas of 600 feet, thinning out again to about 150 feet in the eastern part of the area.[1]

The name Brownstown, as shown by Veatch, was first applied by Hill [2] to marl beds typically developed at Brownstown, Ark., the stratigraphic position of which was not recognized until later.[3] As now defined, the term includes the blue marly clays and clay marls between the Blossom sand member of the Eagle Ford and the Annona chalk in Texas and the equivalent beds in Arkansas which rest upon the Bingen sand, which is considered to be the representative of the Eagle Ford clay and the Woodbine sand as developed in Texas.

Annona chalk.—The chalk beds constituting the upper formation of the Austin group in northeastern Texas were named Annona chalk by Hill,[4] who correctly recognized their equivalency to the chalk occurring on Little River in Arkansas, to which he had previously applied the term White Cliffs chalk.[5] The formation consists of bluish and creamy white chalk similar to the corresponding beds of the Austin chalk farther south. At White Cliffs, Ark., the chalk beds are about 100 feet in thickness and underlain by argillaceous chalk marl grading downward into sandy chalk marl.[6] The exposures in Texas are less

[1] Veatch, A. C., op. cit., p. 25.

[2] Hill, R. T., Ann. Rept. Geol. Survey Arkansas for 1888, vol. 2, pp. 86–87; Bull. Geol. Soc. America, vol. 1894, p. 302, pl. 12.

[3] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 340.

[4] Hill, R. T., Bull. Geol. Soc. America, vol. 5, 1894, p. 308 (there spelled Anona); Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1899–1900, p. 340–341. In the former paper Hill says: "It is not known what has become of the Austin chalk in this section (Paris), but my hypothesis, backed by some evidence, is that to the southward it has been faulted down. The Annona (White Cliffs) chalk is an entirely distinct and higher bed." In the later publication he says: "The writer has considered this chalk (Annona) to represent a higher horizon than the Austin, but its exact relationship is subject to future determination."

[5] Hill, R. T., Ann. Rept. Geol. Survey Arkansas for 1888, vol. 1888, pp. 87–89.

[6] Taff, J. A., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, pp. 706–707.

extensive, but so far as can be determined the rock presents essentially the same characters near Annona and westward to Sherman.

The first appearance of the chalk in Texas is to the north of Annona in Red River County, from which place it takes its name. At this point its outcrop is about 4 miles in width and is cut off on the east by deposits of Quaternary age. From this point the chalk extends west through Clarksville, Atlas, and Roxton in Lamar County, and thence west to Sherman. From Atlas the northern border swings northward to Petty on the Texas & Pacific Railway, thence westward about a mile north of Honey Grove. About 3 miles west of Clarksville the exposures of chalk and accompanying marls are interrupted by Quaternary deposits, partly filling a broad shallow valley now occupied by the headwater branches of Cuthand Creek.

The composition of the chalk is shown by the following analyses:

Analyses of the Austin chalk.

	1	2	3	4	5
Calcium carbonate	82.51	84.48	84.14	90.15	70.21
Silica and insoluble silicates	11.45	9.77	10.14	5.77	23.55
Ferric oxide and alumina	3.61	1.25	4.04	2.14	1.50
Magnesia	1.19	Trace.	[a] 1.68	.58	.58

[a] Mg and H_2O.

1. Texas chalk; locality not given. Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1899-1900, p. 329.
2. Rocky Comfort, Arkansas (Annona chalk). Idem.
3. Annona chalk, 7 miles south of Paris. Analysis furnished by J. A. Porter, Paris, Tex.
4. Quarry of the Alamo Cement Works, 3 miles north of San Antonio, Tex. Average material used in the manufacture of cement. Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, p. 737.
5. Average fresh rock from quarry of the Texas Portland Cement Works, 3 miles west of Dallas, Tex. Lower 20 feet of white chalk. Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, p. 737.

With complete disintegration the Annona chalk breaks down into a black waxy soil similar to that of adjacent formations. As a rule, however, owing to its greater hardness, the soil is thin and less productive than adjoining areas. Over the area where it constitutes the surface formation its outcrops are conspicuous in all the slopes and drainage ways by reason of their glaring white color.

The Austin chalk is characterized by many fossils, of which large specimens of *Inoceramus cripsi* var. *barabini* Morton and *Exogyra ponderosa* Roemer are conspicuous from the base to the top. As these fossils occur also in the formations above the Austin, they do not constitute a reliable means of discrimination. Hill has given several other forms as occurring in the Austin, such as *Exogyra læviuscula* Roemer, *Gryphæa aucella* Roemer, and *Hemiaster texanus* Roemer.[1]

The thickness of the Austin group as revealed by the Clarksville wells corresponds closely with the estimate given by Taff for the

[1] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 336.

central Texas region (p. 21). In the Clarksville wells the water-bearing sands (Blossom sand member) were reached at a depth of about 600 feet. The drill is reported to have passed through "white rock" all the way, the lower portion being softer. As the wells are located very near the top of the Annona chalk, these figures may be considered a close approximation of the thickness of the Austin group in this locality.

TAYLOR MARL AND NAVARRO FORMATION.

Attempted differentiations.—Above the Austin group occurs a series of beds of calcareous clays, chalky marls, and greensands, the differentiation of which is rendered extremely difficult by reason of the unindurated character of the material and the consequent lack of good exposures.

Numerous efforts have been made by Hill and others to classify these beds, but the results have been unsatisfactory. Taff [1] divided the Cretaceous rocks above the Austin chalk in central Texas into (1) Greensand marl; (2) Marly flags, 100 feet; (3) *Ponderosa* marl, 1,000 feet; and (4) Chalk marl, 100 feet. In his latest report on the Texas Cretaceous, Hill divided the Upper Cretaceous into two divisions, the lower of which he called the Taylor marl and the upper the Navarro formation, a name originally proposed by Shumard. In northeastern Texas he divides [2] the Navarro into Arkadelphia beds, Washington beds, Annona chalk, Roxton beds, and Brownstown beds. As it is now clear that the Annona and the Brownstown represent the Austin, the overlying Taylor marl must be represented in part at least by the marls overlying the Annona, to which Hill originally applied [3] the name "Kickapoo." He states that the formation bears a growth of hardwood, including Bois d'Arc, and adds "this is the only marly terrane in the entire range of Cretaceous formations in Texas which is covered by arborescent vegetation."

In Arkansas the equivalents of the Navarro and Taylor formations, as made out by Hill and Veatch, are as follows:

Arkansas equivalents of the Navarro formation and Taylor marl.

3. Arkadelphia clay: Dark laminated clays; 200 to 500 feet.
2. Nacatoch sand: Glauconitic sands and thin ledges of calcareous sandstones; 60 to 160 feet.
1. Marlbrook marl: Blue chalky glauconitic marls; in places, impure chalk. A chalky layer, 20 to 50 feet thick, which occurs 200 to 300 feet above the base, is called the "Saratoga" chalk member. Thickness, 50 to 750 feet.

[1] Third Ann. Rept. Texas Geol. Survey, 1891, pp. 354-359.

[2] Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 340. In describing the "Washington beds" the author states that they "surmount the Brownstown marls," evidently an error carried over from his earlier descriptions wherein the Brownstown marl was considered as being above the Annona chalk.

[3] Hill, R. T., Bull. Geol. Soc. America, vol. 5, p. 308, 1893.

Hill recognizes two lithologic phases of the upper part of the Navarro in the region north of the Brazos. The lower division, called by him the "Corsicana beds," consists of brown sandy marl with an occasional bed of hard, calcareous sandstone. Limestone concretions and a few bands of limestone occurring in these beds suggest the formations occurring in the vicinity of Cooper, Delta County. The upper division, which he called the "Kemp beds," consists of a yellow clay with nodules which apparently corresponds to the beds observed one-half mile north of Sulphur Bluff. However, very little information is available concerning the relation of these beds.

Character and thickness.—No satisfactory data bearing on the thickness of the Navarro and Taylor formations in this region are available. They are estimated to have a combined thickness of about 1,000 to 1,200 feet. The Sulphur Springs well shows 381 feet of blue shale with some sand, which evidently represent in part the Arkadelphia clay and Nacatoch sand.

Although well-marked correspondence with the Arkansas section can be made out in the character and sequence of the formations in Delta and adjoining counties, the lack of good exposures due to the unconsolidated character of the beds renders the definition of formation boundaries impracticable, and the whole is mapped as a unit.

At the base of the section in southern Lamar County a clay marl containing varying proportions of sand, and having an estimated thickness of 100 to 150 feet, forms a deep black soil in which no outcrops appear. This marl grades upward into fine marly sands containing thin ledges of limestone or chalk. These beds are exposed at Ladonia (Pl. II, *A*), Wolfe City, and elsewhere along a narrow belt extending from the northeast part of Delta County westward along the south side of North Fork as far west as Ladonia and thence southwestward through Wolfe City. Above the sands lies a highly calcareous marl or impure chalk, 20 to 50 feet thick, corresponding in position and character to the "Saratoga" chalk member of the Arkansas section. These beds are exposed in the slopes of North Fork about 2 miles north of Enloe, south of Ladonia, and in the vicinity of Fairlie in Hunt County.

The chalky beds grade upward into unconsolidated arenaceous marls in which occur concretionary masses of dense blue fossiliferous limestone. These marls constitute much of the surface of Delta County, but owing to the readiness with which they succumb to the weather exposures of unaltered material are rare. The estimated thickness of the marls is 350 to 500 feet, but as no wells extend through them in this region the data on which to base an estimate are very imperfect. Toward the south the black lands representing the outcrop of the marls give place to sands the exact relations of which are not clear, but which represent apparently the horizon of the

A. RAILROAD CUT AT LADONIA STATION.

Exposures of fine, marly sands containing thin ledges of limestone or chalk representing a part of undifferentiated Navarro-Taylor marl division. (See p. 26.)

B. RAILROAD CUT AT AVINGER STATION.

Exposure of sands and clays of Wilcox ("Sabine") formation.

Nacatoch sand, though some doubt exists owing to the near proximity of the Wilcox ("Sabine") formation.

In the vicinity of Commerce, Hunt County, green sands occur bearing *Crassatellites subplanus* (Conrad)?, *Cardium* sp., and *Fusus* sp.

Above the glauconitic sands are beds of blue bituminous sandy shale and dark laminated clays, which are exposed only near Sulphur Bluff and 3 miles north of that place on the south side of South Fork, where a bluff 50 feet high is composed of black laminated clay with thin laminations of ferruginous sand grading downward into blue bituminous sandy shale. The blue sandy shales contain characteristic Cretaceous fossils which are best preserved in a hard, chalky ledge near the middle. The dark laminated clays and associated beds are thought to represent the horizon of the Arkadelphia clay, the larger part of which in this region is covered by the overlap of the Eocene.

Fossils.—Arenaceous and chalky beds 2 miles north of Enloe yielded the following fossils, as determined by Dr. T. W. Stanton, of the Survey:

Exogyra ponderosa Roemer.
Cucullæa sp.
Cinulia sp.
Mosasaurus, weathered centrum of a caudal vertebra and a fragmentary element of the skull.
Ostrea sp.
Inoceramus cripsi var. barabini Morton.
Baculites asper Morton?

From the chalk 1½ miles south of Ladonia in the southern part of Fannin County the following were obtained:

Gryphæa vesicularis Lamarck.
Gyrodes sp.
Avellana sp.
Baculites anceps Lamarck.
Cucullæa sp.
Anchura? sp.
Nautilus sp.

In a railway cut near Cooper the overlying marls yielded the following in considerable numbers:

Exogyra costata Say.
Inoceramus cripsi var. barabini Morton.
Trigonia.
Morea sp.
Gryphæa vesicularis Lamarck.

In the greensands 1½ miles west of Commerce the following were obtained:

Crassatellites subplanus (Conrad)?.
Cardium sp.
Fusus sp.

The following were obtained in the blue sandy shale at Sulphur Bluff, 3 miles north of the town of that name in Hopkins County:

Inoceramus proximus Tuomey.
Crassatellites subplanus (Conrad)?.
Lunatia sp.
Cucullæa tippana Conrad.
Turritella trilira Conrad.

Clays occurring one-half mile north of the town of Sulphur Bluff gave the following:

Ostrea sp.
Veniella conradi Morton.
Exogyra costata Say.
Anchura? sp.

All the above are considered by Dr. Stanton as belonging to the Navarro and Taylor formations, but there are no distinctive species that fix the exact horizon. In fact, as pointed out by Dr. Stanton, the paleontology of the Upper Cretaceous in northern Texas has not as yet received sufficient study to make fine discriminations practicable with only the small collections submitted.

TERTIARY SYSTEM.

EOCENE SERIES.

MAJOR DIVISIONS OF THE EOCENE.

The Eocene underlies all the area south of Sulphur Fork, as well as a small isolated area on the north side of that stream extending west from Texarkana south of New Boston nearly to the west boundary of Bowie County. In the eastern part of the area along Sulphur Fork the Eocene is covered by a wide belt of deposits of later age.

As developed in eastern Texas and the adjoining portions of Louisiana, the Eocene comprises the following subdivisions:

4. Jackson formation. Calcareous clays containing marine fossils in abundance.

3. Claiborne group. Lower portion: Fossiliferous, calcareous clay, argillaceous limestone, greensand, limonitic iron ore, etc., upper portion lignitiferous sands and clays.

2. Wilcox ("Sabine") formation. Lignitiferous sands and clays, with marine fossils in the seaward or southern portions.

1. Midway formation. Dark-colored calcareous clays and fossiliferous limestones.

MIDWAY FORMATION.

The Midway formation, called the "Basal" or "Wills Point clays" in the Texas reports,[1] consists of calcareous clays with more or less sand and closely resembles the underlying Cretaceous clays and marls. The chief differences noted are the more distinctly stratified structure of the Eocene beds with laminations of sand and the presence of concretionary masses of limestone, which toward the east in Arkansas appear to become regularly bedded limestones. Large quantities of gypsum are also found in the clays, but the lignitic material so prevalent in the overlying Wilcox is wanting. The surface exposure of the Midway is limited to the extreme western por-

[1] Penrose, R. A. F., jr., First Ann. Rept. Geol. Survey Texas. Kennedy, William, Third Ann. Rept. Geol. Survey Texas, 1891, p. 47.

tion of the Eocene area and is marked by a belt of clay prairie lands extending with interruptions from Wills Point northward to Cumby and thence curving eastward past Ridgeway to South Fork.

The characteristic fossils of the formation are:

Enclimatoceras ulrichi White.
Ostrea crenulimarginata Gabb.
Ostrea pulaskansas Harris.
Volutilithes limopsis Conrad.

In common with other beds of the Eocene it contains:

Venericardia planicosta.
Pseudoliva vetusta.
Calyptraphorus velatus.
Turritella mortoni.[1]

The thickness of the Midway formation at Texarkana is about 214 feet and in Texas is from 260 to 300 feet.[2] The beds lie in a horizontal position, dipping slightly toward the southeast. These clays underlie a belt of prairie land with scattered belts and groves of hardwood timber, consisting mostly of post oak, black jack, and hickory.

