DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Bulletin 619

THE CADDO OIL AND GAS FIELD
LOUISIANA AND TEXAS

BY

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

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By George Charlton Matson.

ACKNOWLEDGMENTS.

The cordial assistance rendered by citizens of northwest Louisiana and northeast Texas has added much to the value of this report, though so many persons have aided in the work that it is impossible to mention every one specifically. The Shreveport Chamber of Commerce, through its secretary, E. L. McColgin, took an active interest in the investigation and was especially helpful in suggesting sources of information and in obtaining the assistance of other organizations and persons. For information concerning logs of wells used in preparing the structural map special acknowledgments are due to those who are engaged in the production of oil and gas. Among those who have assisted in this work are C. D. Keen, manager of the Koster Oil Co.; W. B. Pyron, L. B. Webster, F. E. Chalk, and A. M. Arthur, of the Gulf Refining Co. of Louisiana; A. G. Curtis, manager of the Southwestern Gas & Electric Co.; C. K. Clark, C. C. Averill, and J. W. Anderson, of the Standard Oil Co. of Louisiana; Judge R. E. Brooks, president, C. N. Scott, vice president, C. K. Clayton, and C. R. Jones, of the Producers Oil Co.; O. A. Wright, manager of the Atlas Oil Co.; F. M. Hutchinson, president, and R. B. Nash, of the land department of the Higgins Fuel & Oil Co.; B. F. Rodgers, manager of the Rodgers Oil & Gas Co.; W. E. Morris, manager of the Cloverleaf Oil Co.; Carl Lemon, Vivian Oil Co.; S. A. McCune, superintendent of the Arkansas Natural Gas Co. at Vivian; D. C. Richardson, of the Richardson Oil & Gas Co.; Heilprin & Shropshire, W. C. Augurs, and William L. Henning.

LOCATION.

The Caddo oil and gas field is on the Gulf Coastal Plain in Caddo Parish, La., and extends from Louisiana a short distance westward into the eastern part of Marion County and the northeast corner of Harrison County, Tex. (See fig. 1.) The producing wells occupy an area extending northwestward from Mooringsport, La., for about 12 miles and a long, narrow belt extending nearly 10 miles northeastward from the north end of the main field. The belt which contains the most productive wells is not more than 12 miles in extreme length, and the large producing wells are scattered through a strip 4 to 5 miles wide, extending from Mooringsport to the north end of the field.

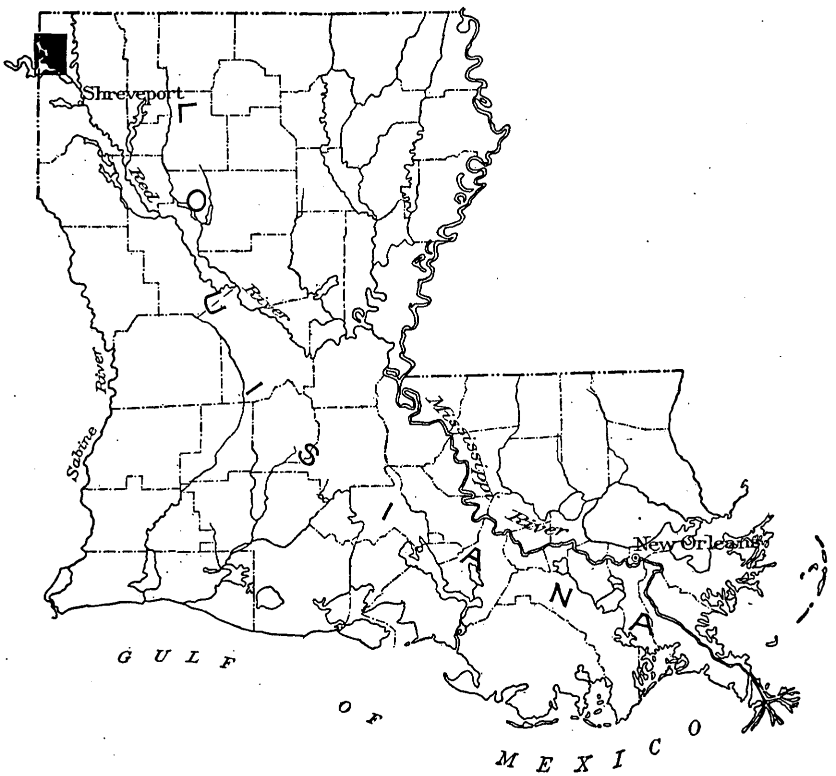

FIGURE 1.—Index map of Louisiana showing the location of the Caddo oil field.

The area has been divided into seven districts that merge more or less closely into each other. The Mooringsport district lies near the town of that name, and the Oil City district, likewise named for a town, adjoins the Mooringsport district on the north. West of the Oil City district is the Jeems Bayou district, and north of this is the Monterey district, which in this report is extended southward to include the Harts Ferry district. The Vivian district extends from the vicinity of the town from which it takes its name northeastward to Hosston, a somewhat detached area east of Oil City takes its name from Black Bayou, and an area northeast of Oil City is known as the Pine Island district.

The conditions in the area south of the Caddo oil and gas field favor the accumulation there of a large volume of gas and some oil. The areas that have been tested are limited to the city of Shreveport, where some good gas wells have been drilled, and the vicinity of Naborton, Bayou Pierre, and Red River, where both gas and oil have been encountered and where small areas have been very productive. It is possible that other pools may be found between those already developed, but no favorable localities have yet been prospected. Close to these producing fields there is considerable undeveloped territory that might warrant exploitation.

HISTORY.

Natural gas has been known at Shreveport for more than a quarter of a century, though its exploitation at that locality was not begun until 1912, after large gas-producing areas had been developed in the northern part of Caddo Parish. Gas is now obtained from wells in a zone extending from Vivian and Hosston southward to and beyond Mooringsport. It is found as far west as Jeems Bayou and nearly as far east as Dixie, though the best producing territory lies between Black and Jeems bayous.

The Caddo gas field supplies natural gas to Shreveport, La., Marshall, Tex., and Texarkana, Little Rock, and several other cities in southwestern Arkansas. Since the supply, though large, is not inexhaustible, its proper utilization and conservation has become a matter of concern not only to the companies having money invested in wells and pipe lines but also to the citizens of the region supplied from the field.

The production of oil in 1906 was only 3,358 barrels, which is considerably less than was obtained in a single day by some of the large companies during the spring of 1913 and falls far below the maximum daily output of the new field in De Soto Parish. The production fluctuates greatly, being influenced chiefly by success in drilling, a single large well frequently more than doubling the output of a company. The field has produced a large amount of oil and there is reason to believe that there is still much remaining. The statistics given below have been compiled by the division of mineral resources in this Survey.

Petroleum production in the Caddo district, La.

	Barrels.		Barrels.
1906	3, 358	1911	6, 995, 828
1907	[1] 50, 000	1912	7, 177, 949
1908	499, 937	1913	9, 628, 177
1909	1, 028, 818	1914	7, 572, 254
1910	5, 090, 793		

In this field there have been several disastrous fires, resulting in nearly continuous loss of gas and periodic losses of oil. Burning gas wells have been especially numerous, because the early gas wells

[1] Estimated.

were imperfectly finished, and if once they caught fire it was extinguished with difficulty. One of the earliest burning gas wells, Producers No. 2, blew out in May, 1905, the gas escaping around the casing for a distance of several hundred feet and forming a mud volcano by loosening the earth. Another well that attracted considerable attention was just west of the Kansas City Southern Railway track. Probably the best known of the burning gas wells was the one in sec. 7, a short distance southeast of Oil City. This well burned for several years, and although it was frequently extinguished its presence caused enormous loss of gas and lowered the pressure of other wells in the Oil City district. Until recently the gas from this well escaped in the bottom of a pond of water, causing constant motion, the waves dashing several feet into the air. The ignited gas formed a striking spectacle, and the well was usually kept burning to evaporate the salt water from the pond and prevent its overflowing the adjacent land. The loss of gas was stopped in the summer of 1913, when the State conservation commission, with the assistance of the oil and gas companies, had the well killed by drilling a well near it to relieve the pressure and then pumping mud into the burning well until the flow of gas was stopped. An attempt will be made to avoid similar accidents by having the casings cemented at the bottom so as to prevent the escape of gas into the earth surrounding the wells.

The most noted of the burning oil wells was the Producers Oil & Gas Co.'s Harrell No. 7, in the SE. ¼ sec. 7, T. 21 N., R. 16 W. This well, which had a very large flow of oil, accidentally caught fire and was with great difficulty brought under control. This fire was probably the most spectacular one that has ever occurred in the field. The burning of the Star Oil Co.'s well No. 3, on the Louck's lease, was also a disastrous fire, and probably no greater ingenuity was ever shown in dealing with a burning well than was displayed in extinguishing the fire at this well, which was accomplished by drawing oil from the well, thus lessening the amount of fuel and making it comparatively easy to smother the flames with steam. The oil was drawn by running trucks carrying a pipe line into the flames and forcing the end of the pipe over the connections at the top of the casing. Oil then flowed through the pipe and was collected in an earthen tank situated beyond the reach of the flames.

PHYSIOGRAPHY.

CHARACTER OF SURFACE.

A large part of the Caddo oil and gas field is so level that it is very imperfectly drained. The largest tract of flat land is in the vicinity of Oil City, from which it extends westward to Jeems

Bayou and northward to Lewis. The level area is bordered by rolling hills, the remnants of an upland that formerly extended across the field. Some of the highest hills are southeast of Vivian, where small areas rise more than 300 feet above sea level, or more than 120 feet above low water in Caddo Lake. The transition from the lowlands to the hills is abrupt, some of the slopes being very steep. The most notable hill in the vicinity of the oil field is at the south end of Potters Point, where a bluff rises more than 130 feet above the level of ordinary low water in the lake.

ARRANGEMENT OF DRAINAGE.

The development of the present topography began when this region was a comparatively level upland covered by formations that have since been removed by erosion. Possibly remnants of the original upland may still exist on the tops of some of the highest hills that now surround the Caddo oil field, but in most places, if not in all, erosion has removed the materials that constituted the surface of this old plain. In shaping the present topography the streams followed the original slopes, so that the locations of the principal drainage lines were in a measure controlled by conditions that existed before the upland was greatly eroded. The major streams then eroded valleys where the rocks were least resistant, and some of the lines of least resistance coincided with axes of folds formed during an earlier geologic period. Thus the axis of the old valley from the Louisiana-Texas line nearly to Mooringsport agreed in position and direction very closely with the axis of the Caddo Lake anticline. This coincidence between structure and direction of the drainage accounts for the relation of the oil pools to the lake. The positions of the present tributaries of this stream may have been influenced somewhat by the structure of the underlying formations, though their relation to the structure is not so close as that of the stream which eroded the lake basin.

PLEISTOCENE TERRACE.

The period of erosion during the early Pleistocene and late Pliocene, when the principal valleys in Louisiana were formed, was followed during the Pleistocene by a period when drainage was obstructed by a relative rise of the level of the sea, which invaded the area now occupied by the prairies and some of the level pine lands in southern Louisiana and extended far up the rivers. This invasion of the sea checked the velocity of all the streams and caused the deposition of more or less sand and clay, which filled the valleys above their earlier levels. In places where the sea formed estuaries the valleys were broadened by the action of the waves, which cut into the bluffs, and the material thus eroded away was deposited in the bottoms of the estuaries, producing a more or less even surface. This submergence may have extended into the region now occupied by the Caddo oil field, though if it did the water was probably only slightly brackish, because of the volume of fresh water brought in by Red River and its tributaries. The extensive plain that lies from 200 to 215 feet above sea level was developed during this period, and it is upon the surface of this plain that the numerous "gas mounds" are found. Subsequent drainage and erosion, together with other factors, have modified the details of the topography, but the general physiographic features have remained unchanged since the close of the period of submergence.

MOUNDS.

Low mounds occur on the level lands in the Caddo oil field and, though not evenly distributed, are numerous in the flat areas and present, though less common, on some of the more rolling land. They are from 1 to 5 or 6 feet high and 5 to 50 feet in diameter, and, though roughly circular, a few appear somewhat irregular because of partial overlapping of the edges of smaller mounds. These mounds are composed of light-yellow or gray loam or fine sandy loam, in places resembling the materials a few feet below the surface. They are separated by flat or basin-shaped depressions floored with clay, fine sand, or sandy loam. Similar mounds may be seen in places on the level lands near the coast in Louisiana and Texas and they extend northward into Arkansas, Oklahoma, and Missouri.

The common name of "gas mounds" conveys the idea, which is generally accepted, that these elevations were formed by gas escaping from below, but this explanation is probably incorrect, though it is possible that a few of them were formed in this way. Gas has produced similar mounds in the Caddo field by passing laterally through the subsurface sands and escaping through some weak point in the surface clays, bringing to the surface some of the sands that formed a subsurface stratum. It is possible that marsh gas arising from buried vegetation might similarly produce some low mounds, though the construction of the thousands of mounds that occur on the level areas would require more gas than could reasonably be expected from such a source.

Several other theories have been offered to account for these mounds. It has been supposed that they were made by men, by animals, by the wind, by water, and by pressure of the surface clays on subsurface sands. The wide distribution and the large number of these mounds proves that they were not made by men. Somewhat more credible is the theory that they were made by animals, and of these, ants seem a more probable agent than burrowing animals. The peculiar distribution of the mounds in large numbers where the surface is level makes it improbable that they are wind-made, and their shape and size is an additional objection, because the wind usually builds large, irregular deposits in the most exposed situations, where conditions are most favorable for its activity. There is a further objection in the fact that the wind acts on a large scale only in regions of small rainfall and scanty vegetation, whereas the mounds are in a region where rainfall is abundant and vegetation luxuriant. There is, moreover, good reason to believe that uniform climatic conditions have prevailed since the formation of the plains that carry most of the mounds.

