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NATURAL GAS RESOURCES OF PARTS OF NORTH TEXAS

GAS IN THE AREA NORTH AND WEST OF FORT WORTH

BY

EUGENE WESLEY SHAW

GAS PROSPECTS SOUTH AND SOUTHEAST OF DALLAS

BY

GEORGE CHARLTON MATSON

WITH NOTES ON THE GAS FIELDS OF CENTRAL AND SOUTHERN OKLAHOMA

BY

CARROLL H. WEGEMANN

Work done in cooperation with the cities of Dallas and Fort Worth

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INTRODUCTION.

By David White, Chief Geologist.

The citizens of Dallas and Fort Worth, numbering about 210,000, owe their prosperity in no inconsiderable degree to the supply of natural gas which, during the last 6 years, has contributed materially to their household comfort and industrial advantage. Dallas and Fort Worth utilize, for heat and power, natural gas piped from the Petrolia gas field, near Red River, in northern Clay County, about 105 miles northwest of Fort Worth. The gas is brought to the city limits by a producing company and is distributed within the cities by local organizations.

Confronted by questions as to the sufficiency and the prospective duration of the gas reserves, in view of the rapid increase in gas consumption, the mayors and city governmental commissions of these cities, in order to promote the welfare of the citizens, began inquiries as to the extent of the present source of supply and as to the existence of other sources within reach of these cities. The information sought should be available for their guidance in determining just and reasonable rates to be fixed in future franchises. In accordance with this purpose, the United States Geological Survey was, on the initiative of Mayor Henry D. Lindsley and the city of Dallas, requested to investigate the gas resources of the region tributary to that city. Favorable consideration being given by the Director of the Geological Survey to the request for a service so distinctly public, a conference of the city officials and the chief geologist of the Survey was held at Dallas, September 7, 1915, in which Mayor E. T. Tyra and other representatives of the governing muncipal commission of Fort Worth participated.

At this conference it was arranged that the Geological Survey should make an investigation of the gas resources of the Petrolia field, in Clay County; of the Mexia field, in Limestone County, the utilization of which by these cities had been under local discussion; and of such other areas within reach of the two cities as might possibly contribute, on a successful commercial scale, to meet adequately the eventual demands for natural gas. The two cities jointly pledged the greater part of the cost of the field examinations, thus making the investigation cooperative. The Survey undertook to investigate the resources of the gas fields mentioned and to examine the geologic structure, as far as it affects oil and gas, of so much of the area tributary to Dallas and Fort Worth as might be surveyed with the funds allotted and within the time available before January 1, 1916, when the conclusions of the geologists were to be communicated simultaneously to the mayors and to the public, according to the Survey's usage. Geologists G. C. Matson and E. W. Shaw were assigned to the investigation of the regions southeast and northwest, respectively, of Fort Worth, and within a few days after the conference geologic examinations were begun by Mr. Matson in the Mexia field and Mr. Shaw in the Petrolia field.

Besides the detailed studies of the geologic structure and gas resources of the two principal gas fields already discovered in the zone tributary to the cities, reconnaissances were made of several counties and local structural studies were made at a number of points where either gas had been reported or the surface indications or geologic structure were found, in the course of the reconnaissances, to be favorable to the occurrence of pools of oil or gas. Such local studies were made along Wichita River and near Henrietta, in Clay County; near Benbrook, in western Tarrant County; and both north and south of the Mexia-Groesbeck gas field, at Wortham, Currie, Mabank, and Cash, along the general trend of the axis of the anticline. The geographical relations of the regions studied in detail are shown on figure 1, which shows also the areas covered by previous reports.

After the return of Messrs. Matson and Shaw to Washington, in November, for the purpose of compiling their field data and preparing their reports, field examinations were continued by Heath M. Robinson, assisted by C. W. Hammen, in the vicinity of Strawn and Weatherford. At the same time a structural survey of the Corsicana field was made by O. B. Hopkins. Time is not available for the inclusion in the present report of the detailed description, with structure maps, of any of these areas, but a map and short description of the Strawn field are given.

Meanwhile, in order better to advise the cities as to the possibilities of augmenting the city supplies, if the need should arise, by gas drawn from the southern border zone of the east-central Oklahoma oil and gas region, the examinations of 1914 in the Loco and Duncan[1] gas pools were supplemented by brief field inspections and some local studies by C. H. Wegemann of the gas developments resulting from recent drilling south of Muskogee and westward to and beyond

[1] Wegemann, C. H., The Loco gas field: U. S. Geol. Survey Bull. 621, pp. 31–42, 1915. The Duncan gas field: U. S. Geol. Survey Bull. 621, pp. 43–50, 1915.