WILCOX ("SABINE") FORMATION

The Midway formation grades upward into a series of siliceous and glauconitic sands, variously colored from white through yellow, red, and brown to black, interstratified with clays, which are generally dark blue or black. The sands that constitute the major part of the formation are laminated, thinly stratified, massive, and cross-bedded and are frequently interlaminated with clay. Many beds of lignite occur, varying in thickness from a few inches to several feet, and the sands and clays generally are impregnated with vegetal matter to such an extent that they burn white or buff on being exposed to heat. The sands contain more or less carbonate of lime, in places in sufficient amount to cement the sands into a calacareous sandstone or arenaceous limestone. Some of these indurated portions occur in somewhat even beds and some of them in concretionary masses of various sizes and shapes. When met in wells, these indurated masses are usually designated "rock" or "bowlders" by the driller.

According to previously published reports the Wilcox formation has an aggregate thickness of about 900 feet. In the well at Sulphur Springs (p. 61) the drill penetrated 1,317 feet of sand and clay that apparently represent the Wilcox and Midway formations, combined. Of this thickness 810 feet is assigned to the Wilcox.

[1] For a detailed discussion of the paleontology of the Midway formation see Harris, G. D., The Midway stage: Bull. Am. Paleontology, vol. 1, 1896, pp. 117-270.

[2] Penrose places the thickness at 250 to 300 feet (First Ann. Rept. Geol. Survey Texas, p. 23); and Kennedy (Third Ann. Rept. Geol. Survey Texas, 1892, p. 49) assigns them a thickness of 260 feet. In the Sulphur Springs well (p. 61) 324 feet of clays and sands have been referred to this formation.

CLAIBORNE GROUP.

The Claiborne group overlies the Wilcox and is said to contain "the most persistent and widely spread marine beds of the Coastal Plain." (See Veatch's map, fig. 2.) In northeastern Texas and northern Louisiana the group is divisible into a lower fossiliferous formation which has been called "Lower Claiborne," but for which Harris [1] has recently introduced the name St. Maurice formation, and an upper lignitiferous formation to which the name Cockfield has been given.

The upper portion of the Claiborne group consists of lignitiferous sands and clays, in which no marine fossils have been found except at the very top at Robertson Ferry, on Sabine River, and is known as the Cockfield formation. The bed exposed at Robertson Ferry containing marine fossils is included in the Cockfield formation.

The lower portion of the Claiborne is more calcareous, glauconitic, and clayey than the Wilcox and contains no lignitic matter. The thickness of the lower formation (St. Maurice) varies from 250 to 700 feet. The upper formation (Cockfield) consists of 400 to 500 feet of lignitiferous sands and clays, which are evidently of near-shore origin.

In southern Texas the "Lower Claiborne" was included by Kennedy in his "Marine beds" [2] and was subdivided into a lower division called Mount Selman and an upper division called Cook Mountain.[3] The "Marine beds" of Kennedy, however, included also a portion of the Wilcox which contains marine fossils.[4]

In southern Cass County and westward the Wilcox formation merges upward in places into brown and blue sands and clays, and glauconitic beds containing deposits of iron ore which may belong to the Claiborne.

Beds of this character occur in isolated areas and if of Claiborne age evidently represent outliers left in the general process of erosion. The fossils reported from these localities are not stratigraphically distinctive and the correlation with the Mount Selman formation is made chiefly on the presence of the iron ore and the general lithological character.

In the lower beds the iron exists in the form of carbonate of iron or clay ironstone, as scattered masses and nodules inclosed in the sand, in places coalescing into a bed continuous for several hundred yards. These layers are usually only a few inches in thickness and rusty from oxidation. In the southern part of Morris County, and

[1] Science, April 1, 1910, p. 502.
[2] Kennedy, William, Third Ann. Rept. Geol. Survey Texas, 1891, p. 52.
[3] Hayes, C. W., and Kennedy, William, Bull. U. S. Geol. Survey No. 212, 1903
[4] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 36.

in the southwestern part of Cass County, and extending thence west into Morris, Camp, Upshur, and the counties lying to the west, occur deposits of brown iron ore, lying horizontally near the tops of the hills, in some places at the surface and in others overlain by 1 foot to 30 feet of sand. The ore occurs in a variety of forms, botryoidal, stalactitic, mammillary masses, etc., but its characteristic form is that of loose nodules and geodes in a ferruginous sandy matrix or consolidated into irregular beds varying in thickness from 1 foot to 10 feet. The ores were termed "nodular or geode ores" by Penrose[1] who considers them to have been formed by the alteration of clay ironstone.

LATER TERTIARY DEPOSITS.

No marine deposits of Tertiary age later than Claiborne have been recognized in this part of northeastern Texas. Until near the close of the period the region appears to have been above sea level, or if temporarily depressed and subjected to sedimentation the deposits were subsequently removed by erosion. During Oligocene, Miocene, and early Pliocene times a general uplift caused the seacoast to recede toward the south to near the present coast. As a result of this elevation the region was subjected to more or less profound erosion and reduced to a level estimated by Veatch [2] to have been 500 to 700 feet above the present sea level.

In late Pliocene time there was deposited over the worn land surface a sheet of silts, sands, and gravels to which the name Lafayette was given by Hilgard.[3] In this part of northeastern Texas these deposits appear to have been removed by subsequent erosion. Redeposited remnants, however, occur as high-level terraces along the valleys and also as a thin gravel veneer over the rolling uplands.

QUATERNARY SYSTEM.

PLEISTOCENE SERIES.

PORT HUDSON FORMATION.

During the long interval of erosion which succeeded the deposition of the Lafayette formation the gravels derived from that formation were concentrated in many places by stream action. Then came a slow subsidence, which converted the bottom lands into swamps and caused the deposition of the Port Hudson formation of sand, silts, and clays containing remains of animals and plants characteristic of

[1] Penrose, R. A. F., jr., First Ann. Rept. Geol. Survey Texas, 1890, pp. 76–81.

[2] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 44.

[3] Hilgard, E. W., Am. Geologist, vol. 8, 1891, p. 130. See also McGee, W J, Twelfth Ann. Rept. U. S. Geol. Survey, pt. 1, 1891, pp. 347–521. Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 44–46.

swamp conditions. In these old valley deposits the streams cut newer valleys of moderate extent, remnants of the Port Hudson now occurring as flat-topped terraces along the principal streams, at no great depth below the present flood plains. The distribution of these terrace deposits in northeastern Texas is shown approximately on Plate I (p. 16). In western Bowie and eastern Red River counties, as will be seen, the terraces belonging to the Red River and Sulphur Fork valleys, respectively, coalesce over the intervening areas. Moreover, over most of the area north of Sulphur Fork a mantle of gravel occurs with some patches of gravel which are possibly due to the augmentation of the rivers by glacial flood waters.

Along Red River, in Bowie and Red River counties, the height of the outer terrace is about 70 to 75 feet above the present flood plain; while about 35 or 40 feet below this another well-marked terrace was noted in places.

RECENT.

EROSION.

A slight elevation following the Port Hudson period of deposition caused a renewal of stream activity with the excavation of the present valleys and the formation of the present topography. The amount of erosion accomplished in this later period, however, is small as compared with that which was effected in late Tertiary and early Quaternary times. The chief changes consisted in the alluviation of river bottoms, the destruction of river banks, and the formation of cut-offs by the wandering of the rivers. In northeastern Texas the topographic and geologic changes have been slight.

NATURAL MOUNDS.

Scattered over the sandy areas in this ana adjoining regions are innumerable small mounds varying from 20 to 100 feet in diameter and from 2 to 5 feet in height. They are especially well developed over the Port Hudson terrace plains, but occur also to some extent over the hill lands. In the Cretaceous area, outside the limits of the Port Hudson deposits, they are confined to the sandy belts representing the outcropping of the Blossom and Woodbine sands. In general, these mounds are rudely circular in outline, but in some localities they show a well-marked tendency toward a northeast-southwest elongation.

Mounds of similar character have a wide distribution and their origin has been a subject of much discussion. The problem is a perplexing one and remains as yet without satisfactory solution. Veatch, in a very complete review, groups the possible agencies of formation as human, animal, water erosion, eruptions, and wind.[1] Of the theories

[1] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 55-59.

included under these heads he concludes that those relating to the dune and the ant hill are the best supported. In a later paper, Campbell [1] summarizes the various hypotheses as (1) human; (2) animal, such as ground squirrels, gophers, and prairie dogs' burrows; (3) ant hills; (4) water erosion; (5) chemical solution; (6) wind action; (7) physical or chemical segregation; (8) glacial action; (9) uprooted trees; (10) spring and gas vents; and (11) fish nests. In his discussion he disposes of all of these hypotheses except that which ascribes the origin to burrowing animals, and adds, "but whether the mounds are due to ants or to small rodents the writer is unable to say." He admits that many mounds may have been produced by wind action, and that probably many others of an entirely different origin may have been modified by the wind, but maintains that "the great number of natural mounds are far too symmetrical in profile and in plan to have been formed by wind-blown material."

In view of the wide distribution of natural mounds and their occurrence in regions widely separated, some doubt may reasonably be entertained as to all having been formed by the same agency. The writer's observations in northeastern Texas has led him to favor the theory which ascribes the mounds in this region to wind action. The fact that they are not uniformly circular but are at times elongated, and that the position of the longer axis is parallel with the direction of the prevailing winds, seems to offer some support to this theory. However, the time at the disposal of the writer did not allow full opportunity to determine satisfactorily the extent to which the linear arrangement prevails and further observations are needed to settle the matter.

STRUCTURE.

The warping of the old Jurassic land surface, which preceded and accompanied the deposition of later formations, gave the beds a gentle slope toward the Gulf, amounting, in Lamar County, to about 55 feet per mile.[2] This dip was estimated by taking the elevation by barometer of the base of the Goodland limestone north of Hugo, Okla. (475 feet above tide), and comparing it with the elevation as shown in the Paris well, 1,125 feet. The distance is about 29.1 miles, in which the rocks are carried down 1,600 feet, or about 55 feet per mile.

As to the attitude of the beds south of Sulphur Fork, no definite data are obtainable. If, however, this region has been affected by

[1] Campbell, M. R., Jour. Geology, vol. 14, 1906, pp. 708-717. Contains a fairly complete list of papers relating to the subject.

[2] Using the observed dips of the Goodland limestone, Taff estimated the dip at about 50 feet per mile, and predicted that the water-bearing Trinity sand would be found at Paris at a depth of 1,500 feet. In the well subsequently drilled there, however, these sands were reached at a depth of 1,635 feet, to which 91 feet must be added for the difference in elevation between the bench mark on the post-office building (601 feet) and the top of the well.

the Red River-Alabama Landing fault, as indicated by Hill [1] and Veatch,[2] the strata south of Sulphur Fork must lie nearly horizontal.

If, as suggested by Veatch, the Red River fault and the Alabama Landing fault constitute parts of the same general displacement, the fault line would occupy approximately the position of the Sulphur Fork, including North Fork. Owing to the covering of alluvial deposits, however, no traces of the existence of this fault can be observed except a disturbed condition of the Austin chalk beds noted by Hill [3] in the cut north of Pecan Gap station.

According to Hill and Veatch the displacement of this fault is about 600 feet, with the downthrow to the north. It is scarcely conceivable that a displacement of 600 feet could escape recognition in the vicinity of North Fork, as it would be sufficient to bring the Austin chalk to the surface in Delta County. The writer was at first inclined to think that the chalk near Enloe might be the Austin brought up by faulting, but his further study of the stratigraphic relations and faunal contents of these beds did not support this conclusion. It seems probable, therefore, that if any displacement has occurred here its extent is much less than 600 feet.

UNDERGROUND WATER.

SOURCE.

All underground water is derived from rainfall. A considerable part of the rainfall runs off the surface and is carried away by streams; a part is removed by evaporation or consumed by living organisms and in chemical work; and the remainder sinks into the soil and unites with the underground waters, to reappear in part as springs at more or less distant points.

The proportion of the rainfall disposed of by evaporation and run-off and by percolation and absorption into the rocks, varies with climatic, topographic, geologic, and other conditions. The portion which sinks into the ground furnishes the entire supply for both deep and shallow wells, and it is this alone that need be considered so far as underground waters are concerned.

The percentage of the rainfall which sinks into the earth is determined by (1) the character of the rains, whether slow and steady or of a torrential nature; (2) the topography of the country, whether flat or with many steep slopes; (3) the character and amount of vegetation covering the surface; and (4) the porosity of the soil and the physical character and state of saturation of the underlying beds.[4] The surface of the zone of saturation varies with climatic conditions,

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[1] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, p. 384.
[2] Veatch, A. C., op. cit., pp. 68-69.
[3] Hill, R. T., op. cit., p. 342.
[4] Veatch, A. C., op. cit., p. 70.

rising in periods of long continued rains and sinking during periods of drouth. In regions of excessive rainfall and limited evaporation its upper limit usually coincides with the surface, whereas in arid regions it may be several hundred feet below the surface. Moreover, the upper line or limit of saturation—the water table—conforms in a general way to the surface, rising somewhat higher under elevations than under depressions.

AVAILABILITY OF UNDERGROUND WATER.

The availability of the water that sinks into the soil depends on (1) the adequacy of the supply and the quality of the water contained in the rock formations, and (2) the depth at which it may be encountered and the height to which it will rise in wells. The permanency of the supply depends on the capacity of the rocks for absorbing and transmitting water, and the quality of the soluble minerals contained in the beds through which it passes. The feasibility of obtaining water at any locality depends on the position and elevation of the rock strata and the structural relations which control the arrangement of the rock masses. It is evident, therefore, that the controlling factors in the utilization of underground water are the composition of the rocks and their arrangement in sheets and masses, or, in other words, the geologic structure.

CAPACITY OF ROCKS FOR IMBIBING WATER.

The capacity of rocks to imbibe moisture varies with their physical structure. Most of the water in rocks occurs in pores and interstices, the larger part of the world's well-water supply being derived from saturated porous beds, only a small part of it being obtained from caverns or large cavities. Practically all rocks, however compact they may appear to the eye, have interstices and small cavities in which water may be stored. The degree of porosity of rocks, however, differs greatly in different rocks, being highest in open-textured loose sands, sandstones, gravels, and chalks, all of which have great capacity for imbibing water, and lowest in close-textured clays, slates, marbles, and granites, which have very small capacity for absorbing and transmitting water. Some rocks, however, such as granite, which in their original condition are almost impervious, become water bearing through the development of fractures and crevices.

The capacity of rocks for transmitting water is different from their capacity for imbibition. In certain fine-grained rocks the pore spaces are so small that they will not readily transmit water. Hence rocks like chalk or brick, which absorb water freely, transmit it slowly, whereas others with no greater total pore space transmit it readily. Sandstones, for instance, vary greatly in texture and consequently in their capacity for carrying water.

ARTESIAN WATERS DEFINED.

Underground waters which under the influence of hydrostatic pressure tend to rise to the level of the water surface at the highest point from which the pressure is transmitted are known as artesian waters. Hence an artesian well is any well in which the water rises under artesian pressure. If the water rises to the surface the well is known as a flowing artesian well; if the water fails to rise to the surface it is known as a nonflowing artesian well. An artesian system is any combination of geologic structural features—such as basins, planes, joints, or faults—in which waters are confined under artesian pressure and will rise if an outlet is afforded by a well or other perforation. An artesian basin is a basin of porous-bedded rock in which, as a result of synclinal structure, the water is confined under artesian pressure. An artesian slope is a monoclinal slope of bedded rocks in which water is confined beneath relatively impervious covers owing to the obstruction to its downward passage by the pinching out of porous beds, by a change in character from pervious to impervious, by internal friction, or by dikes or other obstructions. An artesian area is an area underlain by water under artesian pressure.