The theory that the mounds were formed by erosion does not appear tenable, because the effects of erosive action have been observed in many localities, and the only forms even remotely approaching those of the mounds are the low irregular ridges produced by floods. The pressure of surface clay on fine sands or sandy loam filled with water might cause the sands to be forced up through weak places in the clays to form mounds, though it is not probable that this process would operate on a scale large enough to produce such a great number of mounds. Probably in different places there have been several agencies at work to produce similar results, but it is not possible with the information available to determine the origin of all the mounds. Of all the agencies suggested the best explanation of the origin of a large number of mounds seems to be that they are the work of ants. The chief facts of economic importance are that most of the mounds were not produced by gas, and that even though they are found on level lands in gas and oil fields they are also found on similar areas where there is little or no gas or oil.

GEOLOGY.

STRATIGRAPHY AND LITHOLOGY.

GENERAL GEOLOGIC FEATURES.

If it were possible to examine the deposits in the Caddo oil field, layers of sands, clays, and limestones would be found arranged one above another in a manner similar to layers of masonry, only the layers or beds of the natural formations vary in thickness and in composition. Near the surface sands and clays predominate. In some places the sands are arranged in lenses or thin laminæ in the clay; in other places the clay occurs in lenses or thin laminæ scattered through the sand. At greater depths well-defined sand beds are encountered and the clays occur in distinct layers; and at still greater depths there are thick beds of chalk separated by thin lenses of clay. Beneath these chalk beds lie other sands and clays and some limestones, and still lower there is another bed of sand and sandstones containing many lenses or partings of clay.

Geologists endeavor to separate into distinct formations those deposits that are either alike in lithologic character or that contain similar fossils. At some places several formations are assembled into a group or into a large unit called a series. The series here described and discussed are grouped under three systems, which are underlain by other older systems. The youngest system, known as the Quaternary, has been divided into two series, the Recent and the Pleistocene. Both are represented in the Caddo field, but the deposits are not of sufficient economic importance to warrant their subdivision in this report into formations. Beneath the Quaternary lies the Tertiary system, which has in other places been divided into four series, Pliocene, Miocene, Oligocene, and Eocene. Of these series only the oldest, the Eocene, is found in the Caddo field. The Eocene series of the Gulf region is generally subdivided into five formations, of which only three are found in the Caddo field, the Wilcox, Midway, and Claiborne. Beneath the Tertiary system lie the formations of the Cretaceous system, which is of unusual importance because it includes the formations that contain the oil and gas.

The Cretaceous of the western Gulf region has been separated into the Gulf or Upper Cretaceous series and the Comanche or Lower Cretaceous series, and these have been divided into formations, some of which have been assembled into groups, for example the Austin group, which represents a portion of the Upper Cretaceous series, and the Washita and Fredericksburg groups, which represent parts of the Lower Cretaceous series. The formations of the Gulf or Upper Cretaceous series are, in descending order, the Arkadelphia clay, the Nacatoch sand, the Marlbrook marl, the Annona chalk, the Brownstown marl, the Eagle Ford clay, including the Blossom sand member, and the Woodbine sand. In the Comanche or Lower Cretaceous series the following formations, named in descending order, have been recognized in southwestern Arkansas: Denison formation, Fort Worth limestone, Preston formation, Goodland limestone, and Trinity sand. The formations underlying the Trinity sand belong to the Paleozoic succession and have never been penetrated by any wells in northwestern Louisiana. They are too deeply buried to have any economic value, though some of them contain important oil and gas horizons in Oklahoma and Texas.

The following table shows the formations and their relationships in northwestern Louisiana. They are arranged in descending order, the youngest at the top and the oldest at the bottom.

Generalized section of formations in the Caddo field.[a]

System.	Series.	Group.	Formation.
Quaternary.	Recent.		
	Pleistocene.		
Tertiary.	Eocene.	Claiborne.	St. Maurice formation.
			Wilcox formation.
			Midway formation.
Cretaceous	Gulf (Upper Cretaceous).		Arkadelphia clay.
			Nacatoch sand.
			Marlbrook marl.
		Austin.	Annona chalk.
			Brownstown marl.
			Eagle Ford clay (including Blossom sand member at top).
			Woodbine sand.
	Comanche (Lower Cretaceous).	Washita.	Denison formation.
			Fort Worth limestone.
			Preston formation.
		Fredericksburg.	Goodland limestone.
			Trinity sand.

[a] The Upper Cretaceous formations do not outcrop in the Caddo field and are known from well logs only. The Lower Cretaceous rocks have not yet been reached in the wells of the district, but the formations enumerated in the table are probably present in the Caddo field.

Of the formations given in the table only those belonging to the Quaternary and Tertiary systems are exposed at the surface in the Caddo oil field. The Eocene beds are not fully exposed in the area covered by this report, and their discussion is based largely on observations in adjacent portions of Louisiana, Arkansas, and Texas, together with the knowledge obtained from well logs. The knowledge of the Cretaceous formations in northwest Louisiana is derived only from well logs, and, so far as known, no borings have reached the base of the Upper Cretaceous. The data supplied by logs of wells are supplemented by material obtained from reports describing the Upper Cretaceous formations where they are exposed in northeastern Texas and southwestern Arkansas. Knowledge concerning the Lower Cretaceous is confined to the formations of that age to the north and northwest in Arkansas, Oklahoma, and Texas, where they are exposed at the surface. Their presence beneath the Caddo field may safely be inferred from the fact that they have a southeasterly dip in the area where they outcrop. Conclusions concerning the character and thickness of any of the Lower Cretaceous formations are less certain than those for the Upper Cretaceous, because they may not maintain the same lithologic characteristics and thickness at such a distance from their outcrops. However, the major subdivisions of the Lower Cretaceous should be recognized in deep wells, and the lowermost formation, the Trinity sand, should be present as a well-defined sand bed.

CRETACEOUS SYSTEM.

COMANCHE SERIES (LOWER CRETACEOUS).

Lower Cretaceous beds underlie the Caddo oil field, but they do not appear at the surface in the region. They are, however, of considerable geologic interest and they may prove to be of economic importance at some future time.

TRINITY SAND.

Though the lowest formation of the Lower Cretaceous, the Trinity sand, has not been penetrated in drilling, its presence and lithologic character beneath the Caddo field may be inferred from what is known of the geologic history of the region. This formation, according to Gordon,[1] consists of fine clean sand with occasional pebbles and bowlders of quartz derived by erosion and redeposition from the older Paleozoic formations. Lenses and laminæ of clay occur in the sand and remains of vegetable matter and brackish-water fossils are reported. In Caddo Parish the lenses of clay might naturally be thicker and more numerous than farther north, where the deposits were made nearer shore, though probably the base of the formation would be a comparatively pure sand and other porous sand lenses may be expected within the formation. Thin lenses of limestone may also be expected, since some occur in the formation in southwestern Arkansas.

[1] Gordon, C. H., Geology and underground waters of northeastern Texas: U. S. Geol. Survey Water-Supply Paper 276, p. 14, 1911.

GOODLAND LIMESTONE.

The Fredericksburg group of this region is represented by only one formation, the Goodland limestone, which in southwestern Arkansas consists of 25 feet or less of chalk or limestone. It may be a thicker and a purer limestone in the Caddo field, where the deposits were laid down in quiet water farther from shore. It was at first supposed that the bed of hard crystalline limestone encountered in some wells in northwestern Louisiana might be the Goodland or the Fort Worth limestone, but it is now known to be much younger.

WASHITA GROUP.

In northeastern Texas and Oklahoma the Washita group consists, in descending order, of the Denison formation, the Fort Worth limestone, and the Preston formation. In Louisiana these formations are all probably present but have not been differentiated because of lack of information about them; the group as a whole consists of clays and limestones with some sand beds. In Louisiana the upper portion can not be distinguished in well sections from the overlying Upper Cretaceous, unless the red clay that is so widely distributed represents the top of the Washita. The Fort Worth limestone, which is more than 50 feet thick in Oklahoma, might be recognized in wells.

GULF SERIES (UPPER CRETACEOUS).

The basal part of the Gulf or Upper Cretaceous series in the Caddo region is a succession of interbedded and interlaminated sands, clays, and shales that are not readily separable from the similar deposits forming the upper portion of the Lower Cretaceous. If the formations were exposed at the surface it would probably be comparatively easy to separate them, because the uppermost formation of the Lower Cretaceous contains more lime than the lowermost portion of the Upper Cretaceous. In examining well logs (see Pls. I–VI) it is rarely possible to determine the minor characteristics of the beds penetrated by the drill, and soft marls are apt to be classed as clay or gumbo, whereas hard marls are almost invariably called shale, unless they contain enough lime to be described as chalk. It is to be regretted that samples of drillings from some of the deeper wells are not available, as an examination of them might make it possible to determine where the Upper Cretaceous ends and the Lower Cretaceous begins.

WOODBINE SAND.

The lowest formation of the Upper Cretaceous in northeastern Texas is known as the Woodbine sand. This formation, according to Gordon,[1] consists of ferruginous and argillaceous sands with some bituminous clays. The pyrite and glauconite (iron-bearing minerals) which it contains give the formation a yellow or brown color on weathering, and where the iron is concentrated it forms a cement that binds the sands together into a ferruginous sandstone. An abundance of plant remains aids in differentiating the Woodbine sand from the overlying marls of the Upper Cretaceous.

In the Caddo field the Woodbine sand is represented by a part, but not all, of the interbedded and interlaminated sands, clays, and shales that underlie the "sandrock" (1,800-foot sand, second gas sand) of the well drillers. It is not possible from well logs to determine the upper or lower limits of the formation, and it differs in character from the Woodbine sand of northeastern Texas by being more argillaceous, though it contains many thin beds of sand or sandstone.

EAGLE FORD CLAY.

Above the Woodbine sand are dark colored clays that contain some thin lenses of sand and earthy limestone, and above the clays is a sand or sandstone containing thin lenses of clay. This succession of beds is collectively known as the Eagle Ford clay, the sand and sandstone in the upper part being known as the Blossom sand member of the Eagle Ford clay.

Lower part of formation.—An examination of well logs in the Caddo field shows that the lower part of the Eagle Ford clay is composed of layers of varying character, described by drillers as shale and gumbo. Probably the variation depends on the hardness and plasticity, the harder layers being regarded as shale, whereas the soft plastic clays are called gumbo. The shale predominates and occurs in thick beds, separated by thinner layers of gumbo. Scattered throughout the beds are lenses of sand or soft sandstone, ranging from a few inches to more than 20 feet, but in few places exceeding 5 feet in thickness. The logs do not supply detailed descriptions of the lithology of the material, and it has not been possible to separate the Eagle Ford clay from the underlying Woodbine sand, though, as one is called a clay and the other a sand, they might reasonably be expected to be very unlike.

Blossom sand member.—At the top of the Eagle Ford clay there is a well-defined series of arenaceous beds which was called "sub-Clarksville" by Veatch[2] and Blossom sand member by Gordon.[3] In this report the name Blossom sand member will be used for the

[1] Gordon, C. H., Geology and underground waters of northeastern Texas: U. S. Geol. Survey Water-Supply Paper 276, p. 16, 1911.

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

[3] Gordon, C. H., op. cit., pp. 19–21.

member described by Gordon, which consists of sand and rock known to oil operators as the second gas sand, the 1,800-foot sand, and the sandrock. The Blossom sand member is composed of sand or sandstone containing lenses of clay, the whole ranging in thickness from less than 50 feet in the southern end of the Caddo field to more than 100 feet in the northern end. The following sections show the character of this member in different portions of the oil field.

Section of Blossom sand member of Eagle Ford clay, from logs of wells.

Well in Marion County, Tex.

	Feet.
Packed sand	9
Hard sandrock	5
Packed sand	37
Hard sandrock	2

Well in the Oil City district.

Hard sand	20
Gumbo	6
Rock	3
Gumbo	13
Rock	5
Gumbo	5
Rock	4
Gumbo	9
Hard rock	5

Well in the extreme northern end of the Caddo field.

Sandrock	65
Gumbo	1
Sandrock	26
Shale and bowlders (probably interbedded sandrock and shale)	20

The gumbo of this section is probably shale. It will be noted that in addition to containing less clay the Blossom sand member is thicker here than in the preceding sections. Near the southern end of the field the proportion of sand decreases, and this member is thinner than in the section from the Oil City district, whereas in the northern part of the field the member is more sandy and thicker than in the first section.

A section of the Blossom sand member in the Mooringsport district shows 21 feet of sandrock that doubtless contained some shale partings.

Other wells show great variations from the sections given above, both in thickness and in the arrangement of the different materials, but there is a general similarity in their lithologic character. The term packed sand is used in these sections and elsewhere in the report to designate a loosely cemented, friable sandstone.

AUSTIN GROUP.

The Austin group of the Upper Cretaceous includes two formations, the Annona chalk and the Brownstown marl, both differing in lithologic character from the formations above and below.

Brownstown marl.—Above the Blossom sand member of the Eagle Ford is a series of marls and clays that contain a few lenses of impure limestone but are nearly free from sand. The transition from the Blossom sand to the Brownstown marl is generally abrupt, though in a few places, especially in the southern part of the Caddo field, there is enough interbedding of the sands and marls to make the separation of the two formations difficult. The change from the Brownstown marl to the overlying Annona chalk is gradual in many places, and well logs show limestone beds in the upper part of the marl, indicating a transition from one to the other.

The Brownstown marl, as described by Veatch,[1] consists of blue or gray clay containing more or less calcium carbonate. In the Caddo region the marls and clays vary in lithologic character, and the drillers' reports describe alternating beds of shale and gumbo containing a few thin lenses of sand and rarely one or more thin beds of chalk. The general range in thickness is 100 to 150 feet, the variation depending in part on the amount of material described as chalk. Extreme thicknesses of 50 to 300 feet have been noted, but in such logs the drillers did not make careful distinction between the chalk and marl.

Section in the Jeems Bayou district.

	Feet.
Annona chalk:	
Hard shale	31
Hard shale rock	11
Brownstown marl:	
Shale	79
Rock	3
Hard shale	5
Gumbo	28
Slate and shale	8
Shale	32
Eagle Ford clay (?):	
Hard shale (Blossom sand member?)	8

This section is unusually thick, probably because the first two members, with an aggregate thickness of 42 feet, belong to the overlying Annona chalk. The last 8 feet of the section may be a part of the underlying Blossom sand, for sandstone may easily be mistaken for shale if considerable clay is used in drilling.

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

Section of the Brownstown marl north of Caddo Lake.

	Feet.
Gumbo	50
Shale	16
Rock	4
Gumbo	8
Shale	62

The following section shows an unusual condition, where the chalk extends down nearly to the top of the Blossom sand:

Section of the Brownstown marl in the Caddo field.

	Feet.
Hard chalk rock with bowlders (Annona chalk?)	18
Sand	7
Shale and gumbo	17
Gumbo	20

The section below shows an unusual thickness of the Annona chalk, which accounts for the thinness of the Brownstown marl.

Section of the Brownstone marl north of Caddo.

	Feet.
Shale and gumbo	21
Gumbo	5
Hard sandy shale	30

The following section illustrates the thickness of the Brownstown marl in the northern end of the Caddo field:

Section of the Brownstown marl at north end of Caddo field.

	Feet.
Shale	90
Shale and gumbo	74

Annona chalk.—The upper formation of the Austin group, known as the Annona chalk, is one of the best known lithologic units of the Caddo oil field. It differs from place to place both in thickness and character, but there is at the top a series of interbedded blue or gray chalk with shale or gumbo. At greater depths the shale beds grow thinner, and near the base hard chalk predominates. This formation is not sharply separated from either the Brownstown marl below or the Marlbrook marl above. Apparently the conditions during the opening and closing stages of the deposition of the Annona chalk were such that chalk was being formed in some places while marl was laid down in areas near by. The transition from the Brownstown into the Annona was gradual, presenting some interbedding of the two, and the change from the Annona to the Marlbrook was still more gradual, with a general interbedding of marl and chalk.

Section of the Annona chalk, from log of a well northwest of Oil City.

	Feet.
Chalk rock	39
Chalk and shale	109
Oil sand	4
Chalk rock	7
Shale	8
Chalk rock	77

In a near-by well the Annona chalk has a thickness of 197 feet and is separated by 147 feet of shale and gumbo from a 13-foot bed of chalk above, which is probably the "Saratoga" chalk member of the Marlbrook marl, and many well logs give the total thickness of the chalk from the top of this bed. The logs of wells in the Caddo field show that the Annona chalk varies greatly in thickness, ranging from less than 200 feet to slightly more than 600 feet. As described by the well drillers the variation is in general between 300 and 500 feet, but the actual thickness of what has heretofore been classed as the Annona chalk in this region is less than the thickness given by the drillers, because in many of the recent logs of wells the measurement of the chalk is made from the top of the "Saratoga" to the bottom of the Annona chalk, thus including a portion of the Marlbrook marl.

Section from the log of a well in Marion County, Tex.

	Feet.
Marlbrook marl (?):	
Chalk ("Saratoga"?)	20
Gumbo and shale	148
Annona chalk:	
Chalk rock	121
Shale	105
Chalk	28

The 20-foot bed at the top of this section probably represents the "Saratoga" chalk, and if so the gumbo and shale below it belong to the Marlbrook marl.

MARLBROOK MARL.

The Marlbrook marl forms a very calcareous series of marls and clays that contains one layer of chalk known as the "Saratoga" chalk member, which appears to be very persistent. It also contains many minor layers of chalky marl or limestone that are sometimes classed by well drillers as bowlders and sometimes as limestone or chalk. This formation is well developed in the Caddo field and occupies the interval between the Annona chalk below and the Nacatoch sand above.

Though the thickness of the Marlbrook marl is irregular, the actual amount of difference is much less than appears from an examination of well logs, because many drillers describe as chalk all the beds encountered below the top of the "Saratoga" chalk and the base of the Annona chalk. This gives the Annona chalk an apparent thickness greater than the actual and diminishes the apparent thickness of the Marlbrook marl. In other well logs it is thought that the soft layers in the upper part of the Annona chalk are described as shale, which gives an exaggerated thickness to the Marlbrook marl. Probably the correct thickness of the Marlbrook marl is from 325 to 375 feet, though extreme thicknesses, ranging from 175 to 450 feet, have been noted.

Sections of the Marlbrook marl, from logs of wells.

Well near Caddo.

	Feet.
Shale	8
Shale and bowlders	51
Hard shale	15
Gumbo	46
Shale	7
Gumbo	15
Shale	7
Gumbo	39
Chalk	20
Gumbo	87
Shale	22
Gumbo	26

Well in the Jeems Bayou district.

Shale	146
Gumbo	2
Gumbo and shales	32
No record	58
Gumbo and shale	28
Chalk rock	12½
No record	22½
Shale	50

Well in the Oil City district.

Marlbrook marl:	
Shale and gumbo	237
Chalk ("Saratoga" chalk member)	25
Shale and gumbo	135
Shale	9
Rock	1
Annona (?) chalk:	
Shale	185
Chalk rock	20
Shale	151

NACATOCH SAND.

In different parts of the Caddo oil field the Nacatoch sand has been known by local names, such as the "Caddo," the "Vivian," or the "Shreveport" gas sand. It is composed of light-gray to greenish fine sand, alternating with layers of indurated sandstone and thin layers of clay. Locally the formation is calcareous, and in a few places the pores between the sand grains are filled with a cement of calcium carbonate, so that it contains little or no gas even where the structural conditions favor the accumulation of gas. The formation is in few places cemented, though it has been so reported in two wells out of the total number drilled—more than a thousand. Scattered grains of glauconite may be seen in some samples of the Nacatoch sand and their presence in samples from wells may be readily detected by the green color, except where it is obscured by a coating of petroleum on the surface of the particles of sand.

Where it is not filled with oil or gas the Nacatoch sand contains a large volume of salt water, indicating that the formation is very porous. The presence of shale and gumbo, which are reported in well logs, may be explained by the occurrence of clay lenses, though some of the material described as shale may be indurated fine sand.

In the well logs of the Caddo field the Nacatoch sand shows considerable variation in thickness, ranging from less than 100 to over 125 feet in some parts of the Mooringsport district to about 100 feet at Caddo, and to 175 to 200 feet in places near the northern end of the field. The wide variation is due in part to an actual thickening of the formation toward the north and west, and in part to the fact that in some places the Nacatoch includes beds of sand belonging to the upper part of the Marlbrook marl.

Section of the Nacatoch sand, from the log of a well near Mooringsport.

	Feet.
Gas rock	2
Sandrock	12
Gas rock	81

In the foregoing section the Nacatoch sand apparently has a thickness of 95 feet, which is below the average for the southern end of the field. Another log in the same district shows only 52 feet of Nacatoch, a thickness so slight that it is thought some of the Nacatoch may have been included in the Marlbrook marl.

The following sections show the thickness of the Nacatoch sand in different parts of the field:

Sections of the Nacatoch sand, from logs of wells.

Well in the Mooringsport district.

	Feet.
Sandrock with gas	20
Rock	2
Sandrock and shale	28
Hard rock	2

Well in the Jeems Bayou district.

	Feet.
Rock	4
Shale	3
Hard rock	5
Soft rock	8
Hard rock	1
Soft rock and shale	7
Hard rock	36
Sandy shale	50

Well in the Jeems Bayou district.

Rock	17
Hard shale	38
Gas rock	10
Hard shale	10
Gas rock	10

Well in Marion County, Tex.

Hard sand	10
Gas rock	9
Hard shale	8
Hard gas sand	16
Rock	3
Gas sand	28
Sandrock	3
Hard shale	47
Sand	23
Sandrock and sand	35

Well in the Monterey district.

Gas rock	10
Packed sand	33
Gas rock	1½
Packed sand	11½
Rock	2
Packed sand	28

In other wells in the Monterey district the Nacatoch sand ranges from 175 feet to slightly more than 200 feet thick, and the sections show sand and rock with very little shale.

ARKADELPHIA CLAY.

Above the Nacatoch sand is a tough dark-colored clay that in the well logs of the Caddo field is commonly described as gumbo and shale. Sands and sandstones are rare, though a thin layer of sandstone occurs in many places from 15 to 80 feet above the base. This sandstone bed is hard, like the upper layer of the Nacatoch, and the presence of gas just below it has given rise to the designation "false cap rock." Within a few feet of the base of the Arkadelphia clay in many wells thin laminæ of sand are encountered. The basal Tertiary formation above the Arkadelphia clay is predominantly argillaceous, and therefore the line between the two formations can not be easily drawn in well records, though probably if the colors of the clays were given in the logs of wells it might be possible to separate the dark Arkadelphia clay from the lighter-colored clay above.

The maximum thickness of the Arkadelphia clay in the Caddo oil field may exceed 400 feet and the average thickness of the beds referred to that formation is from 300 feet to 350 feet. In determining the thickness it has been necessary to make more or less arbitrary distinctions that depend on incomplete information, and the measurements given should not be regarded as exact. In most well logs the materials assigned to the Arkadelphia clay contain more gumbo than shale, though in some wells the aggregate thickness of the shale equals or exceeds that of the gumbo.

TERTIARY SYSTEM.

EOCENE SERIES.

The Eocene is represented in the Caddo field by its two lowermost formations, which are in descending order the Wilcox ("Sabine") formation and the Midway formation. A small patch of fossiliferous clay belonging to the St. Maurice formation of the Claiborne group overlies the Wilcox formation southeast of Vivian, but in the Caddo field the area covered by this formation is not important. Doubtless other Eocene formations, together with some post-Eocene deposits, formerly extended over the region, but they have been removed by erosion and a portion of the Wilcox formation has also been carried away.

MIDWAY FORMATION.

The Midway formation is not easily separated from either the Wilcox formation above or the Arkadelphia clay below, though it contains fewer concretions (bowlders) than the Wilcox and less gumbo than the Arkadelphia. The formation is predominantly clayey, though glauconite and sand occur in thin layers. The well logs show thin beds of rock that are probably in part sandstone and in part limestone, though the descriptions are not sufficiently explicit to differentiate them. Probably the thickness of the Midway is from 200 to 300 feet, but accurate determination from well logs is not possible.

WILCOX ("SABINE") FORMATION.

The sands and clays that form the uplands of the Caddo field in this region belong to the Wilcox formation, formerly described as the "Sabine" formation by Veatch and other writers. Good exposures of this formation may be seen in the banks of Ferry Lake and in many roadside gullies on the hills. Some sands and clays in cuts on the Kansas City Southern Railway are referred to the Wilcox and there are excellent exposures in the vicinity of Shreveport. Sands containing some glauconite may be seen in many places, and they alternate with lenses and beds of blue or gray clay. The sands contain many concretions, some of them several feet in diameter, and some thin layers of limestone, both of which are known to the well drillers as bowlders. Layers of lignite from a fraction of an inch to several feet thick are common, and locally the clays contain imprints of leaves or stems of plants. Some shells of marine organisms have been found near Shreveport, but these are not known to occur at more than one locality. The sands present great irregularity in the arrangement of the layers, being cross-bedded on a large scale, and the clay beds are commonly inclined at angles that differ from place to place. This characteristic has proved very confusing to geologists and has led to erroneous conclusions concerning the structure in many localities.

QUATERNARY SYSTEM.

Because of the thinness and the absence of structural features, the beds belonging to the Quaternary system are not important in the Caddo oil field. The sands and clays of this system rest on the eroded surfaces of the Tertiary deposits, and over a large area they conceal the older formations. Where they predominate they interfere with the study of the underlying formations, and in many places the only source of information concerning the structure of the region is the logs of wells.

PLEISTOCENE SERIES.

Some of the red sands and clays that form terraces above the high-water levels in the valleys are referred to the Pleistocene. They were derived in part from the underlying Tertiary formations, which they resemble in general lithologic character. The Pleistocene clays of the Red River valley are very plastic and contain considerable calcium carbonate, either finely divided or in nodules. The thickness of the Pleistocene is in most places less than 25 feet, though the maximum is considerably greater, in places slightly more than 100 feet.

RECENT SERIES.

The Recent series consists of the sands and clays deposited in the channels of the streams and the thin layers of silt spread by floods on the lowlands. These sands and clays resemble those of Pleistocene age and have the same general characteristics.

STRUCTURE.

GENERAL CAUSES AND FORMS.

The attitude of the strata, in so far as it departs from the normal position, is usually discussed under the head of structure. The original attitude of many sedimentary deposits is approximately horizontal, though in some places the strata are more or less inclined.

When sedimentary beds have been subjected to change of position which alters their attitude, structural features are produced that vary in character with the resistance of the beds and the intensity and direction of the forces causing the disturbance. The most common cause for such disturbances of the original attitude of deposits is pressure, and the strata may be either bent or broken. The bending produces folds and the breaking and slipping of severed edges of strata along planes produce faults. The accompanying diagram (fig. 2) shows simple types of folds, the upward bends being known as anticlines and the downward as synclines.

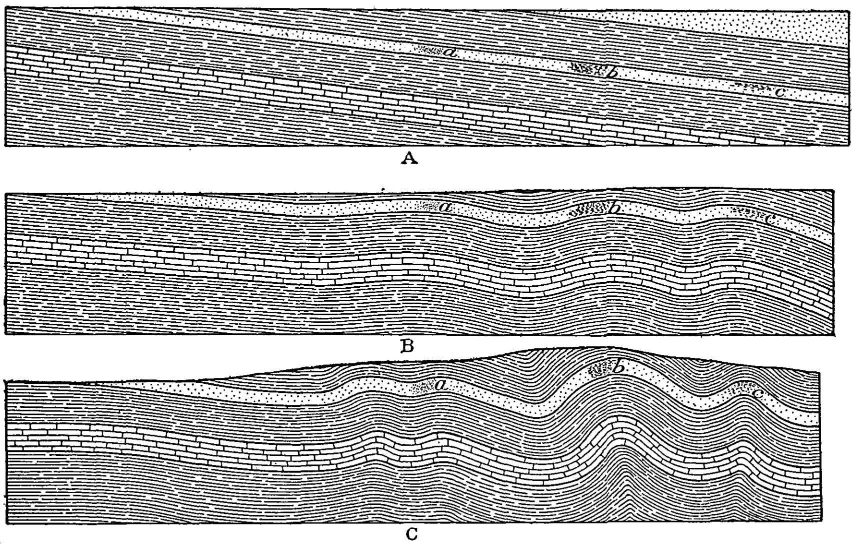

FIGURE 2.—Sections showing simple types of structure: A, Sedimentary beds with gentle dip; B, the same beds gently folded; C, the same beds more intensely folded.