CONDITIONS THAT DETERMINE ARTESIAN WELLS.

The distribution of underground water depends on the arrangement of the rocks in sheets and masses. If the strata are horizontal they constitute storage systems in which the water is under little or no artesian pressure and will escape only laterally as seepage springs where the beds are cut by valleys of erosion. If the water bearing beds are inclined and are included between impervious sheets, the water absorbed over the outcropping area will sink under the influence of gravity and if reached by a well at any point beyonp the limit of its outcrop will tend to rise therein to the level of complete saturation.

The water pressure and, therefore, the height to wnich water will rise depend on several conditions: (1) On the elevation of the groundwater table at the outcrop or source, which in turn depends on the uneven elevation and surface conformation of the catchment area; (2) on the loss by friction in transmission, a factor which depends on the size of the spaces between the grains and is not by any means uniform even in the most even-textured beds; and (3) on the loss by leakage resulting from increases in porosity of the inclosing beds from faults, joints, and other natural breaks, and, locally, from the multiplication of wells within a restricted area. Hence the level to which water will rise in wells is always somewhat lower than the lowest point of the outcrop of the containing beds and becomes lower and lower with increasing distance from the catchment area.

The factors controlling the occurrence of flowing wells may be briefly stated as follows: (1) There should be relatively porous beds suitably situated to collect and transmit the water; (2) the water-bearing beds should be inclosed between other relatively impervious layers to confine the water; and (3) the level of the ground-water table at the source should be enough higher than the surface at the point where the well is located to compensate for the loss of head due to resistance and leakage. As these conditions vary from point to point it is evident that both flowing and nonflowing artesian wells

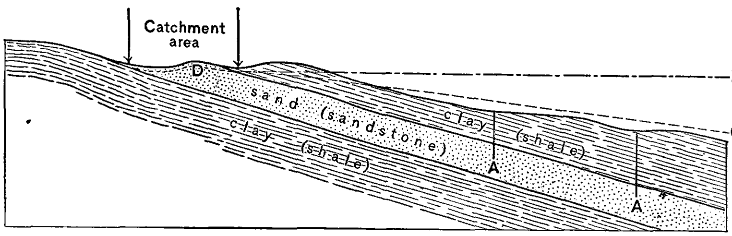

FIGURE 3.—Diagram showing the common arrangement of factors producing artesian wells. *A*, artesian wells; *B*, head of water if there were no loss by resistance or leakage; *C*, actual head of hydraulic gradient; *D*, ground-water table at outcrop.

may occur within the same artesian area. The accompanying diagram (fig. 3) illustrates the most common arrangement of factors producing artesian wells.

ARTESIAN WATERS IN NORTHEASTERN TEXAS.

GENERAL GEOLOGIC RELATIONS OF THE WATER-BEARING BEDS.

Within the area here considered the known water horizons occur in the Cretaceous and Tertiary and may be represented as follows:

Water-bearing formations in northeastern Texas.

System.	Formation.	Character.
Tertiary (Eocene).	Wilcox ("Sabine") formation.	Sands and clays. Certain beds water bearing. No correlation possible.
	Midway formation.	Mostly clays, some thin beds of limestone in places. No water. Some sandy beds slightly water bearing.
Upper Cretaceous (Gulf series).	Navarro formation and Taylor marl.	Clay marls, not water bearing. Glauconitic sands. An important water horizon in Arkansas; of doubtful utility in Texas.
		Clay and chalk marls in places sandy. Near the base a bed of sand appears to be water bearing, but it has not been developed.
	Austin group.	Chalk (Annona) and chalk marl (Brownstown). Not available as a source of water. Contains hard water where porous.
	Eagle Ford clay.	Blossom sand member. Water bearing. Clays. No water, or limited supplies of highly mineralized water.
	Woodbine sand.	Sands and shales. The sands are usually water bearing. Several water horizons.

Water-bearing formations in northeastern Texas—Continued.

System.	Formation.	Character.
Lower Cretaceous (Comanche series).	Washita group.	Impure limestones and usually nonwater-bearing marls; 35 feet of sand [a] with water occurring in the Paris well.
	Fredericksburg group (Goodland limestone).	Massive white limestone. No water.
	Trinity sand.	Sands and clays with thin beds of limestone. Important water horizon in Texas; becomes of less importance eastward.

[a] According to Mr. J. A. Porter (p. 46), the seventh water horizon occurred under a limestone "cap-rock" at 1,635 feet. The sandstone is evidently the one mentioned by Hill (p. 46) as occurring at 1,650–1,685 feet, but Hill does not state that it is water bearing. The discrepancy as to the lower portion of the Paris record is not easily reconcilable, there being no reliable data available for that part of the hole.

CRETACEOUS SYSTEM.

TRINITY SAND.

The Trinity sand is an important water-bearing horizon, supplying a large number of wells in central Texas, where it is divisible into several formations, known as the Trinity group. In the main the beds consist of fine, clean, white sand pressed compactly together and popularly known as "packsand." The group includes some calcareous beds, which increase in thickness toward the southern part of the State, and are there known as the Glen Rose limestone.

The outcrop of the Trinity sand occurs in Oklahoma several miles north of Red River. This catchment area constitutes a belt from 5 to 10 miles in width, extending nearly due east into Arkansas. From this line of exposure the southward dip of the beds carries them beneath all this part of northeastern Texas to depths proportionate to the distance from the outcrop. The only available record of the depth to the Trinity sand in northeastern Texas is that of the well at Paris (p. 45), where it was reached at about 1,735 feet. From this record and from the depth of the sands as shown by a well at Hugo the dip of the formations is estimated at about 56 feet per mile.

Sands being near-shore formations they gradually give place seaward to contemporaneous clays and limestones formed in deeper and quieter waters. This change consists both in an increase in the argillaceous and calcareous constituents of the rocks and in a wedging out of the sands. This imbrication of the strata is shown in the ideal diagrammatic section of the Cretaceous rocks in northern Texas and southwestern Arkansas given by Taff[1] (fig. 4, p. 39).

Water falling upon the outcrop of the Trinity sand or carried over it by rivers sinks into it readily, and for a certain distance from the outcrop these sands furnish an abundant supply of water of excellent quality. Farther away, however, the water becomes affected by

[1] Taff, J. A., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, p. 697.

mineral constituents taken up in its underground passage, and is likely to be too highly mineralized for ordinary use.

The conditions which control the height to which water will rise in wells has been explained (p. 37). Within the main zone of saturation water pressures in a formation are likely to be unequal, owing to differences in the coarseness of the strata, leakage through springs, and local irregularities in the additions supplied by rainfall. Hence there is a gradual decline in the pressure head with increase of distance from the line of outcrop. In the absence of accurate relief maps of northeastern Texas any statement of the areas in which flowing wells may be expected from any particular horizon can be approximate only. At its outcrop north of Hugo the Trinity sand stands about 500 feet above sea level. The elevation of the top of the well at Paris is 510 feet. Water from the Trinity would therefore lack 10 feet of rising to the top even if it sustained no loss of pressure. The amount of such loss is unknown, but assuming it to be 30 or 40 feet the water from the Trinity sand would lack 40 or 50 feet of reaching the surface at Paris. The area in which flowing wells may be expected from the Trinity sand in the vicinity of Paris or at points equally distant from the outcrop must therefore have an altitude of less than 450 or 460 feet above sea level, hence these wells would be confined to the valley of Red River.

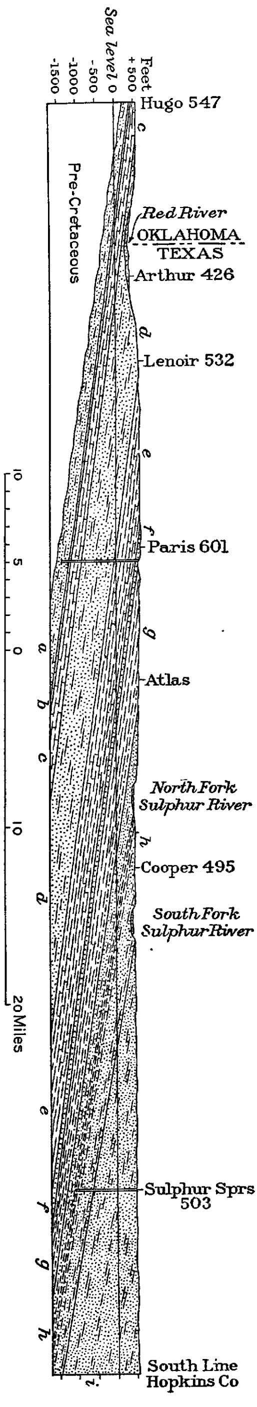

FIGURE 4.—Profile section showing water horizons. *a*, Sands and interlaminated clays; *b*, limestones; *c*, limestones and shales; *d*, mostly sands with some clays; *e*, clays with thin limestones; *f*, Blossom sand member of Eagle Ford clay; *g*, Annona chalk and Brownstown marl; *h*, sandy and clay marl, some chalk; *i*, sands, clays, and sandstones.

WASHITA GROUP.

The Washita group has not hitherto been recognized as including water-bearing beds. Its mention here is based on the somewhat doubtful assignment to it of the seventh water horizon in the

Paris well (p. 45). Even if the seventh horizon belongs to the Washita, some doubt exists as to whether the water came from that level (sandstone No. 24 of the section) or from some lower horizon. Hill in his section (p. 46) gives a sandstone at 1,650 to 1,685 feet, but does not credit it with having water. Mr. Porter's log shows the seventh water horizon at 1,635 feet just below a limestone, a depth very close to that of the bed (24) shown in Hill's section.

A point in favor of assigning the bed to the Washita group is the statement of Mr. Porter that the water from it rose to within 2 feet of the surface. The evidence available does not support the view that water from the Trinity would rise so high. The Washita, on the other hand, outcrops in the vicinity of Hugo at a higher level than the Trinity and can reasonably be expected to furnish flowing wells at a level of 500 to 510 feet in Lamar County. In general the Washita group consists of shales and limestones, but it contains some arenaceous beds in the upper part (Denison formation; the Pawpaw beds of Hill), and these may contain water in some places.

Flowing wells may be expected from the Washita group, if water bearing, along the south side of Red River in Lamar County at altitudes of 500 feet and under. Toward the east the pressure evidently declines because of the gradual lowering of the surface of the outcropping beds in the territory. The area in which flowing wells may be had from this horizon is probably confined to Lamar County and the extreme northern part of Red River County.

WOODBINE SAND.

The Woodbine formation consists of alternations of sands, sandstones, clays, and marls, commonly lignitiferous and glauconitic and containing iron pyrite. The character of the waters also indicates that some of the beds contain more or less iron and salt. The lower portion of the formation, called by Taff and Hill the Dexter sand, has layers of considerable thickness, which are free from mineral matter and rather porous. The water from this horizon (sixth) in the Paris well (p. 45) rose to within 6 feet of the surface. Its character was not adequately tested, however, as it was allowed to mingle with the more mineralized waters from the higher beds. The upper portion of the Woodbine includes several beds of sand which are water bearing, but they contain quantities of vegetable and animal remains which, together with soluble salts, so impregnate the water as to render it useless.

North of Paris Red River flows upon the outcrop of the Woodbine formation, the sands appearing on both sides of the river in the bluffs bordering the alluvial bottoms. On the south side of the river the sands outcrop in a belt several miles wide, extending through the northern part of Fannin, Lamar, and Red River counties, except where covered by Recent alluvial formations.

EAGLE FORD CLAY.

Lower clays.—The lower portion of the Eagle Ford consists of blue marly clays containing hard concretions, with occasional layers of sandy shale. The sandy constituents increase downward and the formation gradually passes into the Woodbine sand below. This part of the formation is for the most part dry, but in places it contains small quantities of water, which, however, is too highly charged with deleterious substances to be used.

Blossom sand member.—The upper 50 to 80 feet of the Eagle Ford clay consists of glauconitic sands irregularly interlaminated with clays. On exposure the sands become red from the oxidation of the contained iron. These sands outcrop in a narrow band from 1 mile to 2 miles wide, extending east and west across Red River, Lamar, and Fannin counties and adjoining on the south the Eagle Ford black prairies or clay belt. The towns of Blossom, Paris, and Detroit are located on the outcrop of these sands, the first named giving the name to the beds. The shallow wells along the outcrop commonly range from 25 to 75 feet in depth and yield an abundant supply of soft water, which in some wells is of good quality, but which in most is impregnated with variable amounts of mineral matter. The quality of the water from the embedded portion of this sand seems to be good, as shown by the Clarksville waterworks wells, which derive their supply from it.

The sands appear to have a thickness of more than 60 feet generally, but only a small part of the member is water bearing—a fact that must be taken into account in sinking wells to this horizon.

AUSTIN GROUP.

The Austin group consists chiefly of chalks (Annona chalk) and chalk marls (Brownstown marl) and is in the main destitute of water. In places, however, the beds are somewhat porous and may then furnish limited supplies of very hard water.

NAVARRO FORMATION AND TAYLOR MARL.

The Navarro formation and Taylor marl consist of clay and sandy marl, with some sand and chalk. Near the base is a bed of chalk, which outcrops near Enloe and southwestward in the vicinity of Pecan Gap and Ladonia. Underneath the chalk is a soft yellow sand, which outcrops at Ladonia. The thickness of this sand is nowhere clearly shown, but probably does not exceed 50 or 60 feet. At Pecan Gap 30 feet of sand underlie the chalk, the base of the sand not being exposed. Portions of the sand become notably calcareous, with occasional thin chalky layers. Downward the sands grade into sandy yellow clay containing many *Exogyra*.

The outcrop of this sand constitutes a narrow band through the northern part of Delta County and southwestward in Hunt County through Wolf City. Its water-bearing character has not been tested underground, but its character and outcrop indicate that it may constitute a source of supply in a belt a few miles wide along its south border. As the catchment area is not extensive it is not likely to prove a very important horizon and will probably not be available for wells except in a comparatively small area.

In Arkansas the Nacatoch sand (see p. 25) constitutes an extensively exploited water horizon. At Texarkana it contains no less than eight water-bearing beds, two of which (at 1,020 and 1,174 feet, respectively) showed strong pressure. In Texas these beds show a diminution in their porous sandy character, and though still water bearing to some extent are of less importance in this respect than in southern Arkansas. In southern Delta County a narrow belt of glauconitic sandy shales and sands, which apparently represent this formation, outcrops along the north side of South Fork and just west of Commerce. The outcrops are meager, however, and the character and relations of the beds are not clearly shown. In a well 100 feet deep at Sulphur Bluff these sands were reached at 30 feet and were found to contain water, which, however, was not used. The overlap of the Eocene south of Sulphur Fork has covered the higher portions of the Cretaceous and nothing can be said of these beds here.

TERTIARY SYSTEM.

WILCOX ("SABINE") FORMATION.

The Wilcox ("Sabine") formation in this region consists of ferruginous and lignitiferous sands, ferruginous sandstones, and blue and brown clays, with one or more beds of lignite and local beds of iron ore. The formation is generally water bearing, but as its character changes from place to place no definite correlation can be made between the water sands in different localities. Owing to the lenticular character of the bedding it is probable that the water sands are of local extent only and occur in different positions within the formation.

Underground-water conditions in the Wilcox formation differ materially from those in the Cretaceous. In the Cretaceous the sandy beds lie between more impervious strata, thus permitting the water to enter only at the outcrop. In the Tertiary (Eocene) no such definite relationship exists between the clays and sands, there being no well-defined persistent clay layers. The whole series being predominantly sandy the water is relatively free to penetrate the beds at any point. Hence the head in any case is dependent not on the height of the ground water table at the outcrop of the horizon tapped, but on its height near the well.[1]

[1] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 81-82.

From the evidence supplied by the Sulphur Springs well (see p. 61) it would appear that below a depth of 50 feet in that vicinity the beds of the Wilcox are largely barren. At Mount Vernon, however, 20 to 25 miles farther east and about 25 feet lower, an abundant supply of water is found at about 400 feet. At Mount Pleasant no water was found below the surface sands to a depth of 300 feet, but at Pittsburg, 12 miles south, 33 feet of water sand occurs at 151 to 184 feet. At Daingerfield, 15 miles east of Pittsburg and at about the same level (400 feet above tide), the gin well is apparently supplied from the same bed at a depth of 186 feet, the water rising to within 20 feet of the surface. This sand probably has its outcrop somewhere between Mount Pleasant and Pittsburg. At Jefferson a well whose top is 196 feet above tide obtains water at a depth of 830 feet.[1]

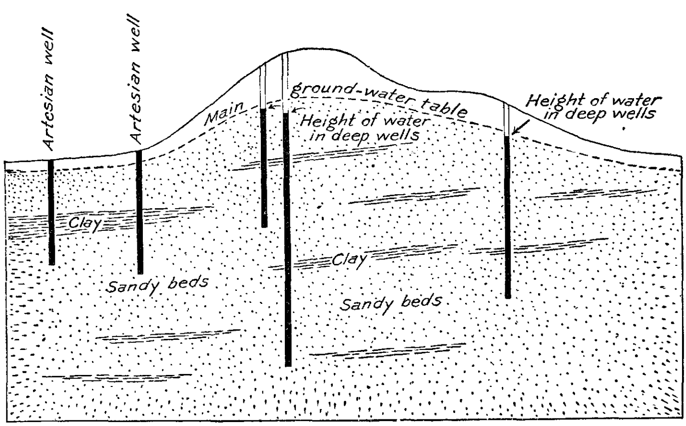

FIGURE 5.—Diagram showing water conditions in the lower Eocene strata in northwestern Louisiana and southern Arkansas. The beds are predominantly sandy, with irregular discontinuous clay masses; water is relatively free to pass to any part of the beds, and the hydraulic head depends on the local position of the ground-water table rather than on its position at the outcrop of the water-bearing beds.

At Hawkins, in the valley of the Sabine River, in Wood County, a flowing well is reported at a depth of 200 feet. The elevation of the town is 394 feet.

In general the water-bearing character of the Wilcox formation beds is controlled by the variation in the porosity of the beds from place to place, and hence the successful development of a well depends on finding a bed coarse enough to act as a natural horizontal strainer and so aid in removing the water in the adjoining finer beds. Although the sand beds vary greatly in physical character and thickness within short distances, there are, nevertheless, certain beds in which the chances of developing a satisfactory well are greater than in others. Of these the most important are located toward the top of the formation and are represented in the Pittsburg and Daingerfield wells.

[1] The authority for the depth of this well is Mr. J. M. De Ware, of Jefferson. In Hill's report (Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 414) the depth of this well is given as 802 feet.

SURFICIAL SANDS AND GRAVELS.

The irregular deposits of sand and gravel of late Tertiary and Quaternary age, which in places overlie the older Tertiary and Cretaceous beds, are of varying value as water carriers. Wells in these beds situated on the hills are likely to be of some slight local importance. In the larger river valleys, however, they may yield large supplies.

REVIEW BY COUNTIES.

LAMAR COUNTY.

Geographic relations.—Lamar County adjoins Red River, in the extreme northwestern part of the area included in this report. It comprises an area of 903 square miles and in 1910 had a population of 46,544. Its county seat and chief town is Paris, with a population of 11,269. The county is traversed by the Texas & Pacific, St. Louis & Southwestern, and Texas Midland railways.

The drainage of the county is divided about equally between Red River and North Fork of Sulphur River, the divide between the two systems passing east and west across the county near the middle. The general slope is toward the southeast. The surface is rolling, without pronounced relief, the drainage ways being but moderately incised below the general plain level.

Geology.—The south half of the county is underlain by light to dark-brown and jet-black clay or clay loam designated Houston clay and Houston black clay by the Bureau of Soils; these, constituting what is locally known as black waxy land, are residual soils derived from the weathering of the clay and chalk marls of the Austin group. Northward from Paris the gray sandy clay loam derived from the Eagle Ford clay extends to the vicinity of Lenoir, from which point north to the river a strip of sandy soil 2 to 10 miles wide represents the outcrop of the Woodbine sand.

Lamar County lies upon the outcrop of the lower half of the upper Cretaceous, comprising within its boundaries the Woodbine, Eagle Ford, Brownstown, and Annona formations and the Taylor marl, which outcrop in successive belts extending east and west across the county. North of the Brownstown area is a strip of sandy soil 1 to 2 miles wide which represents the outcrop of the upper arenaceous layers of the Eagle Ford, to which in this report the name Blossom sand member is given. The approximate distribution of the outcrops of the different formations will be seen on the map (Pl. I). Within the area of the Eagle Ford clay a number of isolated patches or outliers of overlying formations have not been entirely removed by erosion. No attempt has been made to map these areas. The strata have a dip of 50 to 60 feet per mile toward the south-southeast.

Water resources.—Throughout the clay-land area cisterns and tanks constitute practically the sole source of water supply in Lamar County. Paris derives its supply from a rain reservoir about 6 miles west of town. In 1896 the city made a determined effort to develop an underground supply, but without satisfactory results. Shallow wells and springs are common in the area of the Woodbine sand, the supply for the most part being ample and the quality good.

Although the Trinity sand underlies the whole county (see fig. 4) only in the northern part is it near enough to the surface to be practically available. Its catchment area northward in Oklahoma is lower than the surface of most of Lamar County, hence flowing wells from this horizon can be expected only in the low-lying districts, notably along the valley of Red River.

A well put down by S. J. Wright on the banks of Red River opposite the mouth of Kiamichi River is reported to have found an abundant flow of water in these beds at a depth of 301 feet, the water having sufficient force to rise to a considerable height above the surface. Owing to the caving of the well, the drill was lost and the well abandoned.

The Woodbine sand outcrops in the northern part of the county and over its area the ground-water table can be reached by wells at depths of 20 to 50 feet. Southward from the outcrop the sands lie at constantly increasing depths. At Paris the first water sand of this formation was found at 600 feet.

A detailed section of the Paris well has been kindly furnished by Mr. John A. Porter, the superintendent. The boring, which was made by the city waterworks, is located 2½ miles east of the city square. The elevation is 510 feet above tide (91 feet lower than the United States Geological Survey bench mark on the Government building, which reads 601 feet). The well was completed December 19, 1906.

Record of the Paris well.

Formation.[a]		No.	Character.	Thickness.	Depth.
				Feet.	*Feet.*
Eagle Ford clay.	Blossom sand member.	1	Sand with thin soil on top	60	60
		2	"Packsand;" first water	20	80
		3	Blue marl	100	180
		4	Blue marl with trace of sand at top	320	500
		5	Marl of lighter color; second water at 570; rose to within 110 feet of surface.	100	600
Woodbine sand.		6	Gray sandrock	50	650
		7	Marl	125	775
		8	Sandrock; third water; rose to within 100 feet of the surface	8	783
		9	Marl	175	958
		10	Gray sandrock; fourth water; rose to 75 feet from surface	25	983
		11	Marl	66	1,049
		12	Gray sandrock; fifth water; rose to 30 feet from surface	31	1,080
		13	Marl	33	1,113

[a] Identifications by the writer.

Record of the Paris well—Continued.

Formation.	No.	Character.	Thickness.	Depth.
			Feet.	*Feet.*
Woodbine sand.	14	Red sandrock	52	1,165
	15	Sandrock and clay	6	1,171
	16	Sandrock with indications of lime; sand almost white	105	1,276
	17	Unrecorded; "was drilled while sand bucket was being drilled out."	39	1,315
	18	Marly lime and sand } Sixth water; rose to within 6 feet of the surface.	33	1,348
	19	Sandrock	39	1,387
	20	Loose sand	25	1,412
	21	Gravel	8	1,420
Washita group and Trinity sand.	22	Sand, followed in succession by shell rock (8 to 10 inches) and alternating layers of limestone and marl darker below.	130	1,550
	23	Unrecorded; said to penetrate limestone at the bottom	85	1.635
	24	Unrecorded; sand at top; seventh water, which rose to within 2 feet of the surface.	360	1,965

The above record to a depth of 1,550 feet (Nos. 1 to 22) corresponds with that published by Hill.[1] The remaining portion of Hill's record, which stops at 1,726 feet, is as follows:

Record of lower part of Paris well (by Hill).

Formation.	No.	Character.	Thickness.	Depth.
			Feet.	*Feet.*
Washita group.	23	Unrecorded	100	1,650
	24	Grayish friable sandstone	35	1,685
	25	Impure argillaceous limestone with fossils	15	1,700
	26	Impure limestone with *Gryphæa washitaensis*	10	1,710
Goodland limestone.	27	White limestone resembling Goodland limestone	15	1,725
	28	Hard arenaceous limestone with *Pecten* and *Anomia*	+1	1,726

According to Porter, water was found in sand at 1,635 feet. This is evidently the sand noted in Hill's section at 1,650 to 1,685 feet (No. 24). Hill makes no mention of water at this horizon. From the greater detail given by Hill from 1,550 to 1,726 feet it is probable he had before him the drillings from the well. Later the well was extended to 1,965 feet, but no record is available for this portion. The Trinity must have been reached at about 1,735 feet, but nothing is known of its water-bearing character.

The Paris well is located on the outcrop of the Blossom sand member, which constitutes the upper part of the Eagle Ford clay, in which five small water reservoirs were encountered within the first 100 feet. In the Woodbine, aggregating about 800 feet in thickness, are six beds of sand, five of which are water bearing. The first yielded at 570 feet a strong flow of briny water, which rose to within 110 feet of the surface; it may represent a water sand within No. 5, not otherwise noted. The second (No. 8) also yielded salty water,

[1] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 629.

which rose 10 feet higher than that from No. 5. The third at 958 feet yielded water that rose to within 75 feet of the surface, and the fourth at 1,049 feet water that rose to within 30 feet of the surface. All of the waters were briny and unfit for use. In the fifth sand (No. 19) a strong flow was reached at 1,350 feet and rose to within 6 feet of the surface. The quality of this water is unknown, as the waters from above were allowed to mingle with it. This sand is inferred to be the basement reservoir of the Woodbine, which is so prolific of wells in regions to the southward. The next water, the seventh, according to Porter, came from beneath a bed of limestone at 1,635 feet and rose to within 2 feet of the top. The failure to exclude the higher waters throws doubt on the character of those from the two lowest flows. The height to which the water rises indicates that flowing wells may be obtained from these horizons in Lamar County at localities having elevations under 500 feet.

In the area of outcrop of the Blossom sand member water is found in shallow wells at depths ranging from 15 to 50 feet. The water from many of these wells is strongly mineralized, but a notable difference is manifested by the waters of wells which are near together. The well of the Texas Midland Railway at Paris is located in these sands at an altitude of about 566 feet. The following record, which has been published by Hill,[1] was supplied by the president of the company, E. H. R. Green.

Well of the Texas Midland Railway, Paris, Lamar County, Tex.

No.	Character.	Thickness.	Depth.
		Feet.	*Feet.*
1	Residual soil grading into sand and clay	18	18
2	Black sand, water bearing, yielding 1,200 gallons per day	15	33
3	Hard barren pack sand	12	45
4	Top portion of barren joint clays	28	73

At Blossom, a station on the Texas & Pacific Railway 12 miles east of Paris, a number of wells have been sunk to depths of 15 to 40 feet. W. E. Moore's well, located near the edge of the Black Prairie, in the south part of the town, gave the following record:

Well of W. E. Moore, Blossom, Tex.

No.	Character.	Thickness.		Depth.	
		Ft.	*in.*	*Ft.*	*n.*
1	Top soil and clay	6		6	
2	Sand and clay mixed	25		31	
3	Red sand rock		10	31	10
4	Dark sand	4		35	10
5	Dark clay or slate	110		145	10

[1] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 631.

Water, doubtless coming from the sand of No. 2, rose in this well to within 30 feet of the surface. The water is not used.

A well 117 feet deep put down near the depot several years ago yields a small supply of mineralized water which is regarded locally as having valuable medicinal properties. The only soft-water well in town is that of John Carter, on the north side of the village. It is about 30 feet deep. (See analyses of water of the Blossom wells, p. 74.)

In the south part of the county the Blossom sand member apparently underlies all the black-land area and can be reached at gradually increasing depths up to 1,400 or 1,500 feet. Wells located on the Annona chalk belt will reach the sands at depths of from 300 to 600 feet. The water-bearing character of these sands underground in Lamar County has not been tested and their availability is largely a matter of conjecture. At Clarksville, in Red River County, however, they yield an ample supply of good water for the use of the city and it is quite probable tnat similar supplies may be found in them in Lamar County. In the absence of well records no definite statement can be made as to the height to which water from the Blossom sand member will rise in the county. At Clarksville the wells have an elevation of about 450 feet and the water rises to within 55 feet of the top. At their outcrop 4 miles north of town t e sands have an elevation of about 400 feet. Westward there is a rise in the surface outcrop with a corresponding rise in the water table to about 550 feet at Paris. From this it will appear that flowing wells can not be expected from the Blossom sand member in Lamar County at elevations greater than 500 to 525 feet.

DELTA COUNTY.

Geographic relations.—Delta County borders Lamar County on the south and occupies the triangular-shaped area between North and South forks of Sulphur River. It has an area of 266 square miles, with a population of 14,566; the county seat is Cooper. The county is traversed from northeast to southwest by the Texas Midland Railroad and is intersected for short distances in the northwest and southwest corners by the Gulf, Colorado & Santa Fe and St. Louis & Southwestern railroads, respectively.

The county is an eastward-dipping plain, grading from the rolling black prairie on the north and west to an almost flat surface on the east. Elevations are: Enloe, 495; Cooper, 495; Klondike, 478; and Ben Franklin, 465 feet, above sea level. It is drained entirely by North and South forks of Sulphur, the larger part going to the latter on account of the general slope. None of the drainage ways are conspicuous.