Other types of folds and faults have been described, but they are not represented in the Caddo oil field, and the reader who desires information about them is referred to textbooks on geology or reports dealing with the subjects of folding and faulting.

METHODS OF REPRESENTATION.

Structure may be represented diagrammatically, as in Plate VIII, or by means of contour lines, as in Plate VII. These lines are drawn through points, on the top or bottom of a stratum of rock, that have the same distance above or below a given horizontal plane, generally sea level. When contour lines are thus drawn at levels of every 25 or 50 feet of difference in elevation, or at any other definite interval (called contour interval) in elevation that may be adopted for the whole map, it is possible, by noting the closeness and the direction of the contours, to interpret the character, the direction, and the pitch of the slope at any point of the bed that has been uplifted or warped out of a horizontal position. The refinement with which the minor warping can be shown depends upon the amount and accuracy of the information and the refinement in contouring that can be based thereon. The elevation at any point of the stratum in the contoured area may be determined by referring to the elevations indicated by the nearest contour line. Diagrams give a more graphic picture of structure than contours, but their usefulness is limited because they show structure only along certain lines across the field. The use of contours possesses the advantage of showing the structure over the entire area shown on the map. In regions of complex folding and faulting, where it is impracticable to draw structural contours, diagrams may be necessary, but in regions where the rocks are only slightly deformed contour maps are more satisfactory. The reliability of the contouring depends on the adequacy of the information available. Usually some prominent bed of rock or some easily recognized formation is chosen as the base on which the contours are drawn.

In many oil fields of West Virginia, Illinois, and Pennsylvania persistent coal beds are used for this purpose, but in the Caddo field some one of the more persistent sands or a chalk bed is more useful. The formations thus chosen are known as key rocks. The contours show the key rock as it would appear if it were stripped of all overlying formations and had not been subjected to erosion.

ACCURACY OF THE STRUCTURE CONTOURS.

The position of the structure contours was determined by subtracting the elevations of the wells from the depth to the formation to be represented, thus obtaining the depth of the surface of the key rocks below sea level. The altitudes of the wells were obtained from the engineers of the various companies or from rapid leveling by the author. The elevations of a large number of wells were supplied by F. E. Chalk, engineer of the Gulf Refining Co. of Louisiana; J. W. Anderson, engineer of the Standard Oil Co. of Louisiana, gave a list of elevations for the wells of his company; and a partial list of elevations of the wells of the Busch-Everett and the Vivian oil companies was obtained from Carl Lemon. The author's instrumental work consisted of rapid leveling from the nearest points of known elevation to the wells whose altitudes were to be obtained. Approximate elevations were considered satisfactory, and hence the determination was made to the nearest foot.

The logs of wells were supplied by the managers of different companies and by contracting drillers. In most of these logs, even the most accurate, some error exists, because measurements of depths to formations are made by computing the length of the pipe used in drilling. In checking these measurements by means of steel lines they are usually found to be 5 or 6 feet too great, and there is, in addition, an uncertainty in ascertaining the exact point where a formation is first encountered, though the amount of error resulting from this cause is not easily determined. A few logs appear to be so unreliable that they have been disregarded in drawing the structure maps. Fortunately, records of this kind are few, and the increasing tendency toward steel-line measurements should result in still greater accuracy. The use of reliable information obtained in that way will make possible the construction of more accurate structural maps and facilitate the systematic control of drilling operations.

In the present work it is believed that enough reliable information was obtained to permit the compilation of a structure map that is fairly accurate as to the general type of structure and the position and form of the major anticlines and synclines, although the details can not be shown until more data are gathered.

KEY ROCKS IN THE CADDO OIL FIELDS.

ANNONA CHALK.

The Annona chalk has been regarded as an important key rock because of its wide distribution and distinctive character. It possesses the advantage of being unlike the formations immediately above and below it, but unfortunately the drillers do not always separate it from the "Saratoga" chalk member of the Marlbrook marl, which is stratigraphically somewhat higher. Probably the true depth to the Annona chalk can be determined in these wells by adding the difference in depth between the two chalk beds where the depth to the top of the "Saratoga" chalk is given. The base of the chalk would be a valuable key for contouring if it were not for the fact that as long as the cuttings from the well appear white the material is classed by many drillers as chalk, even though the drill may have penetrated some distance into the underlying marl.

NACATOCH SAND.

One of the most useful formations for contouring is the Nacatoch or upper gas sand, as this formation is lithologically distinct from the strata above and below it, and it is reached in every successful well in the field, whether shallow or deep. It is the first formation encountered that contains enough gas to be of economic value, and all successful wells are either drilled into it for the purpose of obtaining gas or through it to some of the deeper oil or gas horizons. Moreover, in most places the presence of the gas causes drillers to record the depth, even though they intend to drill to one of the underlying sands. Because of the large number of wells reaching the Nacatoch sand it has been possible to draw approximate contour lines for each variation of 25 feet in its elevation. (See Pl. VII.) These contours are placed on the same sheet with those showing the surface of the Blossom sand member of the Eagle Ford clay, which are represented by broken lines.

BLOSSOM SAND MEMBER OF EAGLE FORD CLAY.

The Blossom sand is present and readily recognized by most drillers, who designate it the 1,800-foot sand or the big sandrock, and its identification is facilitated by the presence of gas, which leads to its designation as the second gas sand. The Blossom sand is nearer to the deep oil-bearing formation than either the Nacatoch sand or the Annona chalk, and its structure more nearly corresponds to that of the oil sands, but it is not penetrated by as many wells as the higher formations, and hence information concerning it is not as complete. The broken contours on Plate VII show the variations in elevation of the surface of the Blossom sand for each 25 feet.

RELATIONS OF THE NACATOCH SAND AND THE BLOSSOM SAND MEMBER OF THE EAGLE FORD CLAY.

The relations of the key rocks, the Nacatoch and Blossom sands, have been examined to determine whether the interval between the two is constant throughout the oil field. Striking differences were found in some wells close together, amounting in places to more than 50 feet, which may indicate errors in recording logs, though a certain amount of variation is to be expected, because the upper surfaces of the two sands as originally deposited were probably somewhat uneven. The degree of accuracy in the determination of the depths to the sands differs from place to place and the decisions of different drillers as to the position of the tops of the sands do not always agree. After allowing for all these factors the persistent variations that remain suggest that the sands are not exactly parallel and that the change in the interval between them is not simply due to the thickening of the intervening formations toward some parts of the field and thinning in opposite directions. The discordance in dip of the two sands in places illustrates the lack of a constant interval between them and shows that the anticlines have slightly steeper slopes when the dip is measured on the Blossom sand than when it is based on the Nacatoch sand. This condition suggests that the deformation began after the deposition of the Blossom but was renewed and culminated after the deposition of the Nacatoch. On the north slope of the Monterey uplift the contours indicate approximately the same dip for the two sands. The fact that the earlier folding in that region was slight may account for this condition, but it is more probably due to the generalized character of the map (Pl. VIII) in that area, where the information is scanty.

An examination of the contours shows that the axes of folds indicated by contours on the Blossom sand do not agree in position with the axes of folds shown by the contours of the Nacatoch sand. This disagreement was at first thought to be the result of inaccurate contouring but was subsequently found to be general, and the axes were found to bear a more or less systematic relation to each other. This peculiarity, together with the absence of systematic variation in the interval between the sands, suggests that some general explanation must be sought, either in the geologic history or in the character of the deformation. If the folding had been sufficiently intense the beds might have suffered unequal thrust and the Nacatoch sand might have been thrust bodily over the lower sand by crumpling of the beds or by shearing movement between the beds of the intervening formations. The extensive folding of this area, which culminated in the high anticline in the vicinity of Caddo Lake, brought about a complete reversal of the general inclination of the Cretaceous and Tertiary formations of the region. The original slope of the Cretaceous beds had been toward the southeast, but in the processes of uplift and deformation a general inclination toward the northwest was produced. This change was accompanied by a crumpling of the formations and a general shifting of the folds toward the northwest. The thrust was apparently tangential to the beds rather than parallel to them, so that the position of the folds in one formation was shifted more than in the other, though the readjustments caused by the unequal movement were doubtless in the form of crumpling rather than shearing, because of the plastic character of the intervening deposits. It is presumed that movements of this character may account for some of the variations in the positions of the axes of the folds shown by the contours of the surface of the key rocks.

SABINE UPLIFT.

The existence of interesting structural features in northwestern Louisiana was recognized by Veatch,[1] who says: "It [the Angelina-Caldwell flexure] has almost entirely destroyed the southern element

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 68, 1906.

of the dip of the beds between its northern border and a point about 60 miles south of the Paleozoic border." The Angelina-Caldwell flexure, as described by Veatch, extends from Angelina County, Tex., north of east, passing near Many, north of Nachitoches, and as far east as Mississippi River. The region affected by this flexure includes the territory from a short distance north of Nachitoches northwestward beyond the northern edge of the Caddo oil field.

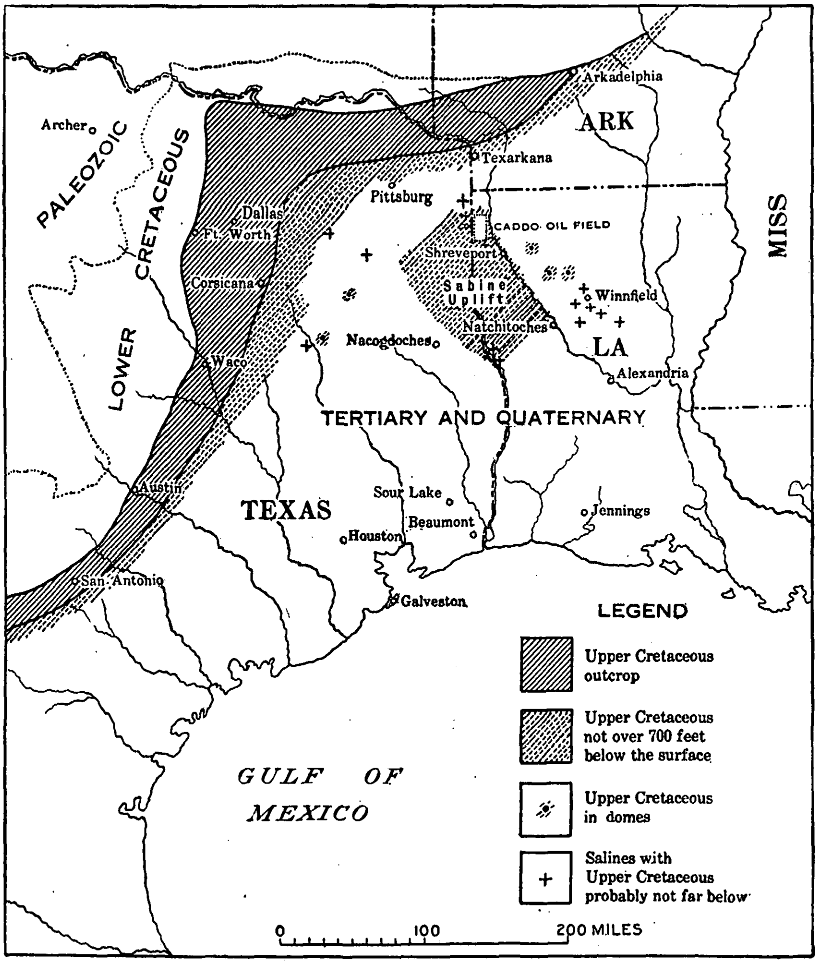

FIGURE 3.—Map of the Sabine uplift (after Harris) showing the important structural features in the Upper Cretaceous (gas and oil bearing) formations in eastern Texas and Louisiana. These formations dip beneath younger (Tertiary and Quaternary) deposits to the southeast.

The Sabine uplift (figs. 3 and 4), as outlined by Harris,[1] is given more definite form. The extensive crustal movements in its vicinity have brought Upper Cretaceous beds up within less than 700 feet of

[1] Harris, G. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, pp. 26–29, 1910.

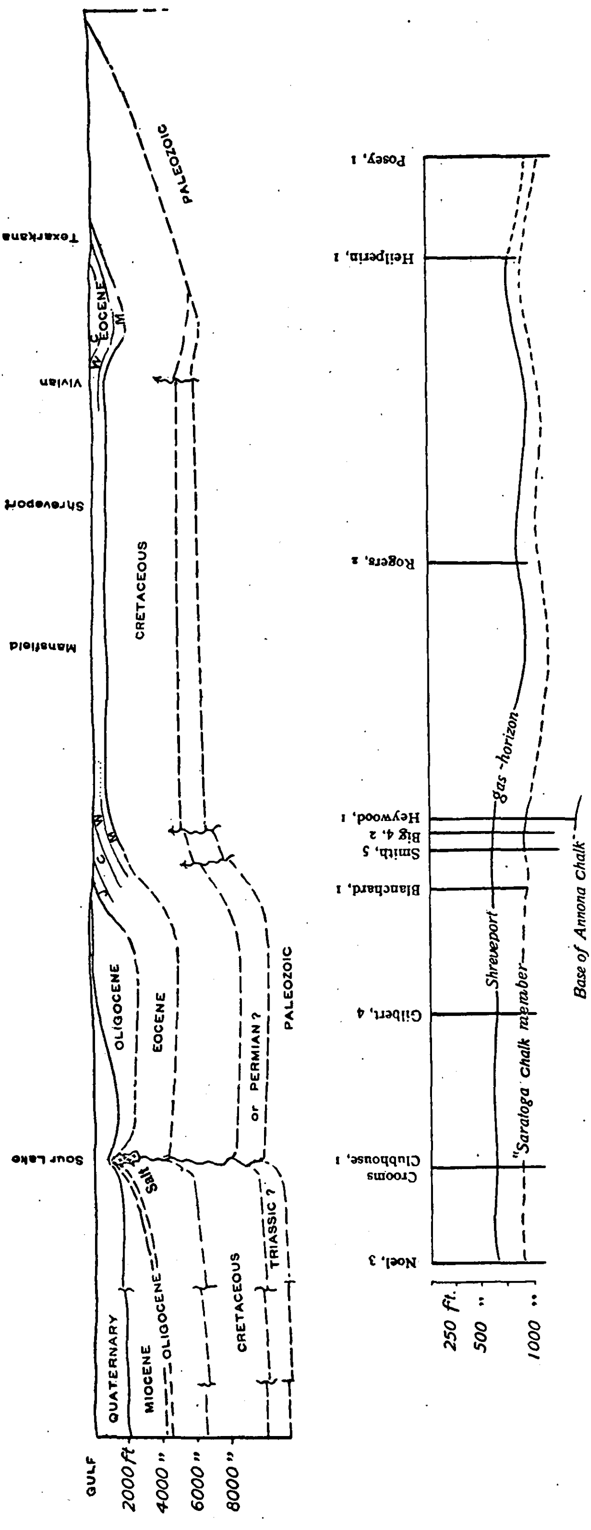

FIGURE 4.—Cross section of the Sabine uplift (after Harris) from the Paleozoic outcrop north of Texarkana, Ark., through the Caddo oil field and Sour Lake to the Gulf of Mexico, near Galveston.

the surface over a large area. This movement has brought about structural features of prime importance in oil and gas concentration.