Geology.—The county is situated on the outcrop of the uppermost beds of the Upper Cretaceous as represented in Texas, South Fork following approximately the boundary between the Cretaceous and the overlying Eocene Tertiary. A single small area of Cretaceous in the form of an inlier occurs south of South Fork at Sulphur Bluff in northeast Hopkins County. Outside a narrow belt bordering South Fork the soils of Delta County are of the black waxy type characteristic of the black-prairie region of Texas.

Water resources.—In the black-land areas the water for domestic use is derived almost entirely from cisterns and tanks. In the rather small sandy areas both wells and cisterns are in use. A boring made by Mr. E. H. Bond 3 miles southwest of Cooper to a depth of 263 feet was wholly in clay marl. The section is as follows:

Record of E. H. Bond's well 3 miles southwest of Cooper, Tex.

No.	Character.	Thickness.	Depth.
		Feet.	*Feet.*
1	Black soil	5	5
2	Yellow sandy clay marl	45	50
3	Blue clay marl	213	263

No water was found except a "slow seep" from No. 2. This is the source from which the water of the shallow wells is derived, but the water is hard and brackish and little used except for stock.

In the sandy areas in the south part of the county the wells range in depth from 10 to 100 feet. The water is reported to be fairly good and the supply ample, but cisterns are coming into general use. Throughout the county rain reservoirs and tanks are relied upon mainly for stock supplies.

No effort has been made to exploit the underground waters of Delta County. A study of the geology shows that although the Trinity and Woodbine reservoirs undoubtedly extend beneath the county, they are at too great depth to be available even if they were likely to furnish a desirable quality of water, which is improbable. The estimated depth of the Trinity at Cooper is about 3,000 feet. The depth to the first water sands of the Woodbine is 1,800 to 2,000 feet and to the lowest, the only one concerning whose quality doubt exists, is 800 to 900 feet deeper. The Blossom sand member can be reached at a probable depth of from 1,200 to 1,300 feet. In the absence of any test well in the region, however, no safe prediction can be made as to its availability as a source of water supply so far from the outcrop.

The only other apparent source of underground water over the larger portion of the county is the sand bed which outcrops along the south side of North Fork. This sand evidently extends beneath the larger part of the county. From its outcrop it appears to dip south by southeast, and can be reached at increasing depths according to the elevation of the surface and the distance from the outcrop. At Commerce, Hunt County, it lies at a depth of 600 feet and, as shown by the Midland Railway well (see below), is water bearing. At Cooper the sand is estimated to lie at a depth of 500 to 600 feet. As the surface is 30 to 50 feet higher at Cooper than at the outcrop of the sand, flowing wells could not be expected, but the water would probably rise to within 50 feet of the top of the well. The width of the outcrop or catchment area of the sand is from 1 to 2 miles.

The upper sands (Nacatoch?) outcrop in a narrow belt along the south side of the county through Klondike and to the north of Commerce just over the line in Hunt County. These sands would be available for wells only in a restricted area bordering South Fork. At Horton, 4 miles south of Klondike, these sands were reached at 315 feet:

Record of well at Horton, Delta County, Tex.

No.	Character.	Thickness.	Depth.
		Feet.	*Feet.*
1	Surface sand	30	30
2	Blue "slate"	60	90
3	Black clay	225	315
4	Water sand	(?)	....

At Commerce, Hunt County, which is located at about the same geologic horizon, the same sands occur at a depth of 370 to 385 feet, according to the somewhat imperfect records available.

Record of Capt. Ander's well; elevation, 548 feet, approximate.

No.	Character.	Thickness.	Depth.
		Feet.	*Feet.*
1	Soil	10	10
2	Joint clay	30	40
3	Blue shale	330	370
4	Water sand beneath a hard ledge	......	......

Record of Texas Midland Railroad well; elevation, 548 feet, approximate.

No.	Character.	Thickness.	Depth.
		Feet.	*Feet.*
1	Blue and yellow clay	20	20
2	Thin stratum of flowing sand with 6 inches of limestone	....	....
3	Blue sandy shale	365	385
4	White water saud	4	389
5	Hard limestone	4	393
6	Blue sandy shale	195	588
7	Hard sandstone	6	594
8	White sand with water	6	600
9	Blue sandy shale	55	655
10	Unrecorded	25	685

The depth of this well is given on the authority of Mr. L. W. Wells, assistant to the general manager of the Texas Midland Railroad, who states that the upper horizon has been cased off. The upper sands (No. 4) apparently represent the Nacatoch. The lower sands (No. 8) apparently represent the sands which outcrop near Ladonia. The statement by Hill[1] that a well 2,390 feet deep had been put down by H. G. Johnston at Commerce is an error, as Mr. Johnston writes that he has never put down a well at Commerce.

RED RIVER COUNTY.

Geographic relations.—Red River County adjoins Lamar County on the east and, like Lamar, lies between Red River on the north and Sulphur River on the south. It has an area of 1,061 square miles and a population of 28,564. The county seat is Clarksville. It is traversed from east to west by the Texas & Pacific Railway, which follows the crest of the divide between Red and Sulphur rivers.

The general slope to the southeast has the effect of throwing the principal part of the drainage into the Sulphur. The surface is rolling without marked relief and the drainage ways are for the most part inconspicuous. The most important tributaries are Pecan Bayou on the north and Cuthand Creek on the south. The plateau level ranges from about 530 feet above sea on the west to 390 feet above on the east. Detroit has an elevation of 482 feet; Bagwell, 476; Clarksville, 442; and Annona, 370.

Geology.—The geologic conditions in the northern and western parts of Red River County present essentially the same features as are found in Lamar County on the west. The outcrop of the Upper Cretaceous formations constitute a series of belts extending northeast two-thirds of the way across the county, where they disappear under a covering of Quaternary sands and gravels. In the northern part of the county the Woodbine sand appears along the south side of the Red River valley, bordered on the south by the clays of the Eagle Ford formation. Then comes the Blossom sand member of the Eagle Ford in a strip a mile or two wide extending from Blossom eastward nearly across the county to where the formation disappears beneath the alluvium of the Red River valley about 10 miles north of Annona. South of this comes the black-land area representing the outcrop of the chalk marls (Brownstown), chalk (Annona), and clay marls (Navarro and Taylor), each constituting a belt 5 to 6 miles in width, disappearing under the Quaternary deposits a short distance east of Annona. In the southern and eastern parts of the county the Cretaceous formations are entirely hidden from view by the early Quaternary (Port Hudson) deposits, which cover the higher areas,

[1] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 637.

and by the flood-plain deposits which occupy the valleys. Moreover, the Quaternary sands and gravels occur in broad, shallow depressions eroded in the Cretaceous area. A case in point is that of Cuthand Creek, the headwaters of which west of Clarksville are engaged in removing the filling of sand and gravel, occupying a depression in the surface of the chalk and chalk marls. The Annona chalk makes its appearance on the east side of this valley 6 or 8 miles southwest of Clarksville and extending northeastward constitutes the broad ridge on which the town is situated.

Water resources.—The areas in which shallow wells constitute a source of water supply are confined chiefly to the valleys of the main streams. Outside the valleys a few shallow wells, sunk in areas covered by the Quaternary sands and gravels, in places furnish an abundance of fairly good water, but not uncommonly are found to be too highly charged with deleterious substances to be used. Wells located in the northern part of the county on the outcrop of the Woodbine sand find water at depths varying from 20 to 40 feet. In general the water is good and the supply ample. The outcrop of the Blossom sand member constitutes a third but less important area of shallow wells. Water is found at a depth of 10 to 30 feet in this area, but it is likely to contain a large amount of mineral substances in solution. Wells differ greatly in the character of the water they furnish, those located near together often showing wide discrepancy.

Few surface wells have been dug in the Eagle Ford prairie or blackland areas; and such as have been attempted secure but a limited supply of water of poor quality in the seepage that finds its way along the joints of the clays and chalk.

The artesian conditions in Red River County are similar to those in Lamar County. The southward dip of the Trinity sand carries it too far below the surface to be available for wells located anywhere outside of the valley of Red River. It seems possible that flowing wells may be obtained in this formation in the lowlands bordering Red River, but in the absence of a suitable topographic map no definite prediction as to this can be made.

The Woodbine sand contains plenty of water, which when tapped by wells in the area to the south of the outcrop will tend to rise to the surface. The uncertainty of finding good water in the upper beds, however, makes these horizons of doubtful utility in this county. In an effort made some years ago to find artesian water the city of Clarksville drilled to the Woodbine sand, finding water at a depth of about 1,100 feet. The water, which was too salty for use, is reported to have been accompanied by natural gas and to have spouted out at the surface when first struck, but quickly subsided to 10 feet below the top. The elevation of the top of the well is about 430 feet, which indicates that flowing wells may be expected from this horizon in locations having an altitude less than 420 feet. In 1902 the Clarksville Ice Co. put down a well to a depth of 1,800 feet, passing two water horizons, both in the Woodbine, one at 1,000 feet and one at 1,600 feet. The water from both these horizons was too strongly charged with salt for use. It appears that no attention was paid in either of these attempts to the horizon from which the present water supply of the city is obtained.

In 1902 the city of Clarksville [1] completed two wells, finding water in sand immediately underlying the chalk and chalk marl on which the city is located. This bed, to which the name Blossom sand member has been given, was reached at a depth of about 600 feet. The water, which rises to within 55 feet of the surface, is soft but rather high in alkalies, and the supply is apparently ample. The sands from which this supply comes outcrop along Pecan Bayou about 4 miles north of town. The elevation of the outcrop is about 400 feet, as determined by the aneroid, and the top of the well 450 feet, indicating that the Blossom sand member has a southward dip here of about 130 feet per mile. Assuming this rate of dip to continue it is evident the member will not be available as a source of water supply south of a line drawn east and west 7 or 8 miles south of Clarksville. Between this line and the outcrop of the member on the north the indications are favorable for good wells in this sand, but flowing wells can be expected only in those localities whose elevations are under 400 feet.

Indications of oil and gas are reported to have been found in a well 100 feet deep on the farm of Mr. Cox, about a mile north of Detroit. If correctly reported, these evidently came from sandstone lenses in the Eagle Ford clay.

BOWIE COUNTY.

Geographic relations.—Bowie constitutes the third and most easterly of the three counties occupying the narrow divide between Red River and Sulphur Fork. Its population is 4,827. Its width from north to south varies from 25 miles at the west end to 20 at the east. The relief is low and the crest of the divide, which is occupied by the Texas & Pacific Railway, is located north of the center line of the county. The divide slopes gradually eastward, as shown by the following list of elevations taken in order from west to east: DeKalb, 407; New Boston, 352; State line, 282.

Geology.—As shown on the map (Pl. I, p. 16), the larger portion of the area included between the flood plains of the two rivers is occupied by sands and gravels of Quaternary age. A considerable area in the southern and eastern part of the county is of Eocene (Wilcox) age, the north boundary of the formation extending through Old Boston

[1] For information concerning the Clarksville wells indebtedness is acknowledged to Mayor F. B. Mason.

and crossing the railroad track in the vicinity of Whaley station. New Boston is situated in a plain underlain by clay apparently representing the outcrop of the Midway formation (Eocene).

Three miles north of Malta station, on the Freeze place, is a small outcrop of the fossiliferous clay marl belonging to the undifferentiated Navarro and Taylor. The exposure occurs on the edge of a river terrace and has an area of about 2 square miles. Calcareous clay and greensand about 25 feet in thickness are here overlain by a thin capping of Quaternary sand and gravel. The locality is noted throughout the surrounding region for the Cretaceous shells found in the clays.

Water resources.—Throughout the county water is usually found in shallow wells varying in depth from 20 to 60 feet. The quality is in general good and the supply ample except in certain elevated localities where the water-bearing sands have been dissected by erosion. Instances are noted where wells when first drilled supplied good water, but after a time became highly charged with deleterious substances, especially hydrogen sulphide (HS_2). This is probably due to the entrance of low forms of plant life or to the decomposition of iron sulphide in the sand through the accession of air.

In the area covered by the Port Hudson (Pleistocene) deposits water is found in packsand or quicksand underlying clay near the middle or base of the formation, which does not usually exceed 60 feet in thickness. In the deeper wells the water is said to occur in a black sand immediately below a sandy clay "rock." Most wells are from 20 to 30 feet in depth. A few have been extended through the Port Hudson into the underlying clays of the Midway or the Cretaceous formations, but the results generally have not been satisfactory.

Where erosion has dissected the formation, exposing a bed of clay, springs are likely to occur at the top of the clay. Such a case is seen at De Kalb, where a fine spring occurs in a ravine about one-half mile southwest of the railroad station. The water, which is of good quality, flows out at the top of a dark-brown tough sandy clay.

In the Eocene area water is found in shallow wells at varying depths, from 20 to 50 feet, according to locality. The soils of this area are chiefly red and yellow sands, grading downward into partly consolidated sands and sandy shales, portions of which consist of hard ferruginous sandstone. The water from this horizon is usually more or less strongly mineralized. Dalby Springs, four in number, derive their supply from these beds; the water from them varies somewhat, but in all is rather strongly mineralized. (See p. 74 for analyses.)

In the eastern part of the county the Wilcox formation is more or less obscured by the later deposit of the Port Hudson. In this part of the county the water occurs in the surficial sands and gravels at depths varying from 15 to 45 feet. The supply of the Texarkana Water Co. is obtained from 52 wells located in a branch valley in the northeastern part of the city. The supply comes mainly from the surficial sands at from 15 to 45 feet below the surface.

Deep wells.—While several deep wells are known to have been put down in this county, only very meager information concerning them is at present obtainable. In 1905 a boring was completed a mile south of De Kalb to a depth of 1,833 feet in the search for oil and gas. The top of the well is about 350 feet above sea level, or 50 feet lower than the station. The only record obtainable of this hole is the following, given from memory by Mr. N. E. McKinney, the president of the company:

Record of well 1 mile south of De Kalb, Tex.

No.	Character.	Thickness.	Depth.
		Feet.	*Feet.*
1	Sand and sandy clay	93	93
2	Compact bed of clay with water below	7	100
3	Unrecorded	400	500
4	White rock	530	1,030
5	Blue clay. (Showing of oil and gas at 1,503)		

Water was encountered which at first overflowed and at the time of visit stood a little below the surface. No attention was paid to the water horizons nor to the character of the water. It is probable the water which rose to the surface came from the Blossom sand member, which was evidently penetrated at a depth of about 1,030 to 1,050 feet.

In 1898 a well was put down on the public square of New Boston to a depth of 1,270 feet, according to Mr. Paul G. Ruff. The drill is said to have passed through alternate strata of blue shale and sand rock, finding at about 500 feet one flow which rose to within 40 feet of the surface and another at about 700 feet; both flows were strongly salt. Mr. C. A. Berkshire states that the drill passed through about 450 feet of blue shale and then sand and sandy shale, with a number of beds of hard rock, to a depth of 1,200 feet. The water, which occurs in the sandy beds at a depth of about 500 feet, is highly mineralized and is not used except to some extent for watering stock. It is evidently from the Nacatoch sand. The elevation of the top of the well is 350 feet.

In 1906 a test well for oil and gas was drilled at Redwater to a depth of 2,000 feet. The well, which is located 450 yards west of the station, was completed April 30, 1906. It was drilled by

J. J. Boynton, who furnishes the record. The elevation of the collar is about 286 feet above sea level.

Well of the Redwater Oil & Mineral Co., Redwater, Tex.

Formation.		Character.	Thickness.	Depth.
			Feet.	*Feet.*
Wilcox ("Sabine").		1. Soil and clay	15	15
		2. Sand and water	2	17
		3. Lignite	4	21
		4. Sand	3	24
		5. Lignitiferous sand	4	28
		6. Light colored shale	4	32
		7. Black shale	8	40
		8. Gumbo	25	65
		9. Gray sands	2	67
		10. Yellow clay	13	80
		11. Lignitiferous sand	33	83
		12. Soft gray sand	2	85
		13. Yellow clay	20	105
		14. Soft brown shale	60	165
		15. Soft light shale	17	182
		16. Gray sand	36	218
Midway 269.		17. Black shale or gumbo	47	265
		18. Blue shale	67	332
		19. Hard sand	1	333
		20. Black shale	154	487
Navarro formation and Taylor marl.	Arkadelphia 565.	21. Shale and shells; some water in shell bed at 500	113	500
		22. Blue shale	40	540
		23. Black shale	240	780
		24. Hard dark-brown sand	1	781
		25. Soft black shale	79	860
		26. Shale with shells	40	900
		27. Black shale	80	980
		28. Hard lime	28	1,008
		29. Gumbo	4	1,012
		30. Lime	5	1,017
		31. Blue shale	35	1,052
	Nacatoch (?) 232.	32. Sandy shale	21	1,073
		33. Blue shale	67	1,140
		34. Lime (or sand?)	10	1,150
		35. Blue shale	20	1,170
		36. Brown sand	11	1,181
		37. Hard packsand	2	1,183
		38. Blue shale	97	1,280
		39. Sand and clay mixed	4	1,284
		40. Hard blue shale	10	1,294
	Marlbrook (?) 716.	41. Gumbo	24	1,318
		42. Black shale	12	1,330
		43. Gumbo	8	1,338
		44. Shale	40	1,378
		45. Sand rock	3	1,381
		46. Shale	34	1,415
		47. Gumbo	70	1,485
		48. Shale and shells	5	1,490
		49. Blue shale	16	1,506
		50. Black shale	494	2,000

No record was kept of any of the water sands except Nos. 2 and 21. No. 2 (15 to 17 feet) is the source of supply for the surface wells of the neighborhood. The beds believed to represent the Nacatoch horizon (1052 to 1294) are probably water bearing. This well did not reach the Austin group, under which lies the water-bearing Blossom sand member of the Eagle Ford, but it evidently stopped not far short of it.

A comparison of this record with that at New Boston indicates that the southward dip of the formations in this locality is about 60 feet per mile.

Several wells put down in Texarkana reach the water-bearing Nacatoch sand at a depth of 800 to 850 feet. According to the superintendent, Mr. R. A. Munson,[1] the well of the waterworks company has the following record:

Record of well of Texarkana Waterworks Co.

Formation.	No.	Character.	Thickness.	Depth.
			Feet.	*Feet.*
Quaternary or Lafayette	1	Dirt, sand, and gravel	50	50
Sabine (Wilcox)	2	White sand and clay, with water	45	95
Midway (?) and Arkadelphia.	3	Dark blue clay, no water	730	825
Nacatoch	4	Sand and sand rock, water bearing	100	925
Marlbrook [a]	5	Blue clay	5	930

[a] Veatch assigns No. 5 to the Marlbrook, but the more complete record of the Oil Prospect well shows it to be evidently Nacatoch.

Analysis[1] shows the water to be highly mineralized. It is used only occasionally to supplement the supply from the shallow wells.

A well put down by the American Well & Prospecting Co. for the Home Ice Co.[2] was drilled to a depth of 1,900 feet, with the following results:

Record of well of Home Ice Co., Texarkana, Tex.

Formation.	No.	Character.	Thickness.	Depth.
			Feet.	*Feet.*
Lafayette (?)	1	Coarse gravel	6	6
Lower Eocene (?)	2	Yellow clay	29	35
Lower Eocene and Arkadelphia.	3	Blue clay	845	880
	4	Sand containing brackish water which rose within 15 feet of the surface.	20	900
Nacatoch	5	Hard sandstone	11	911
	6	Sand containing brackish water which rose within 5 feet of surface.	30	941
Marlbrook	7	Blue clay	759	1,700
Annona	8	White chalky limestone	125	1,825
Brownstown	9	Blue clay	75	1,900

A similar record is shown by a well (No. 480) which was drilled in 1907 by J. J. Boynton, as an oil prospect, 1 mile northeast of the city, and was abandoned at 1,390 feet.

The Texarkana oil prospect well is located in the creek bottom at an elevation about 305 feet. The record was furnished by Mr. J. D. Cook. The well is cased with 11⅝-inch pipe to 145 feet, with 9-inch pipe to 860 feet, and with 6-inch pipe to 1,360 feet.

[1] Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 180, 261.
[2] Idem, pp. 180, 265.

Record of well of Texarkana Oil Prospect Co.

Formation.	No.	Character.	Thickness.	Depth.	Remarks.
			Feet.	*Feet.*	
	1	Soil and clay	5	5	
	2	"Packsand"	40	45	
Recent.	3	Quicksand	10	55	
Wilcox, 145 feet.	4	"Packsand"	55	60	
	5	Hard bowlders	2	62	
	6	"Packsand"	43	105	
	7	Quicksand	5	110	
	8	"Packsand"	35	145	
	9	"Hard rock"	3	148	
	10	Blue shale	27	175	
	11	"Hard rock"	44	179	
	12	Black shale	10	189	
	13	Gravel	20	209	
	14	"Hard rock"	1	210	
	15	Blue shale	8	218	
	16	"Packsand"	2	220	
	17	"Gumbo shale"	26	246	
	18	Gravel	4	250	
	19	Shell rock	4	254	
	20	Blue shale	3	257	
	21	Gumbo	24	281	
	22	Rock	4	285	
	23	Gumbo	18	303	
Midway, 289 feet.	24	Rock	5	308	
	25	Blue shale	10	318	
	26	Gravel	3	321	
	27	Shale	15	336	
	28	Sand	4	340	
	29	Gravel	8	348	
	30	Gumbo shale	20	368	
	31	"Rock"	6	374	
	32	Shale	2	376	
	33	Soft black shale	5	381	
	34	Hard shale	3	384	
	35	"Rock"	4	388	
	36	Shale	7	395	
	37	Gravel	2	397	
	38	"Gumbo shale"	35	432	
	39	Gravel	2	434	
	40	Gumbo	38	472	
	41	Blue shale	30	502	
	42	"Bowlders"	3	505	
	43	Blue shale	37	542	
	44	"Bowlders"	2	544	
	45	Gumbo	16	560	
Arkadelphia, 408 feet.	46	"Bowlders"	4	564	
	47	Shale	108	672	
	48	Lime	18	690	
	49	Blue shale	10	700	
	50	Gumbo	14	714	
	51	Blue shale	20	734	
	52	Gumbo	102	836	
	53	"Rock and bowlders"	6	842	
	54	Gray sand	2	844	
	55	Gravel	2	846	
	56	Blue shale	4	850	
	57	"Hard sand" (sandstone)	20	870	9-inch casing to 860 feet.
	58	"Packsand"	8	878	
	59	Gray sand, water	35	913	
	60	"Hard rock"	4	917	
	61	"Hard sand," water	10	927	
	62	Shale	30	957	
	63	Loose sand, water	13	970	
	64	"Rock"	6	976	
	65	Shale	44	1,020	
Nacatoch, 347 feet.	66	Black sand, water	20	1,040	Strong flow, came almost to top.
	67	Shale	10	1,050	
	68	"Rock"	1	1,051	
	69	Shale	16	1,067	
	70	"Rock"	6	1,073	
	71	Hard sand, water	25	1,098	
	72	"Rock"	3	1,101	
	73	Gray sand, water	38	1,139	
	74	"Rock"	3	1,142	Water comes within 25 feet of the top.
	75	Blue shale	10	1,152	
	76	"Hard rock"	4	1,156	
	77	Soft sand, water	14	1,170	
	78	"Crevice rock"	4	1,174	
	79	Black sand, water	15	1,189	Strong pressure water.

Record of well of Texarkana Oil Prospect Co.—Continued.

Formation.	No.	Character.	Thickness.	Depth.	Remarks.
			Feet.	*Feet.*	
Marlbrook, 441 feet.	80	Shale	2	1,191	
	81	Gumbo	30	1,221	
	82	Blue shale	8	1,229	
	83	Gumbo	21	1,250	
	84	Black shale	16	1,266	
	85	Gumbo	6	1,272	
	86	Shale	8	1,280	
	87	"Crevice rock"	12	1,292	
	88	Gumbo	20	1,312	
	89	Shale	10	1,322	
	90	Gumbo	16	1,338	
	91	Shale	12	1,350	
	92	White chalk rock	50	1,400	6-inch casing to 1,360 feet.
	93	Blue and black shale	97	1,497	
	94	Hard shell rock	13	1,510	
	95	Blue shale	75	1,585	
	96	Hard shell rock	15	1,600	
	97	Black shale	30	1,630	
Austin, 459 feet.	98	White chalky lime	35	1,665	
	99	Black shale	10	1,675	
	100	White chalky lime	80	1,755	
	101	Lime with shells	15	1,770	
	102	Black shale	70	1,840	
	103	Gumbo	30	1,870	
	104	Black shale	35	1,905	
	105	Gumbo	63	1,968	
	106	Sand with shells	12	1,980	
	107	Black shale	16	1,996	
	108	Gumbo shale	18	2,014	
	109	Soft black shale	27	2,041	
	110	Gumbo	6	2,047	
	111	Black shale	15	2,062	
	112	Gumbo	18	2,080	
	113	"Rock" (concretion?)	2	2,082	
	114	Gumbo	7	2,089	
Blossom sand member of Eagle Ford clay, 42 feet.	115	Hard sand	7	2,096	
	116	Gray sand, water	17	2,113	Water salty. Rose rapidly to 1,500 feet, then slowly to top.
	117	Hard sand rock	18	2,131	
Lower clays of Eagle Ford clay and Woodbine sand, 174 feet.	118	Dark blue or black shale	79	2,210	
	119	"Emery rock" (hard rock cut drill badly.)	5	2,215	
	120	Hard sand	15	2,230	
	121	Sand, softer	4	2,234	Water lost here.
	122	Hard sand	11	2,245	
	123	Black shale	10	2,255	
	124	Hard sand	23	2,278	
	125	Light blue shale	14	2,292	
	126	Hard rock	10	2,302	
	127	Rock softer	3	2,305	

A comparison of the foregoing record with records published by Veatch [1] shows some discrepancies in the thicknesses of the different formations. These discrepancies may be attributed doubtless to the incompleteness of the earlier records, together with the varying character of some of the formations. In the ice company's well one chalk bed only is noted, and this is found at a depth of 1,700 feet. In the oil prospect well three chalk beds are penetrated, one at 1,350, one at 1,630, and one 1,665 feet. It is evident that the 125 feet of chalky limestone in the ice company's well represents the two lower beds with their associated marls or shales (Nos. 98, 99, and 100), and that the upper bed of chalk No. 92 evidently grades horizontally into blue

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 261-265.

marly clays which are included in the blue clays assigned to the Marlbrook in the ice company's well. Likewise, the greater thickness of the Nacatoch (347 feet) is probably to be accounted for by local variation in the character of the beds assigned to the lower part of the Arkadelphia or the upper part of the Marlbrook, or perhaps to lack of care in keeping the record.

From the data furnished by the above records it is shown that although the Nacatoch sand furnishes an abundance of water, its quality is such as to make it unfit for domestic use. The water found in the Blossom sand (Nos. 115–117) is too highly charged with saline constituents for use. The bed was not reached in the Redwater well. The only locality in which the Blossom sand member seems likely to constitute a possible source of water supply is in the western part of the county. From DeKalb westward this sand should be reached at from 1,000 to 1,300 feet, according to locality, and in some places the water will doubtless flow out at the surface. The quality of this water differs greatly from point to point, and no reliable statement can be made as to what its quality may be at any place. At Clarksville it is of good quality and this is likely to be true of it in some other places.

HOPKINS AND FRANKLIN COUNTIES.

Topographic relations.—Hopkins and Franklin counties lie just within the northern boundary of the Eocene and have the general relief of an eastward (coastward) sloping plain dissected by the branching tributaries of South Fork of Sulphur River on the north (mainly through White Oak Creek), and of Sabine River through Lake Fork on the south. The drainage of the region is divided about equally between the two systems. On the south and east the surface is diversified by many low eminences mostly rounded out of the unconsolidated sands, but in the extreme southern part of the area the interstream areas present a flat-topped, mesalike appearance, due to the capping of a more resistant layer of hard iron conglomerate. In the north and west a narrow strip of high-rolling prairie constitutes the eastward continuation of the prairie region of the adjoining county and has the White Oak bottom as its eastern limit. Cumby and Ridgeway, the two highest points in the district, are located on this prairie. The drainage ways are for most part broad and shallow and are occupied by insignificant streams, which in the summer or dry season consist merely of a chain of pools. White Oak bottom has an average width of about 3 miles. All the smaller streams are completely dry during the summer season. The population of Franklin County is 9,331, and that of Hopkins County is 31,038.

Geology.—Hopkins and Franklin counties lie on the northern edge of the eastern timber belt, which represents the outcrop of the Eocene

Tertiary. The formations consist for the most part of unconsolidated sands and clays, with local beds of lignite and ferruginous sandstones and iron ore. Owing to the nonpersistent character of the stratification and the lack of fossils, no general sequence can be worked out in the stratigraphy of the region. It is clear, however that South Fork of Sulphur River marks the northern boundary of the Eocene in this region and that the beds belong to the Wilcox formation.

In prospecting for water at Sulphur Springs the city corporation put down, to a depth of 1,515 feet, a well, the record of which has been kindly furnished by Mr. W. B. Baxter. This section is instructive as showing the thickness and character of the formations constituting the lower Eocene in this region. The collar of the well is 500 feet above tide.

Record of city well, Sulphur Springs, Tex.

Formation.	No.	Character rock.	Thickness.	Depth.
			Feet.	*Feet.*
Wilcox.	1	Surface soil	1	1
	2	Red clay	8	9
	3	Lignite	2	11
	4	White sand with water; source of supply for most of the wells of the region.	4	15
	5	Blue sandy shale	18	33
	6	Buff sandstone	2	35
	7	"Pipe clay"	2	37
	8	Black shale with mica	15	52
	9	Sand with water; furnishes city supply	16	68
	10	Shale	59	117
	11	Limestone	1	118
	12	Black shale interlaminated with lighter colored shale; contains iron concretions, iron pyrites, and mica.	565	683
	13	Hard limestone	1	684
	14	Black shale in thin layers with fossils	20	704
	15	Light-colored shale	8	712
	16	Blue shale	88	800
	17	Black shale with iron concretions; and fossils; *Venericardia planicosta.*	10	810
Midway, 324½.	18	Blue shale	90	900
	19	White clay	20	920
	20	Blue shale	80	1,000
	21	Hard sandstone	4	1,004
	22	Blue shale	30	1,034
	23	Fine sand; some water	2	1,036
	24	Soft white clay	15	1,051
	25	Gray sandstone	40	1,091
	26	White "pipe" clay	2	1,093
	27	Sandstone	15	1,108
	28	Hard blue shale	2	1,110
	29	Soft sandstone	15	1,125
	30	Hard sandstone	2½	1,127½
	31	Hard blue shale	5	1,132½
	32	Fine gray sand	1	1,133½
	33	Very hard sandstone	1	1,134½
Navarro and Taylor, 381.	34	Hard blue shale	171	1,305½
	35	Sand with some water	14	1,319½
	36	Blue shale and sand	95	1,414½
	37	Blue shale; some sand with mica	101	1,515½

The upper 1,134 feet of this section are assigned to the Wilcox and Midway, the division between these being placed tentatively at the base of No. 17. The beds below No. 33 apparently represent the Navarro formation and Taylor marl.