This area is of great economic importance because it includes the Caddo, De Soto, and Red River oil fields, which, so far as known, are the only important Coastal Plain oil fields in Louisiana not located on the edges of salt domes. Probably future prospecting will develop other fields outside the Sabine uplift, but there is still much territory on the uplift that should be carefully investigated. In this bulletin a more detailed map of the Sabine uplift is not given because the discussion is limited to some of the important structural features on a portion of it, and an effort is made to show the relations of these features to the occurrence of oil and gas.

GENERAL STRUCTURE OF THE CADDO OIL FIELD.

The general structure of the Caddo oil field is anticlinal and synclinal, though the combination of different forces operating approximately at right angles to each other have produced complex folds of somewhat irregular shapes. Thus all of the folds have curving axes, some are apparently branching, and others lack definite anticlinal form, though this may be due to lack of information which could be used in representing the detailed structure. The successive folds rise in height from northwest to southeast, culminating just north of the eastern end of Caddo Lake, where the formations are structurally highest. South of Caddo Lake there are other folds parallel to those in the oil field, though they are somewhat lower and they may diminish in height toward the south for some distance beyond the lake.

The folds in the Caddo oil field are the result of pressure, and their general forms are typical of the structure in the territory underlain by thick deposits of Cretaceous and Tertiary age, though variations in details may be found in different places. Since they belong to types that are apt to be characteristic of the Gulf Coastal Plain region in western Louisiana and eastern Texas they deserve careful consideration.

The detailed structure of the Caddo field will be discussed on subsequent pages, but it may be noted here that the folds belong to two distinct periods. One series was produced by forces acting in a general northwest-southeast direction, producing anticlines and synclines with axes at right angles to the pressure. These folds are crossed by an axis, approximately at right angles to them and nearly parallel with the east side of the Sabine uplift. The pressure which produced this fold was at about right angles to that which produced the other folds. The two forces did not act simultaneously, for the southwest-northeast folds are clearly older than the folds at right angles to them, as is shown by the fact that they are bent at the point where they cross the northwest-southeast axis.

Another effect of the last period of folding is the inclination of the crests of the older folds away from the points where the two series of folds intersect. This pitch, though less than the dip of the beds on the flanks of the anticlines, is noticeable on all the anticlines. Other folds parallel to the northwest-southeast axis are present, though the information available is not sufficient to show their outlines. They produce variations in the elevation of the crests of the southwest-northeast folds.

The best example of simple anticlinal structure is the fold east of Vivian, which is called the Vivian anticline in this report. Another relatively simple fold, which may be a southwestward prolongation of the Vivian anticline, passes through the northwest corner of T. 20 N., R. 16 W., and thence northeastward into the adjoining township. This fold, which is designated the Mason anticline, has, like the Vivian anticline, a distinctly curving axis. North of the Mason anticline is an irregular fold, called the Monterey uplift, which is a composite of several minor anticlines. The fold that extends from beneath the bed of Caddo Lake northeastward to the southern end of the Pine Island district has been named the Caddo Lake anticline. It is not known what form this fold may take in its extension to the northeast, but, judging from the available information, it has a definite branch toward the southeast just east of Mooringsport, and merges into a shorter fold nearly parallel to the Caddo Lake anticline. This short fold has been the source of some very large wells, but the producing areas are relatively small.

The Monterey uplift, which has been made to include the structural features north of the Mason anticline, is very irregular in shape, and it is difficult to show the details of the anticlinal and synclinal structures because of the small scale of the map. The forces that produced the small folds were here so nearly balanced that the resultant structures have rather indefinite outlines, though probably a part of the apparent lack of well-defined form is caused by the absence of information which would make possible the drawing of more accurate contours.

The syncline between the Caddo Lake and Mason anticlines is better defined than the others, though its bottom lies higher than some of the producing territory in the Monterey uplift. Another syncline is shown in secs. 21, 28, and 29, T. 21 N., R. 16 W. This trough is designated the Trees City syncline, though in reality it contains a number of minor anticlines. The portion shown on the map is high enough to be above the level of producing territory farther north. A broad area where the sands are relatively low occupies a tract between the Vivian anticline and the Monterey uplift, but its form is almost as indefinite as the Monterey uplift, though here again lack of information may account for the inability to recognize a definite synclinal shape.

An examination of the structure where there is a large amount of information available reveals the fact that the folds of the Caddo oil field are not the simple forms that are represented on the maps and diagrams. It is apparent that each large fold is composed of a number of smaller ones having the same general shape and trend. These minor folds are too small to be shown on a map of the scale used, even if their outline could be determined, and at present the information concerning them is too meager to show their shape and distribution, except at a very few places. They play an important part in the oil development at some localities, because where other conditions are the same wells located on the minor anticlines are better than those in the minor synclines. Their influence is most noticeable on wells in the Nacatoch sand, and they are of least importance in the Woodbine sand, where other factors may have greater weight. The northwest-southeast axis of the Caddo oil field extends from the vicinity of Monterey to a point just east of Mooringsport. Its northern end pitches downward gently and bears the oil pool containing Harrell No. 7 of the Producers Oil Co., probably the largest well ever drilled in the field. The crest of this axis is uneven, as it is affected by the cross folds. It is high at the points where the northeast-southwest anticlines cross and low at the intersections of the corresponding synclines. The southern end, which is the highest, contains some excellent gas wells, and the northern end has produced a large amount of oil.

LOCAL STRUCTURAL FEATURES.

NACATOCH SAND.

VIVIAN ANTICLINE.

In the Caddo oil field three well-defined northeast-southwest anticlines, whose crests rise progressively higher from north to south, have been recognized. The Vivian anticline is a pronounced oval fold lying east of Vivian (Pl. VII). It has furnished a large amount of gas and has been an important source of oil from the Nacatoch sand. It possesses the general characteristics of all the folds, being flat-topped and having relatively steep dips on its northern margin. The southern limb of this anticline has not been extensively prospected, and it is not known whether oil will be found upon it. From theoretical considerations, as well as the meager informa-

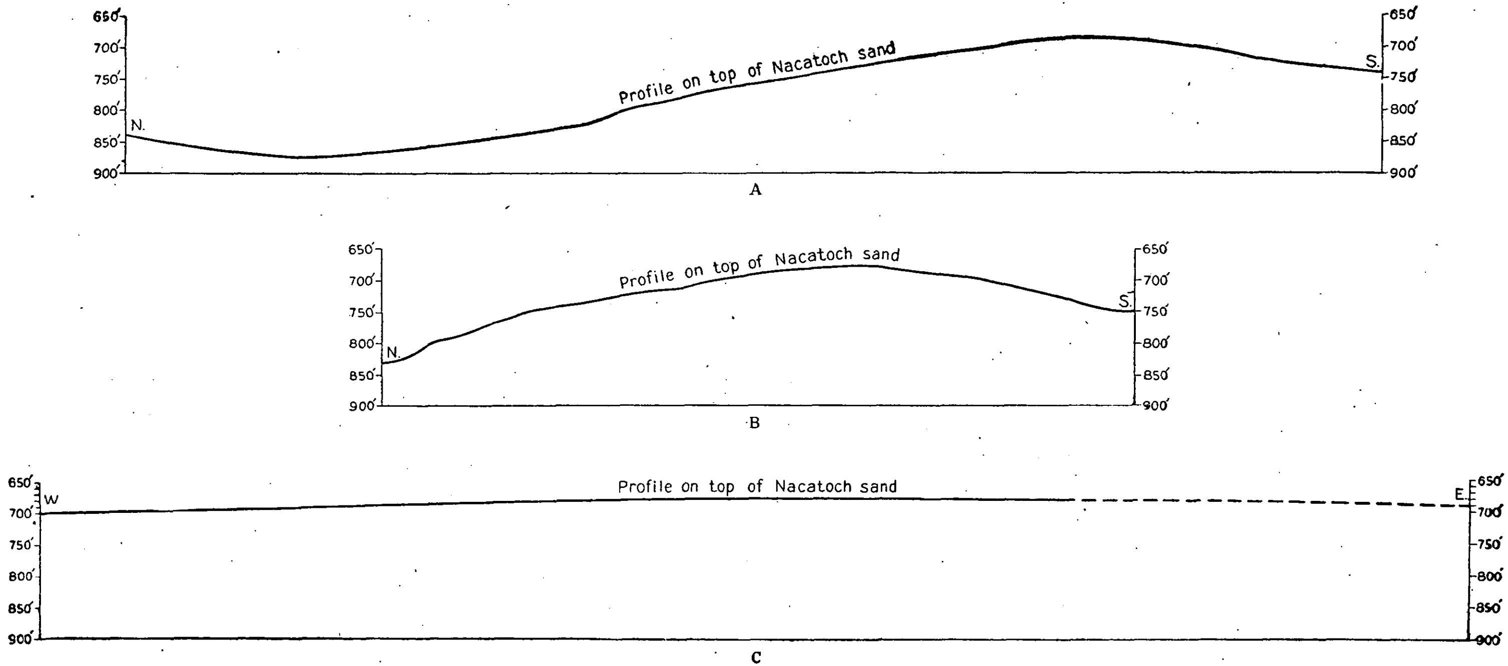

FIGURE 5.—Profiles of the top of the Nacatoch sand on the Vivian anticline: A, From locality near the southwest corner of sec. 34 to well in W. ½ sec. 18, T. 22 N., R. 15 W.; B, the highest part of the anticline in secs. 22, 27, and 34, T. 22 N., R. 15 W.; C, the crest of the anticline.

tion available, the southerly dips should be somewhat gentler than those toward the north, and this is confirmed by a few scattered well logs, together with information gained on a brief reconnaissance of the area.

The Vivian anticline has a curved axis, which results from a combination of the forces that produced the two lines of major folding. At the west end it curves southward and is partly interrupted by a broad syncline east of the Monterey pool. The eastern end of the anticline is bent southward, either as the result of the formation of another broad syncline or because of the downward flexing of the beds at the east edge of the Sabine uplift.

In profile C (fig. 5) the eastern extension of the apex is shown as a dotted line and is represented with a gentle pitch, a condition suggested by the flattening of the slope toward the northeast. The dry hole in the northwest corner of sec. 36 suggests that in some places the eastern end of the anticline may not be productive, but the evidence is not conclusive because the ground has not yet been thoroughly tested.

The occurrence of oil in the Nacatoch sand along the north slope of this anticline has led to extensive drilling and a large production of fuel oil was formerly obtained. Near the eastern end of the fold the line between the gas and oil was approximately along the contour where the sand is 780 feet below sea level. Below this line oil predominated, whereas above it gas was found. Salt water was encountered below the 800-foot contour, though a few small oil wells were drilled where the sand was slightly deeper. Because of the existence of local areas where the sands were elevated by minor anticlines successful wells were encountered in a few places at depths of less than 800 feet below sea level in the area below the 800-foot contour. Similar local irregularities account for the occurrence of gas at what appears to be unusually low levels, and minor depressions in the form of small synclines account for the existence of oil wells within the margin of the gas-producing territory.

Near the western end of the Vivian anticline the general northerly dip becomes gentler, and both gas and oil are found at greater depths in the Nacatoch sand. The influence of minor folds is also manifest over a much wider area; gas wells are found on minor anticlines among the oil wells, and oil wells are located in small synclines some distance southeastward in gas-producing territory. In some of these places, where the detailed logs of wells in the vicinity are available, the local character of the folds is evident. For similar reasons the border between the oil and salt water is irregular, and the number of wells that are failures is apt to be large, because the success of a well on a small anticline, beyond the limits of supposed productive territory, encourages useless drilling. When the local character of the uplifts that give successful wells outside the main belt of production is understood it should serve as a check on extensive operations in unfavorable territory.

At the extreme western end of the syncline southwest of Vivian the oil extends to a somewhat greater depth than it does farther east, and many productive wells are obtained where the sand is more than 800 feet below sea level. However, the structure is connected with that farther west, and it will be discussed with the other anticlines.

MONTEREY UPLIFT.

The structure contours of the Nacatoch sand show complex folding south of Monterey (Pl. VII), with a long, gentle northwesterly dip and a similar but steeper inclination toward the west. The form of the uplift here is so lacking in symmetry that the term anticline is scarcely appropriate. The Nacatoch sand lies so deep on the outer margins of this uplift that large areas are barren, though oil has been found in the south half of sec. 10, T. 21 N., R. 16 W., and there have been a few shallow oil wells to the north and northeast, most of them beyond the 825-foot contour. A notable example of such a well is the Producers Oil Co.'s No. 1, Fee, in the SW. ¼ SE. ¼ sec. 3, T. 21 N., R. 16 W. This well is located near the 850-foot contour, but it encountered a minor anticline, where the sand was locally relatively high and a small production was obtained. To the north and west of this well and on the west side of Jeems Bayou the Nacatoch sand is low and is relatively barren. Near the southeast corner of the NE. ¼ sec. 21, T. 21 N., R. 16 W., a small supply of gas was obtained from one well. The formation has not been prospected for oil on the west side of Jeems Bayou, but to judge from the altitude of the sand only a small area near the bayou would be productive.

East of the bayou extensive areas of both oil and gas are known, and doubtless oil and, in some places, gas could be obtained from the Nacatoch sand in the bayou. In secs. 11, 12, 13, 14, 23, 24, 25, and part of 26, as well as farther south and east, oil and gas have been obtained from this formation. In this area, where the dips are slight, salt water is locally troublesome unless wells are carefully finished. Among the productive gas and oil wells in this territory are those which belong to the Rodgers Oil & Gas Co., and the large proportion of good wells indicates a general prevalence of favorable conditions.

MASON ANTICLINE AND SYNCLINE.

Oil has been found in the Nacatoch sand in Jeems Bayou and east of the bayou in sec. 34, T. 21 N., R. 16 W. The structure here (Pl. VII) indicates a slight easterly dip away from a small fold, the Mason anticline, that extends east of Masons Landing and northeast into sec. 34. The axis of this fold is curved sharply to the east in secs. 33 and 34. The principal wells obtaining oil from the Nacatoch sand belong to the Higgins Fuel & Oil Co. A gas well of the Koster Oil Co., in the SW. ¼ SW. ¼ sec. 34, is located on a minor anticline.

There is a broad syncline in the northern part of T. 20 N., R. 16 W., and the southeast corner of T. 21 N., R. 16 W. The Nacatoch sand in this syncline is mostly above the 800-foot contour, and oil may be obtained in the lowest portion. Gas is encountered in a minor anticline in the bottom of the large syncline and in the territory to the southeast, where the Nacatoch is relatively high.

CADDO LAKE UPLIFT.

On the Caddo Lake uplift (Pl. VII), the highest and most extensive in the field, the Nacatoch sand rises to less than 550 feet below sea level, and the distribution of the contours shows that the fold has a flat top and steep slopes. Throughout this large area the structure is favorable for the occurrence of gas in the Nacatoch sand. However, the formation thins greatly on some portions of this uplift, and locally its porosity is diminished, so that in some places it does not contain much gas. Development of gas has been extended along what appears to be a spur of this uplift southeastward nearly to the township line in secs. 31 and 32, T. 20 N., R. 15 W. Conditions favorable to the occurrence of gas continue to the northeastward through the Pine Island district and as far east as sec. 10, T. 20 N., R. 15 E.

BLOSSOM SAND MEMBER OF EAGLE FORD CLAY AND WOODBINE SAND.

MONTEREY UPLIFT.

The Monterey uplift (Pl. VII) is irregular in outline with slopes toward the west, northwest, and southwest that are extensive but not everywhere alike. The northwestward dip, as shown by contours on the top of the Blossom sand, is moderate, the maximum being 100 feet to the mile near the apex of the uplift and gradually decreasing to less than 50 feet toward the margin. The western slope is somewhat steeper, but there is a marked flattening of the dip on the outskirts of the uplift. Throughout the uplift the dips of the surface of the Blossom sand are slightly greater than those shown by the contours of the surface of the Nacatoch sand.

The interval between the top of the Blossom sand and the arenaceous beds in the Woodbine sand is somewhat irregular on the Monterey uplift, but the variations are in general less numerous than in other parts of the field. In a large number of wells the depth of the oil sand below the top of the Blossom sand lies between 350 and 375 feet; in many others the depths are from 330 to 350 feet. The interval between these sands as a rule is less than 330 feet, though in a few wells it falls below 300 and in two wells amounts to slightly more than 400 feet. In one well the interval between the tops of the sands is about 215 feet, and near the northern end of the uplift a well was drilled to a depth of 525 feet below the top of the Blossom sand before encountering a sand bed in the Woodbine, but these conditions are both unusual.

The Monterey uplift has been very productive. Successful wells were numerous, some of them very large, the best being the Producers Oil Co.'s Harrell No. 7, in sec. 4, T. 21 N., R. 16 W. The most uniform development has been on the leases of the Standard Oil Co., where the sands dip down toward the shallow Trees City syncline shown on the structural map. This territory has furnished a large number of excellent wells, and some of them have had initial productions of several thousand barrels a day. The bottom of the syncline is sufficiently high to be above the level where the beds are saturated with salt water and it has been uniformly productive. Deep drilling on the eastern slope of the Monterey uplift has so far proved unprofitable except near the southern end.

MASON ANTICLINE.

The crest of the Mason anticline (Pl. VII), as shown by the contours on the Blossom sand, extends from the vicinity of the Bonham lease of the Gulf Refining Co. northeastward to secs. 34 and 35, T. 21 N., R. 16 W., where it turns northward toward sec. 23 of the same township and range. The information on which this contouring is based is meager, and subsequent developments may necessitate considerable modification, especially near the northern end of this anticline. On the apex of the fold the Blossom sand rises to somewhat less than 1,675 feet below sea level, and the anticline has a flat top with steep dips toward the west and northwest. The production is mostly from one or more sands in the Woodbine at depths of 350 to slightly more than 400 feet below the top of the Blossom sand, which is shown by the broken contour lines on Plate VII. Some wells encountered sand beds that may have furnished oil at depths of about 250 to 260 feet and one at only about 215 feet below the top of the Blossom sand, but in a few the interval is greater than 400 feet. In general drilling on the slopes and top of this anticline has been successful, and a large area has not yet been exploited.

The wells on the western side of this anticline have been uniformly successful, and some especially large ones have been procured by the Producers Oil Co., the Busch-Everett Oil Co., and the Standard Oil Co., in sec. 33, T. 21 N., R. 16 W., near the top of the slope, where the beds dip steeply down from the top of the fold. Farther southwest and across the State line in Texas the rich Burr pool of the J. M. Guffey Petroleum Co. is located farther down the slope of the anticline. The Standard Oil Co. has drilled a large number of successful wells on the north limb of this anticline as well as in the shallow syncline just north of it.

In the syncline south of the Mason anticline many successful wells have been drilled, some of them being large. The best yield in this portion of the field was from the Producers Oil Co.'s well on the Atlanta Shreveport Oil & Gas Co. lease in sec. 3, T. 20 N., R. 16 W. This well lies north of the bottom of the trough, and though the structure here is synclinal it should be noticed that the elevation of the Blossom sand is but little below the elevation of the same sand where the large wells were procured in sec. 33 in the township to the north, and it is not very different from the elevation of the Burr pool on the opposite slope of the Mason anticline. The interval between the top of the Blossom sand and the producing beds in the Woodbine sand is in most places about 325 to 375 feet, though a few wells contain sands within 250 feet of the top of the Blossom sand, and in still fewer there is an interval of slightly more than 400 feet.

CADDO LAKE UPLIFT.

Beneath the bed of Caddo Lake (Pl. VII) and extending to the east and southeast is a large anticline that represents the culmination of the structural features of the field, on which the Blossom sand rises to about 1,500 feet or less below sea level. The anticline is broad and its axis trends north of east, a branch apparently extending toward the southeast at a right angle to the main fold. North of Mooringsport this branch merges with an anticline that is approximately parallel with the Caddo Lake anticline. The axis of the anticline that extends into the Caddo Lake basin has a distinct slope (pitch) in a direction about west-southwest. The slope of the contours of the Mason anticline indicates a similar pitch, but the information concerning this territory is not as complete as that for the Caddo Lake anticline.

Many successful wells have been drilled on the north side of the Caddo Lake anticline, and those on the upper part of the slope, near the lake, have been especially good. In the vicinity of Caddo some large wells have been obtained in the Annona chalk, but the wells penetrating the Woodbine sand in the same neighborhood have not been as successful as the structure would lead one to expect. In the Pine Island district good wells have been procured on the north slope of this anticline, but they have not proved lasting and much trouble has been experienced with salt water.

On the north slope of the Caddo Lake anticline the general range of depth for the Woodbine sand below the top of the Blossom sand is from about 325 feet to about 375 feet. Very few wells report this interval to be less than 325 feet, though in two or three it drops to 250 to 300 feet. Several wells encounter sands at 400 to 450 feet below the same datum plane; some wells penetrated as many as three successive sand beds and two sands are not uncommon.

On the top of this anticline wells have been generally successful, though many of them are small. Where there is a definite westward pitch to the crest of the fold some good wells have been obtained, and in sec. 19, T. 20 N., R. 16 W., where there is another anticline, a very rich pool contains a number of large wells within a radius of less than one-fourth of a mile.

Two other small pools, each with a single large well, were encountered on the anticline that lies south of the main Caddo Lake uplift and west of the extension to the southeast. One of these pools was located at the north edge of the village of Mooringsport and included the large Noel well of the Atlas Oil Co.; the second was near the boundary between secs. 26 and 35, T. 20 N., R. 16 W., and centered about the Star Oil Co.'s Loucks No. 3.

Meager information concerning the Woodbine sand on the apex of the Caddo Lake uplift indicates that although in a few places it is about 300 feet below the Blossom sand in most wells the intervals are from 350 to 375 feet. Some wells encountered the deep sand 400 to 450 feet below the datum and extreme depths of slightly more than 550 feet were reported. On the south and west sides of the uplift the development has been recent and information is not yet available for publication; however, the successful wells appear to be located on pools of smaller area than those farther north. Some oil has been obtained on the Standard Oil Co.'s Hunter lease in the northeast corner of the NW. ¼ sec. 5, T. 19 N., R. 16 W., on the Hardy lease belonging to the same company, on the south side of the lake, and on the lease of the Providence Oil & Gas Co. in Texas. A successful well has also been drilled by the Atlas Oil Co. in the south half of fractional sec. 17, T. 20 N., R. 16 W., thus extending the area of possible production somewhat beyond its former limits.

An unusually good well of the Brown Oil Co. is located in sec. 4, T. 20 N., R. 15 W.; it has been flowing steadily with a good yield for over five years. In sec. 10, T. 20 N., R. 16 W., the Black Bayou and Natalie oil companies have drilled several successful wells, leaving a large intervening area untested. These wells are all located on the Caddo Lake uplift, but the information at hand is not sufficient to contour the structure in that portion of the field.

Some deep wells have been drilled near the eastern end, on the northern slope of the Vivian anticline, to test the Woodbine sand, but though good sand beds have been encountered they have proved unproductive. Another deep well was drilled toward the apex of the anticline on the south side. These wells all show some traces of oil in the Woodbine, but none of them encountered paying quantities.

STRUCTURAL FEATURES IN THE REGION ADJACENT TO THE CADDO OIL FIELD.

Structural features similar to those shown on the map of the Caddo oil field are known to exist at Shreveport and near Naborton in De Soto Parish. The structure at these localities is so much like that of the Caddo oil field as to suggest that it has a similar origin. If the northwest-southeast uplift of the Caddo field continues in a straight line it passes through the Naborton field but lies a short distance west of Shreveport. However, it is unlikely that any fold in this region has such great extent in a straight line, and it is more probable that the axis of the uplift curves slightly and is interrupted by numerous synclinal troughs.

SHREVEPORT ANTICLINE.

The Shreveport anticline is imperfectly known, but from the few wells that have been drilled there appears to be a low southwest-northeast fold comparable with some of those in the Caddo field. The Nacatoch sand has an elevation of less than 740 feet below sea level and in several wells it has been encountered at depths of 750 to 775 feet. This fold is high enough to permit drilling of successful gas wells, provided care is exercised in finishing them. Salt water is troublesome in some of the minor synclines that are superimposed on the major fold, and there is a great variation in the yield of gas wells situated a short distance from each other. In general those wells that encounter the sand on one of the minor anticlines similar to those described in the discussion of the Caddo field are more successful than the wells situated in the synclines. Toward the southwest edge of Caddo Parish, in the vicinity of Keithville, enough drilling has been done to show that the Nacatoch sand is too low to supply gas, though a small quantity occurs, together with much salt water. A somewhat similar difficulty was encountered at Reisor, a few miles north of Keithville.

The Shreveport anticline has not supplied any oil, though a few attempts have been made to test the deep sands. In general the formations below the Nacatoch appear to be somewhat more sandy than they are farther north, in the Caddo field. This anticline should be thoroughly tested at least to depths as great or slightly greater than the pay sands in De Soto Parish.

FRIERSON.

Veatch[1] reports gas and salt water in the Nacatoch (?) sand at Frierson at a depth of 800 feet below sea level. More definite information from this locality suggests that the sand described may have been an unusually thick lens in the lower part of the Arkadelphia clay, and that the Nacatoch sand may lie 20 to 30 feet deeper. Here, as at Shreveport, all the Cretaceous formations are more sandy than in the Caddo field, but unless some locality can be found where the sands are higher than where deep drilling has been done there does not appear to be any favorable indication of the occurrence of either gas or oil in commercial quantities.

NABORTON AND VICINITY.

In De Soto Parish structures similar to those in the Caddo field have been known for some time, and though detailed information concerning this field is not available for publication, the anticline in the vicinity of Naborton is known to be about as high as the Caddo Lake anticline. All the Cretaceous formations contain a larger proportion of sand here than they do in the Caddo field, and the oil comes from a deeper bed, possibly in the Woodbine sand or some older formation. It is not yet known whether the Naborton pool is located on the highest part of this uplift, but the sands distinctly pitch south of west and the fold passes north of the properties owned by the Mansfield Gas Co. Dips both north and south from the pool indicate that the field is near the axis of the anticline, and if there are any higher portions they must lie northeast of the producing wells.

Other anticlines similar to the one at Naborton occur at intervals as far south as the northern line of Natchitoches Parish, but the height of the successive folds diminishes toward the southeast, and those nearest the Naborton anticline may be more favorable locations for wildcat wells than those farther south.

North of the Naborton anticline a similar fold probably accounts for the large gas well of the Producers Oil Co. Between this locality and Shreveport there probably are other folds of similar character, but that area has not yet been examined in detail.

SABINE PARISH.

About 15 miles south of the Naborton field, in De Soto Parish, drilling has been carried on for two or three years. Since the prepara-

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 26, 210, 211, 1906.

tion of the major portion of this report a small well yielding some oil has been finished in the southern part of T. 10 N., R. 12 W., a short distance south of the boundary between De Soto and Sabine parishes and only a few miles from the town of Pelican on the Texas & Pacific Railway. This successful well is of considerable interest because it expands the area of possible production nearly to the southern boundary of the Sabine uplift of Harris. The producing sand is reported at somewhat greater depth than in De Soto Parish.