Ridgeway and Cumby are located on a prairie composed of dark soil underlain by yellow calcareous clay in some instances showing the presence of greensand. Some fossils obtained from this clay a few miles north of Cumby are reported by Dr. T. W. Stanton to be "probably of Tertiary age, but they contain no distinctive forms that fix the exact horizon." The stratigraphic relations indicate that the narrow strip of prairie extending from Cumby past Ridgeway represents the outcrop of the Midway clay and shale beds (Nos. 18–22). North of Sulphur Bluff, in the northeastern part of the county, a narrow prairie of black soil overlies yellow calcareous clay over blue chalky sand. Three miles north of this, on the south side of South Fork, 42 feet of blue and black sandy shales and shaly sands, which is strongly bituminous and contains many Cretaceous fossils (pp. 27, 28), outcrops in a bluff, where it apparently represents the lowermost beds of the Sulphur Springs well. This strip of black land is said to extend down the river as far as Goolesboro, in Titus County, where it disappears beneath the alluvium of the valley.

In the vicinity and south and east of Mount Vernon the higher elevations are capped by a deposit of unconsolidated yellow and red sand, white clays, and gravels which rest upon the apparently eroded surface of the Wilcox formation. Both sands and clays are usually distinctly cross-bedded and the contact with the underlying formation is frequently marked by a layer of ferruginous sandstone or iron ore, sometimes in broken blocks irregularly distributed along the plane of contact. These overlying beds are probably of late Tertiary age, though no evidence that would fix their age is at hand.

Deposits of lignite are reported from different localities, but the beds are usually thin and of small horizontal extent. A bed 2 feet thick is reported in the Sulphur Springs well at a depth of 9 feet and similar occurrences are reported in the vicinity of Mount Vernon in Franklin County. At Como, 10 miles south of Sulphur Springs, a bed of lignite 7 feet thick, found at a depth of 75 feet, has been successfully worked for the past six years. The lower 2 feet of the deposit is unavailable on account of impurities. The roof is composed of compact sand and the mine is entirely free from water. This bed comes to the surface 1½ miles north and borings do not indicate workable thickness outside a very small area. Fifteen feet above the Como vein is another bed 2½ feet thick, and 45 feet above is one 2 feet thick. The following record of a shaft put down a number of years ago somewhere in this vicinity is published in the Texas reports.[1]

[1] Dumble, E. T., Report on brown coal and lignite of Texas, 1892, p. 161.

Record of shaft near Como, Tex.

	Feet.
1. Clay	6
2. Sandrock	10
3. Slaty clay	4
4. Brown coal	16
5. Sands and clays	9
6. Plastic clay	30
	75

In places the sands are indurated to form ferruginous sandstones, which weather out in irregular masses and have some use for building and paving, and by the railroads for ballast. No workable deposits of iron ore are reported in this district.

Water conditions.—In the prairie areas cisterns are the sole reliance for water for domestic use. In the remaining areas shallow wells are abundant, the surface sand overlying a clay being a good reservoir. The water is, however, at times mineralized and many persons residing on the sandy lands have cisterns; some have both wells and cisterns. Sulphur Springs is now supplied by a rain reservoir, but for a long time, until it outgrew them, it was amply supplied by three wells.

In the sandy wooded region, the larger portion of which drains southward through Lake Fork and Big Cypress Creek, an abundant supply of water is found in the surface sands at depths varying from 20 to 40 feet. Along the slopes springs are of frequent occurrence. In localities underlain by formations in which clay predominates some difficulty is found in obtaining sufficient supplies of water. The character of the water is quite variable, in some localities being soft and agreeable and in others more or less strongly mineralized. At Mount Vernon, Franklin County, the supply for domestic use is drawn chiefly from shallow wells and cisterns.

Deep wells.—Very few attempts have been made to exploit the deep-lying water beds and the information concerning their extent, character, or location is very meager. The most serious attempt made was that at Sulphur Springs by the city authorities, who drilled to a depth of 1,515 feet without satisfactory results. The record of this well (p. 61) shows that below the upper "veins," Nos. 4 and 9, the only water encountered was a small flow at a depth of 1,034 feet and another at 1,303 feet. At Mount Vernon, Franklin County, the railroad has a 400-foot well which yields a large supply by pumping.[1] No information is available as to the horizon from which the water is derived. At Cumby, wells 300 feet deep fail to find water below the surface supply.

As to the Cretaceous horizons, very few data are available. The record of the Sulphur Springs well indicates, however, that owing

[1] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 230-231.

to the thickness of the post-Cretaceous deposits over most of this region the possibility of exploiting the underlying water horizons is exceedingly remote. The only district in which there is any possibility of obtaining water from the Cretaceous beds is in the extreme northern part of Hopkins County, and the lack of knowledge of the extent and water-bearing character of these beds makes hazardous any prediction concerning them. The conclusion seems warranted, however, that in the valley of the Sulphur Fork, and for 4 or 5 miles to the south, the Nacatoch sand may be reached at depths varying from 500 to 1,000 feet. At Commerce, in Hunt County, which is 9 miles northwest of Ridgeway, these sands were reached at 370 feet. They outcrop between Commerce and Fairlie, 6 miles northwest of Commerce, giving an estimated dip of 50 feet per mile. From this it would appear that these beds may be reached at Ridgeway at a depth of 800 to 1,000 feet and the lower sands about 200 feet deeper. No prediction can be made as to the water-bearing character of the latter beds; the upper or Nacatoch sand is water-bearing at Commerce, but the water is not used because of its mineralized character.

CASS COUNTY.

Topography.—Cass County is in the northeastern part of the State, adjoining the Louisiana State line; it is bounded on the north by Sulphur Fork, and on the south and west by the counties of Marion and Morris, respectively. Its area is 945 square miles and its population 27,587. Linden is the county seat. The county is traversed by two railroads—the Missouri, Kansas & Texas and the Texas & Pacific.

The region constitutes the eastern extension of the general coastward-sloping plain of the eastern timber belt and differs from the counties to the west only in the greater degree to which the original plain level has been dissected by erosion. The drainage is principally to the southeast through small streams emptying into Caddo Lake, Sulphur Fork on the north receiving but a small part of the run-off through a few short tributaries. The surface is decidedly rolling and is characterized in the main by long ridges extending from northeast to southwest, or in a direction at right angles to this. These ridges are separated by steep-sided, narrow, deep ravines, the bottoms of which are generally occupied by narrow streams fed by the numerous springs found everywhere along the sides of the ridges.[1] In some of the ridges deposits of laminated iron ore occur in thin seams at depths of 20 to 40 feet below the summits. Such ridges usually present a terraced appearance due in part to the differential erosion of the hard and soft layers and in part, doubtless,

[1] Kennedy, William, Second Ann. Rept. Geol. Survey Texas, 1890, pp. 67-68.

to landslides brought about by the undermining action of springs which find their way out of the greensands that underlie the ore beds.[1]

The following elevations are shown by the railroad profiles: Alamo, 242; Atlanta, 264; Avinger, 393; Bivens, 314; Hughes Springs, 373; Kildare, 311; Queen City, 349.

The tops of the hills are from 50 to 100 feet above the level of the flood plains of the principal streams and have a general elevation of between 500 and 600 feet above tide level. On the north the wide flood plain of Sulphur Fork is bounded by a relatively narrow northward-facing drainage slope intersected by few and short tributaries.

Geology.—The county lies entirely upon the outcrop of the Wilcox formation and, like the district on the west, is characterized by timber-covered slopes and sandy soils. The deposits exposed within the limits of the county present the twofold division noted in the counties farther west, viz, an upper unstratified deposit of sand with local deposits of iron ore and a lower division of stratified sands, sandy clays, and clays with local deposits of lignites.

The upper part of the lower division consists of thinly laminated red, yellow, and white sands and sandy clays, blending horizontally and vertically in places into unstratified mottled red and white sands. The clays are usually dark blue, gray, or black, or in places red, yellow, or white; they occur interstratified and interlaminated with the sands and are generally sandy, though in places fairly free from sand. These beds are well exposed in the vicinity of Queen City, where they have a thickness of 65 feet or more, for which reason they have been given the name Queen City in the Texas reports.

Below these beds is a series of black, blue, and gray micaceous sands, blue, brown, and gray clays, and beds of lignites of varying thickness and generally of local extent. In places the sands are said to contain thin strata of sandstones and limestones.

Deposits of brown coal appear in different parts of the county, the best occurrences being reported from the northeastern portion, at Alamo and Stone Coal Bluff. At the former locality a bed of brown coal, 4 feet 7 inches thick, was found at a depth of 52 feet and another bed, 1 foot 8 inches thick, 11 feet higher. At Stone Coal Bluff a bed of coal 12 feet thick is said to occur at the bottom of the river.[2]

Resting on the irregular worn surface of the stratified lignitiferous sands and clays constituting the lower division are yellow, brown, and red pebbly sands, for the most part unstratified, ranging from a few feet to 100 feet in thickness. These sands contain the iron-ore deposits of the region, which appear as a kind of pavement

[1] Penrose, R. A. F., First Ann. Rept. Geol. Survey Texas, 1889, pp. 84-86. Kennedy, William, Second Ann. Rept. Geol. Survey Texas, 1890, pp. 68-70.

[2] Shumard, B. F., First Rept. Progress Geol. Survey Texas, p. 12.

under the sands capping the ridges or as aggregations of bowlders accumulated along the slopes.

According to Kennedy, with the exception of some small deposits of laminated ore, no continuously bedded ores occur within the county. For the most part the ores consist of rounded, oval, or lenticular concretionary masses, which in places have the appearance of a regular bed, but which change horizontally into ferruginous sandstone or into the irregular or rudely rectangular blocks of conglomeratic ore usually found along the valley sides or capping the lower hills. The ore deposits vary in thickness from a few inches to a maximum of 10 feet,[1] and for the most part are limited to the surface. Parties who have worked and prospected the ores for years state that on following them into the hills the ore is replaced by dark ferruginous sand. The best deposits are reported to occur southwest of Hughes and east of Linden.

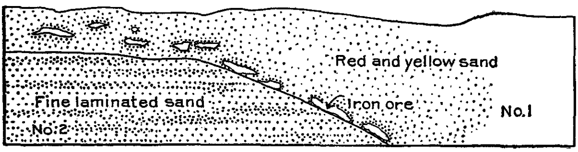

FIGURE 6.—Diagrammatic section of strata near Atlanta, Cass County.

In a railroad cut one-half mile north of Atlanta the beds have the relations shown in figure 6.

Here 4 to 12 feet of red and yellow sand containing irregular masses of low-grade iron ore, blocks of which occur distributed along the plane of contact, rest unconformably upon laminated sand or sandy clay, with little appearance of grit.

The relations of the formations on the western side of the county are shown in the accompanying section, compiled from a series of exposures in railroad cuts north of Hughes:

Composite section in railroad cuts north of Hughes, Tex.

	Ft.	in.
1. Soil and reddish-brown sand with pebbles	4 to	2
2. Yellow and red sand, containing concretionary masses of low-grade iron ore. Portions of the beds are indurated to a hard ferruginous sandstone	8	
3. Laminated red and white sand, sandy clay, locally white mottled clays, containing nodular, concretionary iron ore	4	
4. Brown lignitic sands and sandy clays, and laminated black clay	8	
5. Brownish-red sand interlaminated with fine white sandy clay	25	
6. Lignite		3
7. White sand mottled with red; exposed	3	
	68	3

The age of this upper deposit of sand with its concretionary and conglomerate ores has not been clearly determined. In the Texas

[1] Penrose, R. A. F., First Ann. Rept. Geol. Survey Texas, 1889, pp. 35-65. Kennedy, William, Second Ann. Rept. Geol. Survey Texas, 1890, pp. 65-95.

reports the areas in which the iron ores occurred were regarded as outliers of the lower (Mount Selman) division of the lower Claiborne (St. Maurice). That the ores had their source in the Claiborne beds may be admitted, but their present condition may be due to rearrangement by erosion during late Tertiary time.

Water resources.—The supply of water for domestic and stock purposes in Cass County is obtained almost entirely from shallow wells 20 to 50 feet deep, the most common depth being 30 to 40 feet. The supplies are derived mostly from surficial sands, but in some places come from the lower sand horizons. The water from the surficial sands is usually soft and of good quality, but locally becomes mineralized to a greater or less extent.

Springs are of frequent occurrence wherever the base of the surficial sands has been reached by erosion, but in general are small and are but little used. They are frequently chalybeate in character, that at Hughes having for a long time sustained an excellent reputation for its medicinal properties. Another spring, owned by Mr. Charles Thrasher, 5 miles east of Linden, is also worthy of note. Analyses made in the laboratories of the Survey (p. 74) of the waters of these two springs show them to be very much alike.

The supply of water derived from the surficial sands is in the main ample for present requirements for domestic and stock purposes, but it is not sufficient to meet manufacturing or city needs, to supply which resort is had to rain tanks.

So far as can be learned no attempts have been made to exploit any of the deeper water horizons in Cass County. At Jefferson, in Marion County, 10 miles south of the boundary of Cass, a well put down many years ago to a depth of 802 feet in the search for coal struck a strong flow of water with sufficient pressure, according to reports, to rise 35 or 40 feet above the surface when piped. At first the flow is said to have been very strong, but caving at the bottom resulting from drawing the pipe back 80 feet has greatly diminished the pressure. At present the flow is about a gallon a minute. Kennedy reports as follows concerning this well: "The drill passed through alternate strata of sands, clays, and lignites to a depth of 802 feet. Three heavy beds of lignite and a number of smaller ones are said to have been passed through in the boring." [1]

According to Mr. J. M. De Ware, corroborated by Mr. W. T. Atkins, this well is about 830 feet deep. The elevation at the top is about 196 feet. The water is rather strongly mineralized and has a high reputation locally. (See analysis, p. 74.)

Veatch states [2] that this water comes from the Nacatoch sand. In the absence of satisfactory data no definite statement can be made,

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[1] Proc. Acad. Nat. Sci., Philadelphia, for 1895, 1896, pp. 136–137.
[2] Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 233.

but it seems probable that the source is the lower portion of the Wilcox formation.

If this water horizon is persistent it will undoubtedly be found underlying the whole of Cass County at depths varying from 800 to 1,200 feet, according to locality. In some places the water would no doubt be too strongly mineralized to be of general use, but from the variable character of the water from the Wilcox formation it is not improbable that good wells might be developed in localities 10 to 20 miles away.

Nothing is known of the Cretaceous horizons in this region, but the inference is that they are not practically available, owing to their excessive depth and to the highly mineralized character of the water they yield.

DATA CONCERNING WELLS.

The following table gives the obtainable data in regard to the wells of the region:

Data concerning wells in northeastern Texas.

No.	Locality.	Owner.	Driller.	Authority.	Diameter of well.	Depth of well.	Elevation of surface. (Approximate.)
					Inches.	*Feet.*	*Feet.*
	Bowie County:						
1	De Kalb, 13 miles north	S. L. Moore	Hudson and Cornelius	Hudson and Cornelius	2	425	
2	De Kalb, 1 mile south	N. E. McKinney		N. E. McKinney		1,833	350
3	New Boston	Town of New Boston	John Lowdermilk	John Lowdermilk	$3\frac{3}{4}$	536	352
4	Do			C. K. Berkshire	5	1,200	352
5	Pope post office	Cass Pope		Cass Pope	6	196.5	
6	Rolyat, 4 miles north			Postmaster		247	
7	Rolyat, 3 miles west	I. N. Phillips		I. N. Phillips	6	165	
8	Rolyat	Postmaster		Postmaster	8	119	
9	Redwater	Redwater Oil & Mineral Co.	J. J. Boynton	J. J. Boynton		2,000	286
10	Texarkana (Tex.)	Taxarkana Ice Co.		R. A. Munson		63	
11	Do	Jack Weed	John Lowdermilk	John Lowdermilk		550	
12	Texarkana (Ark.)[1]	J. D. Cook et al	J. J. Boynton	J. J. Boynton, J.D. Cook	$11\frac{5}{8}$–6	2,305	305
	Cass County:						
13	Hughes Spring[2]	Hughes Spring					
14	Linden, 5 miles east	Chas. Thrasher		W. H. Crow			
	Camp County:						
15	Pittsburg	W. C. Hargrove et al		W. C. Hargrove	6–4	1,860	395
16	Do	Arkansas & Texas Consolidated Ice & Coal Co. (No. 1.).		E. L. Wells, jr., manager	6	263	395
17	Do	Arkansas & Texas Consolidated Ice & Coal Co. (No. 2)		do	6	$273\frac{3}{4}$	395
	Delta County:						
18	Cooper, 3 miles west	E. H. Bond		E. H. Bond		263	495
19	Horton					315	
20	Klondike					160	478
	Fannin County:						
21	Honey Grove	Honey Grove		Postmaster		1,700	
22	Ladonia[3]					1,035	625
	Franklin County:						
23	Mount Vernon	St. Louis Southwestern Ry.		A. J. Patton, county clerk		400	476
	Hopkins County:						
24	Cumby	Cumby				300	649
25	Sulphur Springs	Sulphur Springs		W. B. Baxter	6–4	1,514	503

[1] For records of other wells at Texarkana see Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 180.
[2] Analyzed by A. C. Peale, Bull. U. S. Geol. Survey No. 32, 1886, p. 135.

Data concerning wells in northeastern Texas—Continued.

No.	Locality.	Owner.	Driller.	Authority.	Diameter of well.	Depth of well.	Elevation of surface. (Approximate.)
	Hunt County:				*Inches.*	*Feet.*	*Feet.*
26	Commerce *a*			H. G. Johnston		2,390	548
27	Do	Capt. Anders				370	548
28	Do	Texas Midland R. R				900	548
	Lamar County:						
29	Blossom	W. E. Moore		W. E. Moore		146	530
30	Do	Blossom				117	530
31	Paris, 2½ miles east	Paris Waterworks Co	H. G. Johnson	J. A. Porter, W. F. Gill		1,965	510
32	Paris	Texas Midland Ry		E. H. R. Green, president		73	566
	Marion County:						
33	Jefferson, 400 yards north of post office	J. M. De Ware		J. M. De Ware		830	196
	Morris County:						
34	Daingerfield	Joseph Bradfield		Joseph Bradfield		186	400
35	Omaha, 4 miles from	M. C. McCollum		M. C. McCollum		100	
	Red River County:						
36	Clarksville (public square)	Corporation Clarksville		Frank B. Mason, Mayor		1,100	410
37	Clarksville, ¼ mile west of station	do			8-6	600	450
38	Clarksville	Ice factory		Frank B. Mason, Mayor		1,800	
39	Lydia, 4 miles south	W. S. Perkins		Postmaster		200	260
40	Towson, 3 miles above, on bank of Red River.	S. J. Wright		S. J. Wright	6	300	
	Titus County:						
41	Mount Pleasant	H. W. Cheney et al		H. W. Cheney	7-6¼	300	

[1] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 636.

Data concerning wells in northeastern Texas—Continued.

No.	Locality.	Height of water above (+) or below (–) ground.	Depths of principal water-bearing strata.	Yield per minute.		Geologic horizon of water-bearing strata.	Quality.	Remarks.
				Flow.	Pump.			
	Bowie County:	*Feet.*	*Feet.*	*Gallons.*	*Gallons.*			
1	De Kalb, 13 miles north		–2		Very small.			Abandoned.
2	De Kalb, 1 mile south	– 0	(?)	Small.		(?)	Salty	Trace of oil and gas at 1,503.
3	New Boston		500–536			Navarro	do	
4	Do	–60	±500			do	do	Casing 200. Used somewhat for watering stock.
5	Pope post office	+60	145–196			do	Soft	
6	Rolyat, 4 miles north				None.			
7	Rolyat, 3 miles west	–60				Navarro	Hard, alkaline	Drilled in 1900.
8	Rolyat	–49				do	Soft	Drilled in 1902.
9	Redwater		500 1,170?			Navarro-Taylor.		Drilled in 1906.
10	Texarkana (Tex.)	–20	33–63		Large.	Wilcox	Soft	
11	Do	– 0	136 550			Navarro		Lower horizon doubtful.
12	Texarkana (Ark.)	–25 – 0	878–1,190 2,096			Navarro Woodbine.	Soft	Water found down to 888 salty and sulphureted. Cased off. Well completed in 1907.
	Cass County:							
13	Hughes Spring	Spring.		Moderate.		Wilcox	Chalybeate	Local resort.
14	Linden, 5 miles east	Spring.		Moderate.		do	do	
	Camp County:							
15	Pittsburg	*a* –8	220 750 1,700			Wilcox do Navarro	Soft	Cased to 400; drilled in 1900.
16	Do	–20	150–200		50	Wilcox	do	
17	Do	–20	160–200		50	do	do	
	Delta County:							
18	Cooper, 3 miles west							No water, except seep from clays.
19	Horton		315					
20	Klondike							No water; abandoned.
	Fannin County:							
21	Honey Grove				Plenty.		Mineral	Can not be used even for stock without mixing with pure water.
22	Ladonia							Abandoned.
	Franklin County:							
23	Mount Vernon	No flow.			Large.	Wilcox		

a Lowers to 70 feet when pumped.

Data concerning wells in northeastern Texas—Continued.

No.	Locality.	Height of water above (+) or below (−) ground.	Depths of principal water-bearing strata.	Yield per minute.		Geologic horizon of water-bearing strata.	Quality.	Remarks.
				Flow.	Pump.			
	Hopkins County:	*Feet.*	*Feet.*	*Gallons.*	*Gallons.*			
24	Cumby							No water below 40 feet.
25	Sulphur Springs				Small.	Wilcox		Drilled 1900. "Found no sand worth developing."
	Hunt County:							
26	Commerce							"Well was a failure."
27	Do	−90	370			Navarro	Soft	
28	Do		385 900			do	do	"Not good for boilers."
	Lamar County:							
29	Blossom	−25	25–35			Blossom	Hard	Used occasionally.
30	Do	−25	25–35		Small.	do	Hard, mineralized	
31	Paris, 2½ miles east	− 2	0–80 570–1,412 1,635			do Woodbine Washita	Mineralized	Drilled in 1896.
32	Paris		18–33		8	Blossom		
	Marion County:							
33	Jefferson, 400 yards north of post office	+35±	300 500 800			Wilcox	Mineral	"Now clogged by caving.'
	Morris County:							
34	Daingerfield	−20	186		"Inexhaustible."	do	Some mineral	
35	Omaha, 4 miles from				Large.		Mineral	Not used.
	Red River County:							
36	Clarksville (public square)	−10	550 ±1,050		Large.	Blossom Woodbine	Brine	Water accompanied with natural gas.
37	Clarksville, ¼ mile west station	−55	550–600		Large.	Blossom	Good, soft	2 wells drilled in 1902.
38	Clarksville		1,000 1,600?		Large.	Woodbine	Brine	Drilled in 1902.
39	Lydia, 4 miles south				Not any.			
40	Towson, 3 miles above, on bank of Red River.	*a* Flow.	300	Large.		Trinity	Soft	Drilled in 1892.
	Titus County:							
41	Mount Pleasant							Test for oil, incomplete.

a Would flow if piped. Drill lost by caving and well abandoned.

CHEMICAL COMPOSITION OF THE WATERS.

The available information regarding the chemical composition of the waters of northeastern Texas is given in the following table. The number of analyses is too small to permit much generalization regarding the mineralization of the waters. Those tested from the Sabine formation seem to be much superior in quality to those from other underground sources. The waters from the Blossom sand member at Blossom are very high in calcium, magnesium, alkalies, and sulphates, being similar in these respects to the waters tested from the Eagle Ford clay. The single well tested drawing its supply from the Nacatoch sand yields a brine. The analyses are stated in parts per million in ionic form. Most of them were made especially for this report, and the few obtained from other sources have been recomputed to ionic form in order to facilitate comparison.

Chemical composition of underground waters of northeastern Texas.

[Parts per million unless otherwise stated.]

	County.	Town.	Source.	Owner, name, location, etc.	Water-bearing formation.	Date of collection.	Analyst.
1	Bowie	Dalby Springs	Springs		Wilcox		
2	do	New Boston	Well	City supply	Nacatoch	Sept. 10, 1907	R. B. Dole and M. G. Roberts.
3	do	do	do	do	do	do	Do.
4	Cass	Hughes Springs	Springs	H. R. Hughes	Wilcox	Sept. 12, 1907	B. L. Glascock.
5	do	Linden	Well	W. H. Coon	do	Nov. 15, 1907	J. R. Bailey and A. M. McAfee.
6	Delta	Ben Franklin	Creek			Jan. 9, 1902	W. A. Powers.
7	do	do	do			Sept. 30, 1902	Kennicott Water Softener Co.
8	Harrison	Marshall	Well		Wilcox	Sept. 19, 1907	B. L. Glascock.
9	do	do	do		do	do	Do.
10	do	do	Springs	Hynson Springs	do	Feb. 3, 1908	J. R. Bailey and A. M. McAfee.
11	Lamar	Blossom	Salt well	Well on Main Street	Eagle Ford	Apr. 7, 1908	R. B. Dole and M. G. Roberts.
12	do	do	Well	Dr. A. J. B. Beauchamp	Blossom	Feb. 9, 1907	Do.
13	do	do	do	Well on Main Street	Eagle Ford	do	Do.
14	do	do	Black well		do	Feb. 14, 1907	Do.
15	do	do	Well	J. C. Thompson	Blossom	Feb. 11, 1907	Do.
16	do	do	do	Ed. Arnold	do	Apr. 7, 1908	Do.
17	do	do	do	W. J. Wallace	do	Feb. 9, 1907	Do.
18	do	do	do	T. F. Hefner	do	Apr. 7, 1908	Do.
19	do	do	do	Cotton-yard well	do	do	Do.
20	do	do	do	J. W. Williams	do	do	Do.
21	do	do	do	A. P. Ball	do	do	Do.
22	do	Paris	Artificial Lake	City supply		Dec. 1, 1902	Kennicott Water Softener Co.
23	do	do	Wells	Frisco Plant	Blossom	Nov. 29, 1902	Do.
24	Marion	Jefferson	Well	J. M. DeWare	Wilcox	Sept. 19, 1907	B. L. Glascock.
25	Morris	Daingerfield	do	Joseph Bradfield	do	do	Do.
26	Red River	Clarksville	Seep cistern	B. F. Mason	Annona	Mar. 5, 1907	H. S. Spaulding.
27	do	do	Well	600-ft. well	Blossom	Mar. 5, 1907	Do.
28	Wood	Mineola	do	Mineola Light & Ice Co.	Wilcox	Feb. 3, 1908	J. R. Bailey and A. M. McAfee.
29	do	do	do	City supply	do	do	Do.

	County.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
1	Bowie	78	9.1	1.0	7.1	3.8	38	2.3		41	31		39	230
2	....do	16	.5		11	.8	862		24	717	1.6		1,134	2,271
3	....do	48	2.3		14	1.6	882		26	706	3.6		1,152	2,333
4	Cass	21	12	4.9	4.9	4.4	3.4	2.7	.0	18	25	.0	5.2	86
5	....do	23	12		11	8.5	13			41	1.9	1.0	5.5	112
6	Delta				38	3.5	57		8.5		17		8.5	161
7	....do	16	a 2.7		36	4.5	11		60		20		9.1	
8	Harrison	24	.51	1.3	5.4	2.0	15		.0	6.1	24	.44	7.0	86
9	....do	26	.26	1.7	32	11	33	4.3	4.8	171	86	4.9	20	347
10	....do	78	40	10	9.8	16	11	5.4			239	.06	14	435
11	Lamar	49	.21		542	91	542		.0	175	1,670		703	3,788
12	....do	48	.15		510	88	530	35	.0	38	2,485	1.8	151	4,112
13	....do	50	.2		660	110	965	35	.0	78	1,935	.0	1,872	5,558
14	....do	75	.6	8.3	485	113	720	42	.0	11	2,695	.2	328	4,694
15	....do	18	.2		265	28	208	61	.0	227	465	10	499	1,693
16	....do	31	.08		304	24	214		.0	179	767		237	1,932
17	....do	49	3.8		460	128	890	27	.0	146	3,180	.3	79	5,078
18	....do	84	.12	4.0	474	109	892		.0	3.5	3,247		99	5,185
19	....do	42	.04		492	114	960		.0	106	3,241		88	5,089
20	....do	48	2.4		472	44	660		.0	38	2,585		40	3,984
21	....do	16	.44		44	2.9	55		.0	179	55	5.0	31	324
22	....do	45	a 2.7		31	5.1	55		35		57		70	
23	....do	43	a 1.5		25	4.0	85		35		108		66	
24	Marion	31	18	6.4	32	14	25		.0	80	79	1.3	20	297
25	Morris	18	.68	.7	62	1.5	394	1.0	17	518	2.1	2.6	319	1,032
26	Red River	11	Tr.		80	9.2	98		.0	194	96	16	103	5,288
27	....do	9.6	.2		6.4	3.5	304		37	387	147	3.3	122	835
28	Wood	17	3	1.9	2.6	4.2	49	2.8	2.4	102	19	1.8	7.0	154
29	....do	26	.40	.42	8.0	8.6	404	33	31	485	10	.01	310	1,069

a Iron and aluminum oxides.

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