In Tps. 7 and 8 N., R. 12 W., several wells have been drilled by McCann & Harper for the Lumberman's Oil & Gas Co., but none of them have been successful. The logs of all these wells are difficult to interpret in the absence of samples of the drillings or of fossils from the formations below the surface. However, it is possible that the Nacatoch sand has been reached in only one or two of these wells, where a sand is reported to contain a large volume of salt water. Opposed to this theory is the fact that chalk is reported in all the wells at depths which vary from 2,000 to 2,500 feet from the surface. However, this chalk may be a limestone in the basal Eocene (Midway formation). These interpretations are tentative and subject to revision whenever satisfactory samples can be obtained from deep drillings in this neighborhood. It is, however, certain that none of the wells have reached the deep producing sands of the Caddo or De Soto Parish fields. From Veatch's report[1] it appears that there should be a very distinct flexure (the Angelina flexure) crossing this part of Sabine Parish, and from comparison of some of the well logs it is inferred that this or a similar fold may lie south of the wells drilled for the Lumberman's Oil & Gas Co. This suggestion is, of course, tentative, because this field has not yet been examined to determine the exact structure, and it may be found on careful examination of the region that the Angelina fold passes to the north of this group of wells, in the neighborhood of the Logan well of the Pasadena Oil Co.

OCCURRENCE OF OIL AND GAS.

NACATOCH SAND ("CADDO" GAS SAND, "SHREVEPORT" GAS SAND).

The Nacatoch sand (see Pl. VIII) is the most important gas sand of the field and has produced some low-gravity oil suitable for fuel. The description of the formation given in the discussion of the geology includes some sections selected from among a large number of well logs. These sections show that the formation contains many alternations of soft and hard layers, locally known as cap rocks. The thickness of the formation ranges from about 50 feet to over 150 feet,

[1] Veatch, A. C., op. cit., pp. 26, 210, 211.

but only the upper part contains oil or gas. Locally, as at some points east of Vivian, the gas occurs in the upper part of the formation, separated from the oil or salt water below by a hard bed known as a cap rock, but even in wells located near each other this cap rock may lie between the oil and gas in one and not in another, because the hard layers are not persistent. Where the gas or oil bearing sand is limited to a few feet in the upper part of the formation it is necessary to use great care in completing a well, because if it is drilled too deep or the gas is allowed to flow unchecked salt water may interfere with production. In the early development of the field this was not always understood, but the danger of salt water is now avoided, as far as possible, by drilling only a short distance into the formation, or in many gas wells by merely puncturing the hard rock that caps the sand.

ANNONA CHALK.

The Annona chalk has supplied to a few wells large quantities of oil of relatively low gravity, which may occur in crevices or in porous beds of chalk or sand of small extent. The initial yields of some of these wells have been large; for example, the Richardson and Busch-Everett wells, east of Caddo, and the Alamo well No. 2 of the Caddo town site. The Alamo No. 2 was a large gusher and attracted the attention of many operators from the salt-dome fields of the Gulf coast, who acquired small holdings in the vicinity and drilled a large number of unsuccessful wells.

BLOSSOM SAND MEMBER OF EAGLE FORD CLAY.

The Blossom sand (1,800-foot sand, sandrock; see Pl. VIII) is discussed under the heading "Geology." Nearly all wells that penetrate this sand are reported to show strong gas pressure with salt water immediately below. During 1913 the Arkansas Natural Gas Co. finished a gas well in this sand which had a capacity of 18,000,000 cubic feet, and it is probable that other attempts will be made to develop this gas, especially in portions of the oil field where it is difficult to obtain enough gas for drilling and pumping operations. Some showings of low-gravity oil are reported in the Blossom sand, and one successful well is thought to derive oil from it, though in no other places have attempts been made to test the oil-bearing capacity of this sand. Wells located near the margin of the area where the formation contains gas should furnish favorable opportunities for determining the value of the oil showings.

WOODBINE SAND.

The Woodbine sand is the source of the high-grade oil in the Caddo field, and in many places there is sufficient gas to cause strong flows when the wells are first drilled. Locally, where conditions are especially favorable, large yields of dry gas are encountered in this formation, though when allowed to flow freely some of the gas wells soon yield oil. The depth to the oil in the Woodbine sand differs from place to place and in many parts of the field two or more producing sands are reported in the same or in different wells. In general it may be said that there are two fairly definite productive horizons, one about 225 to 275 feet below the top of the Blossom sand and another about 325 to 375 feet below the same datum. The variations from these depths are numerous and the exact depth of the oil sand in many wells is not determinable, because the drillings show so little sand as to give the impression that the oil comes from one or more of the numerous shale beds. The small quantity of sand is due to the fact that the well is finished near the top of the sand. In many places wells of this kind yield a large quantity of oil for a short time. The approximate depth from the surface to the oil sand can be obtained at any point on the map by adding 225 to 375 feet to the elevation of the surface above sea level plus the depth of the Blossom sand below sea level. It is not known whether extreme depths of 500 to 550 feet below the top of the Blossom sand indicate local lenses of oil-bearing sand below the principal horizons or whether the figures given are erroneous.

A still deeper sand than those mentioned in the foregoing discussion is shown by the logs of some wells, but its capacity for producing oil has not been adequately tested. It was probably this sand that supplied some oil of surprisingly low gravity in the Standard Oil Co.'s Barlow No. 1. The low gravity may have been due to a loss of volatile constituents as a result of flowing through a large volume of warm salt water, and it is to be hoped that this horizon will be more thoroughly tested at localities where the structure is favorable with the salt water from the higher sands excluded.

The porous beds in the Woodbine sand are very irregular in distribution, and a few detailed sections have been selected to show their relations.

Detailed sections of parts of the Woodbine sand.

No. 1.

	Feet.
Rock	5
Shale and sand	2
Hard sand showing oil	21
Shale	11
Gumbo	14
Shale and oil sand	40
Shale	12
Gumbo	5
Sandrock showing some oil	17
Sandrock	14
Packed sand	6
Shale	2

Successful, nonflowing.

Detailed sections of parts of the Woodbine sand—Continued.

No. 2.

	Feet.
Gumbo and shale	24
Shale	11
Gumbo	16
Hard shale	24
Hard gumbo	22
Gumbo and shale with some sand	39
Hard sandy shale, in part red	27

Flowed by heads.

No. 3.

	Feet.
Shale and gumbo	42
Shale	20
Sandrock showing oil	4
Shale and sandrock	5
Shale and gumbo	40
Sandrock	1+

A good well.

No. 4.

	Feet.
Gumbo	15
Gumbo and shale	3
Black shale	6
Hard shale	19
Shale showing light oil and gas	10
Shale	5
Pink shale	10
Hard shale	4
Rock	1
Hard rock	2
Rock	3
Oil and gas sand	10
Shale	5
Rock showing oil	11
Hard rock showing oil and gas	4

No. 5.

	Feet.
Gumbo	10
Rock	1
Sandy shale showing oil	80
Hard gumbo	17
Hard shale	10
Oil sand showing a little oil	12
Limerock	13
Hard shale	10
Rock	4
Sandrock	9
Sand and shale showing oil and salt water	12
Gumbo	8
Rock	6
Hard shale	15
Gumbo	9

No. 5—Continued.

	Feet.
Shale with layers of rock	9
Gumbo	6
Hard shale	19
Rock	1
Brown shale	15
Rock	2
Brown shale	16
Rock	2
Sandy shale	18
White rock	3
Blue shale	10

A salt-water well.

No. 6.

Top of section 255 feet below top of Blossom sand.

	Feet.
Hard shale	11
Rock showing gas	5

Top of this sand 266 feet below top of Blossom sand.

	Feet.
Hard sand	14
Soft rock and shale	15
Hard black shale	12
Soft shale and rock	72
Hard gas rock	3

Top of this sand 383 feet below top of Blossom sand.

	Feet.
Hard slate and rock	14
Soft shale showing oil	15

Top of this sand 410 feet below top of Blossom sand.

	Feet.
Rock and hard shale	47
Soft shale	4
Hard shale and rock	4

No. 7.

Top of section 135 feet below top of Blossom sand.

	Feet.
Gumbo and shale	40
Hard thin laminated shale	23
Shale	56
Hard shale	43
Shale	92
Pink shale	6
Rock or hard shale	2
Pink shale	4
Gumbo	3
Soft rock or shale	2
Shale	65

Detailed sections of parts of the Woodbine sand—Continued.

No. 8.

Top of section 214 feet below top of Blossom sand.

	Feet.
Shale and gumbo	69
Gumbo	15
Shale and packed sand	25
Shale	13
Shale and packed sand	62
Rock	3
Shale	20
Sand and pink shale	20
Oil sand, top of which is 441 feet below top of Blossom sand	10

No. 9.

	Feet.
Hard shale, top of section 283 feet below top of Blossom sand	72
Shale, top of which is 355 feet below top of Blossom sand, small showing of oil	17
Red shale	7
Gray and red shale, salt water 379 feet below top of Blossom sand	18

ACCUMULATION OF OIL AND GAS.

CONDITIONS OF ACCUMULATION.

When the occurrences of oil and gas were first investigated, it was found that their distribution was in many places closely related to the geologic structure. The anticlinal theory of oil and gas accumulation resulted from the attempt to explain this relation. This theory was presented to explain the occurrence and relations of oil, gas, and salt water as actually observed in oil pools, and according to it the gas, the lightest substance, is present in the upper part of the anticline; the next heavier substance, the oil, lies below the gas, and beneath the oil is salt water. According to the theory these substances were originally mixed together, and subsequently separated and arranged themselves in the order of their specific gravities.

Nothing was said as to the condition of the water, whether it was under hydrostatic conditions (stationary) or under hydraulic (moving). The important points in the anticlinal theory were that the gas, oil, and salt water were originally mixed together in a porous formation, and that their separation and arrangement in their present positions, with existing relations, was due to their relative weights. This relation is the one which exists where the conditions are ideal—that is, where all the factors governing accumulation are equally balanced.

More recently detailed studies of oil and gas fields have disclosed the fact that the ideal conditions described above are not invariably present, and experimental investigations[1] have thrown doubt on the power of gravity alone to cause the separation of the substances in such porous sands as are found in oil fields. It may be impossible to arrive at a safe conclusion, based on a few months' laboratory observations, concerning the action which might take place in deeply

[1] Munn, M. J., Reconnaissance of the Grandfield district, Okla.: U. S. Geol. Survey Bull. 547, pp. 78, 79, 1914.

buried sands during long geologic ages. However, the conclusion that the water has been under hydraulic conditions is sound and will hold for any extensive sheet of water occupying porous beds, for otherwise all water found in sands of marine origin would be salt. No doubt the folding of water-bearing beds may cause circulation of the water, but unless the folds are lifted above the saturated area where water enters the porous beds the effect of folding will be slight. Probably the chief movement of the water caused by deformation will be away from the folds because of the shortening of the beds as a result of the pressure that caused deformation. This shortening is accomplished by forcing the particles of the deposits close together, thus diminishing the size of the openings between them, and if the formations are saturated with water some of it must be forced out when the size of the openings is reduced.

Wherever there is an opportunity for water to escape from sands at some distance below the intake hydraulic conditions will prevail. This permits the forward movement of water from the place where it enters the ground to the place where it escapes from the sand. The motion of the water under such conditions is caused by gravity and capillarity, and its rate will be controlled by the general slope of the bed, its porosity, and the rate of escape of water from the bed farther down the dip. Variations in the rate of movement in different portions of the same bed will be caused by changes in the porosity and local variations in the altitude of the bed. Wherever there is lessened porosity, as where the sand becomes finer or is replaced by clay, moving water will be retarded and it may also be checked by folds. In such situations as this oil and gas are found, though no extensive accumulations of oil or gas against obstructions on a uniform dip away from the outcrop (see fig. 2, p. 28) have ever been recorded, which suggests that gravity is in reality an important factor in accumulation.

ACCUMULATION IN THE CADDO FIELD.

In the Caddo oil field the rocks appear to be everywhere saturated, so that no extensive dry sands are encountered, and the oil and gas pools occur in intimate relation to structure with barriers, such as relatively dense impervious layers or lenses of fine sand or clay, forming an important element in the Woodbine sand. The oil and gas are thought by the writer to have reached their present positions under the influence of gravity and capillarity, which produced motion of the oil, gas, and salt water and influenced their segregation. The rate of movement was doubtless slow, though probably at some periods it was much more rapid than at others.

NACATOCH SAND.

The conditions in the Nacatoch sand approach the ideal in spite of the numerous dense layers in that formation. In consequence exploitation has shown definite relations between anticlines and the distribution of oil, gas, and salt water, though the volume of gas and oil causes the oil to extend down to the bottoms of some of the shallow synclines. The only exceptions to uniformity of distribution of these substances are due to the existence of minor anticlines and synclines superimposed on the major folds. Nowhere in the field has the exploitation been carried completely around any of the major folds, but the north and west sides have been productive wherever prospected. Some territory that may yield oil still remains on the west and northwest sides of the folds. It is problematic whether the east and south sides of the folds will supply oil from this formation, except east of the Monterey uplift and the Mason anticline. The general dip of the beds and consequently the direction of circulation of water is southeastward from the outcrop of the formation in northeastern Texas and southwestern Arkansas. This would afford the most favorable conditions for accumulation of oil on the north and west sides of the anticlines but not necessarily on the opposite sides. However, the success of wells east of the Mason anticline and the Monterey uplift should encourage drilling south of the Vivian anticline, especially near the western end. Somewhat less promising conditions may be expected south of the Caddo Lake anticline, and the territory south of the western end of this fold may afford better opportunities than that farther east. The least promising territory for oil in the Nacatoch sand is south of the east end of the Caddo Lake uplift.

The exploitation of the gas in the Nacatoch sand has been distributed generally over the uplift, though probably more intensive development operations will yield returns within the oil-producing territory on minor anticlines where the sand is relatively high. The Mason anticline is highest in the NW. ¼ sec. 4 and the SE. ¼ SW. ¼ sec. 33, where the surface of the sand is reported to be less than 730 feet below sea level. The apex of this fold appears to be more favorable for the accumulation of gas than elsewhere on the west side of Jeems Bayou, and if the information concerning the sand in that locality is correct it would warrant drilling for gas in the Nacatoch.

ANNONA CHALK.

The source of the oil in the Annona chalk is problematic, but the most credible explanation of its presence is that it has risen from below along fissures and either accumulated in porous beds or in crevices in the chalk. The large wells as a rule contain considerable gas and flow vigorously for a few weeks, but the yield soon declines. Opposed to this theoretic explanation of the source of the oil is the fact that its specific gravity is lower than that of the oil found in the underlying formations. However, this condition may possibly be explained by the relief in pressure as the oil passes upward to the chalk, which permits the separation of the lighter constituents to form gas. The general parallelism of structure lines with the distribution of the chalk wells near Caddo suggests that in that place there may be fissures which afford opportunities for the oil to migrate from the older beds into the Annona chalk. The erratic occurrence of oil in the Annona chalk, together with the short life of the wells, has discouraged attempts at exploitation, for the few successful wells do not counterbalance the large number of failures.

BLOSSOM SAND MEMBER OF EAGLE FORD CLAY.

The conditions governing the accumulation of oil and gas in the Blossom sand are more complicated than in the Nacatoch sand, because the Blossom contains more extensive shale beds and is less uniform in texture than the Nacatoch. The shale beds and dense layers in the Blossom sand would interfere with the free movement of gas and fluids, and their distribution may therefore be somewhat irregular. However, the meager information available indicates that the high anticlines would be favorable places to drill for gas in this sand. Oil should be sought near the margin of areas where gas is reported and where showings of oil were encountered in drilling wells to the Woodbine sand.

WOODBINE SAND.

The porosity of the Woodbine sand is so variable that the distribution of oil and gas in the formation is very irregular. This is shown by the partial logs of wells previously given (pp. 49–51) and by the relations of small and large wells, for in many places where wells are only a few hundred feet apart one may have a natural flow of several thousand barrels, whereas those surrounding it and only a few hundred feet away may yield only a few barrels when pumped. There are also marked differences in depths to pay sands and in the depth of salt water sands in wells located close together. Doubtless the connection between the lenticular sands is interrupted in many places by increase in density, but in other places the beds are so discontinuous that oil sands are separated by relatively impervious shales. Under such conditions the accumulation of oil and gas, though in a general way controlled by structure, is influenced by the obstructions to free movements of the gas or liquid through the sand. It is, for example, probable that the wells in sec. 4, T. 21 N., R. 16 W., owe their success to some obstruction to free movement in a general southeasterly direction. The obstructions in that part of the field may be formed either by a change in the porosity of the sand or a local diminution in its rate of dip of such magnitude that the circulation of liquid through the sand is retarded. Doubtless the distribution of other small pools is controlled in part by obstructions and in part by the existence of minor changes in the dip of the petroliferous sands.

Under the conditions that exist in the Woodbine sand the gas does not all gather at the top of the anticline, as in the Nacatoch sand, but occurs in different places, though it is present in large volume only where the structure is especially favorable, as on the higher anticlines. Both gas and oil are found in the local pools on the slopes of the major anticlines where movement up the slope of the uplift is checked by obstructions such as relatively impervious beds or minor flexures or both.

Under the conditions outlined above exploitation is necessarily hazardous, and structural studies can furnish only the general outlines of the oil pools. Drilling within a pool is uncertain, because the local variations in porosity and dip can only be determined by that method, and where such changes are abrupt the success of one well gives very little clue to the best location for the next. In considering wildcat territory the structure is, however, of primary importance, because only on the crests or borders of uplifts has any considerable volume of oil and gas been found, and only in these localities is it to be expected. The productive part of the uplift will differ in different localities with the height of the structural features, the character of the formation, and the amounts of oil and gas. In many places the structure can be determined by geologic studies, but the other conditions can only be learned by drilling. As a preliminary step the structural studies of the geologist would probably increase the chances of successful selection of territory more than 75 per cent, and such investigations, when made with careful attention to details of structure, should increase the chances of success over 30 per cent in locating wildcat wells. However, it should be borne in mind that to approach these percentages of efficiency familiarity with the local stratigraphy, with the occurrence of oil in the region, and with their relation to each other is essential.

SOURCE OF OIL AND GAS.

THEORIES OF ORIGIN.

The complete discussion of theories of origin of oil and gas would require much greater space than can be given the subject in this report, but it is desirable to present the general principles of the subject. Two theories have been offered in explanation of the presence of petroleum within the earth: (1) That it is of inorganic origin; (2) that it is of organic origin. In support of the theory of inorganic origin, chemists cite the fact that oil can be produced in the laboratory by the combination of certain inorganic substances. The possibility that favorable conditions for similar chemical action exist deep within the earth furnishes a theme for speculation; but even if such chemical action is conceded a further difficulty is encountered, for in most oil fields free movement of either oil or gas from profound depths into the pay sands is prevented by relatively impervious beds of shale.

In the organic theory of origin processes of slow chemical change are considered to have converted organic matter either into oil or gas, or both. This theory is capable of considerable elaboration and has aroused much controversy as to whether the oil is of animal or vegetable origin. It may be noted here that the organic theory has this advantage—that the source of the oil is considered to be in the sand, or more probably in the formations intimately associated with the sand. This obviates the necessity of extensive migration of the oil and gas through great thicknesses of rock under conditions that in most places may be classed as unfavorable, if not prohibitive.

CADDO OIL FIELD.

The serious objection commonly raised against the theory of inorganic origin, that it is difficult to account for the oil having risen from great depths, is not insurmountable in the Caddo field. If the Red River fault, as described by Veatch, has had a movement of more than 600 feet, the break in the strata must extend to a considerable depth, and upward migration of oil along the fault plane would be possible. Migration of this oil from the fault plane laterally into the porous sands might occur, provided such a movement along the fault plane were once established. However, even if such a migration were proved it would not follow that the oil is of inorganic origin, for it might come from underlying sedimentary rocks.

In the Caddo oil field beds of carbonaceous shales are associated with the oil sands, and the organic matter in these shales and in the sands is a possible source of the oil and gas, and according to this theory the oil may have passed from the shales more or less directly into the sands under the influence of capillarity, gravity, or hydraulic pressure.

In the Nacatoch sand some organic matter existed, and a large amount was disseminated through the overlying Arkadelphia clay. Probably this clay was the principal source of oil, though some might come from beds in the underlying Marlbrook marl. The Blossom sand member of the Eagle Ford clay may have been supplied from layers of clay interbedded with the sand and from the underlying beds of the Eagle Ford clay, which carry a large quantity of organic matter. The overlying Brownstown marl was probably relatively unimportant. The Woodbine sand is shaly and very carbonaceous and may have supplied a large part of the oil found in the sands, though the Eagle Ford clay, and even the underlying Lower Cretaceous, are possible sources of oil and gas.

RELATIONS OF THE OIL AND GAS.

In another part of this bulletin the relative positions of the oil and gas in the producing sands are discussed (pp. 52–55), and it is proposed here to describe briefly the detailed relations and indicate some of the unexplained phenomena.

On the outskirts of the field, both north and west of the producing area, wells encounter small quantities of oil in the Woodbine sand. The depths to the sand are somewhat greater than in localities where successful wells are obtained, and there is a notable difference in the character of the oil. The color of the oil in these wells is commonly light green and the gravity is higher than that of the oil obtained from successful wells; there is also an absence of gas where this high-gravity oil is encountered.

Some differences have been observed in the quality of the gas from the two important producing horizons, the Nacatoch sand and the Woodbine sand. The odor and burning properties of the gases from these sands are unlike, the gas from the Nacatoch sand being practically odorless and the gas from the Woodbine sand having an odor of petroleum. The gas from the Woodbine sand, because of its higher content of hydrocarbons from petroleum, burns with a more pronounced yellow flame than that from the Nacatoch sand.

Practical tests recently made by C. C. Averill, field manager of the Standard Oil Co., have shown that gasoline can be extracted from the gas from the Woodbine sand. Gasoline was produced by subjecting this gas to a pressure of 500 pounds to the square inch and passing it through a coil cooled by water. The pressure used in this experiment is much lower than the rock pressure of the Woodbine sand, and not much greater than the initial rock pressure of 450 pounds of the early gas wells of the Nacatoch sand. It may be inferred that a lower temperature in the Woodbine sand would permit the condensation of the gasoline from the gas.

The gas from the Nacatoch sand did not furnish gasoline when it was subjected to a pressure of 500 pounds to the square inch and cooled in the same manner as that from the Woodbine sand. The oil from the Nacatoch sand is of low gravity and contains a relatively small percentage of the higher hydrocarbons. This fact, together with the absence of gasoline in the gas from the Nacatoch sand, suggests that there may have been initial differences in the quantities of some of the hydrocarbons in the Nacatoch and Woodbine sands.

The oil found in the Annona chalk and Nacatoch sands is of low gravity and is associated with large volumes of gas. Somewhat similar conditions may be inferred for the Blossom sand member of the Eagle Ford clay, where the oil showings are reported to be of low gravity, though the volume of gas in this sand has not been determined in many wells. Because of the small production, it has been impossible to compare the gas from the Annona chalk and the Blossom sand member of the Eagle Ford clay with the gas from the other sands.

POSSIBLE EXTENSIONS OF THE CADDO OIL FIELD.

The history of development in the Caddo oil field, characterized by many rapid fluctuations in the amount of production, has demonstrated that in many places valuable territory has existed where operators have thought the conditions unfavorable. No one familiar with the field can doubt that there is still much unexploited territory within the boundaries of the field, though the cost of drilling combined with the uncertain results, even in proved territory, should be taken into consideration before investing blindly in oil properties.

As noted by Harris,[1] there appears to be a broad syncline between the northern edge of the Caddo oil field and Texarkana (fig. 4, p. 34). This syncline carries the oil-bearing formations to a much greater depth than that in the oil field, and though minor flexures may be expected in the syncline it is somewhat doubtful whether they would supply enough oil to warrant drilling, even where showings might be obtained.

Veatch[2] has mentioned a large fault that extends in a general direction south of east into northwestern Louisiana and cuts across this syncline. This fault, as shown on Veatch's map, would follow approximately the course of Sulphur River. During the field work for this report it was not possible to make an examination of the region where the fault is shown on Veatch's map, and it should be noted that Harris's diagram (fig. 4) indicates no fault in that region. On the whole it appears desirable to examine further that part of the syncline to determine the structural features and what value

[1] Harris, G. D., Oil and gas in Louisiana, with a brief summary of their occurrence in adjacent States: U. S. Geol. Survey Bull. 429, p. 125, 1910.

[2] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 68, 1906.

they may have in connection with the occurrence of oil and gas in sufficient quantities to warrant drilling.

Since the preparation of Harris's report drilling has ceased in the syncline, as the results obtained do not seem to warrant further expenditure of money. On the west side of the Caddo field much less information is afforded by well logs than on the north side. It should be possible to extend the western margin of the field a short distance into Texas at places where the sands are high, and the trend of development has already carried the edge of the field a short distance beyond its location when the field work for this report was in progress. The most promising territory for development lies at the western ends of the major anticlines, such as those north of the Burr pool, a short distance south of this pool, and near the Atlas Oil Co.'s wells, and farther south in Caddo Lake and along its shores near the Texas-Louisiana boundary.

The pitch of the Caddo Lake anticline and of the minor anticlines that parallel it on the north and south has not been determined with sufficient accuracy to warrant a prediction as to just how far development may be successful. For this reason conservative progress can best be made by gradual extension toward the west, as in the recently located wells in and near Caddo Lake in Texas and the well of the Atlas Oil Co. just north of Caddo Lake in Louisiana. By this method it should be possible to determine the limits of the producing territory with a minimum expenditure of funds for dry holes. Since the Caddo Lake anticline is the highest in the field it may be expected to extend farther west from its apex than any of the other folds, but this does not necessarily mean that successful wells can be obtained beyond the Texas boundary, because the apex of this fold lies somewhat farther east than the apexes of other folds north of the lake.

Though the dip of the formations on this side of the field is toward the west, they rise again a short distance farther west and reach the surface in northern Texas. Little is known about the detailed structure of the region between the outcrop and the west edge of the Caddo field, however, and this is an area that is worthy of further study to determine whether there are other folds similar to those found in northwest Louisiana.

Harris[1] states that on the south side of the Caddo oil field there is a shallow syncline (fig. 4, p. 34) that occupies the territory between Mooringsport and Shreveport. The information then available would naturally lead a geologist to this conclusion; however, it is doubtful if this syncline continues throughout the distance between

[1] Harris, G. D., Oil and gas in Louisiana, with a brief summary of their occurrence in adjacent States: U. S. Geol. Survey Bull. 429, p. 127, 1910.

these two points. More probably there are other anticlines parallel to those at Shreveport and Mooringsport, though no great amount of success has been achieved by drilling in this region up to the present time. It is hoped that in the near future it will be possible to make a thorough investigation of the structure in this area to warrant drawing definite conclusions.

On the east side of the Caddo oil field drilling has been successful in the shallow (Nacatoch) sand at the east end of the Vivian anticline. There is still considerable territory on the east and south sides of this anticline that might warrant drilling for heavy oil. Farther south the most promising territory so far discovered is in the vicinity of Dixie, where some wells have encountered a fair amount of oil in the Woodbine sand. There is doubtless much territory between these wells and the pools at Caddo Lake that will prove valuable for oil.

East of Red River, in Bossier Parish, a number of wells have been drilled, and although small quantities of oil have been encountered and good thicknesses of oil sand are reported, none of the wells have been successful. From the meager information at hand concerning this area the most promising territory should be near the river and slightly north of east from the high structures of the field in Caddo Parish. The success of wells near the river will depend on whether the sands of the Caddo field continue high and are petroliferous. The absence of good exposures of the older geologic formations makes it impossible to determine the structure in the river valley, and the presence or absence of oil in the sands can only be ascertained by drilling.

Possibly some deep wells might be moderately successful near the eastern edge of the Sabine uplift, which is near the boundary between the Wilcox formation and the more ferruginous beds of the Claiborne formation. The approximate position of this boundary is shown on Plate XII of Bulletin 429. If oil is discovered near the contact of the Midway and Claiborne formations the pools will probably be small and the sands will be deeper than in the Caddo field.

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