Ada. The importance of the developments, the distribution of the gas wells, the probable life of the wells, and the probabilities of further discoveries of gas in large quantities in this zone are discussed

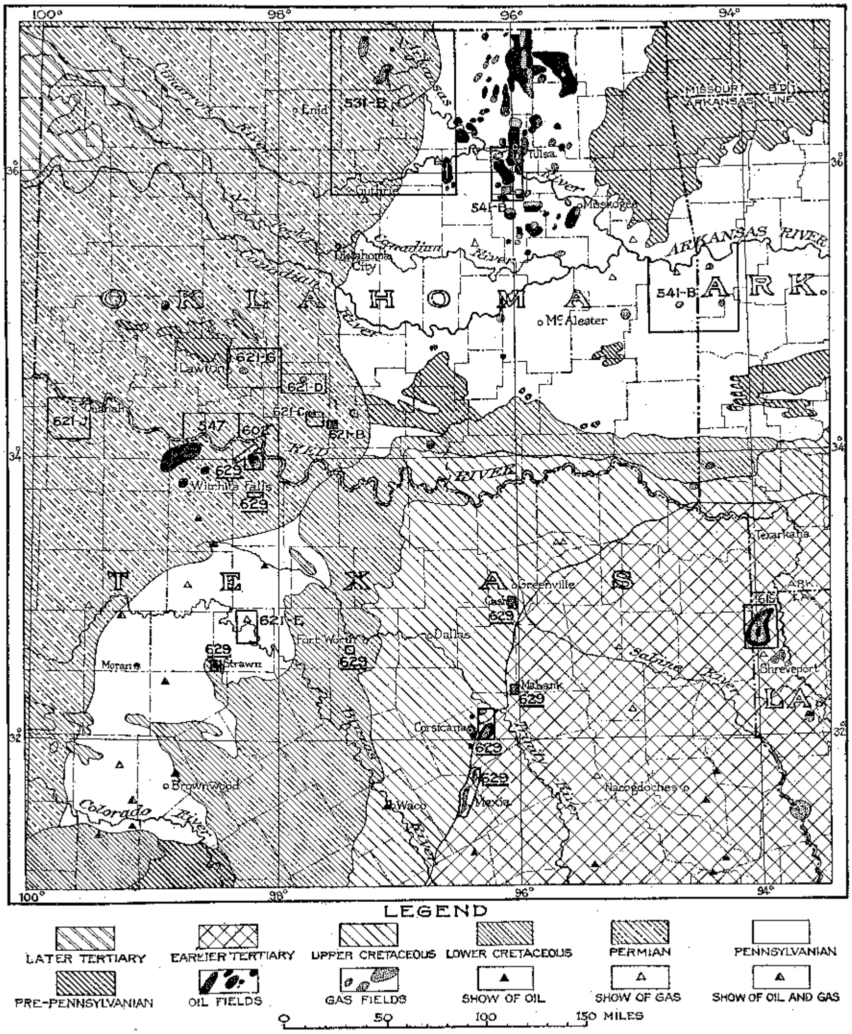

FIGURE 1.—Index map showing oil and gas fields and areal geology in parts of Texas, Oklahoma, Arkansas, and Louisiana. The rectangles marked with numbers indicate areas recently surveyed and the numbers of bulletins of the Geological Survey describing them.

in the notes by Mr. Wegemann. A detailed report by him covering parts of the area will be published later.

In undertaking this investigation, the Survey has endeavored to answer the following questions:

How much gas are the developed fields within reach of Dallas and Fort Worth capable of producing now?

How much gas remains in the developed pools and how long will this gas last, if marketed at an estimated rate?

Is it likely that the area of any or all of the fields will be increased?

Is it likely that new producing sands will be found in any of the fields?

What quantity of gas, within broad limits, is likely to become available through enlargement of existing fields?

Are new fields likely to be discovered; and if so, where?

The conclusions offered in reply to each of these questions represent the experience and judgment of the geologists in charge of the work and are based upon such local studies and information as could be gained within the time allotted. However, the answer to the last question, which is destined ultimately to become first in importance, is only partial, notwithstanding the efforts still in progress at the time of writing this report. If Petrolia be taken as marking the maximum distance (which it does not) within which natural gas can be regarded as tributary to Dallas, the area lying within that radius will include the whole of about 35 counties and the greater part of 6 or 7 others. The impossibility of covering all this area with detailed structural examinations under the conditions as to time and money controlling the present investigation is obvious. To cover even one-fourth of this region within a single year would require far more than all the funds which the Geological Survey has available for such investigations. Nevertheless, the fact is most regrettable; for it is highly probable, if not certain, that within this zone, especially within its western half, there will eventually be found pools of both gas and oil, some of which may possibly be as productive as the Petrolia and Corsicana fields. The value of such examinations and structural studies can not be questioned, for, though it must always be borne in mind that only the drill can determine with certainty the location of oil and gas pools, the geologist, by making structural surveys, can not only render invaluable aid in finding the pools but can also reduce, with still greater economic benefits, the losses incurred in drilling dry holes.

The Survey's examination of the gas resources contributory to Fort Worth and Dallas is purely geological, dealing exclusively with the structure of the areas, the amounts of gas already produced, the probable amounts still reserved in the old fields, and the probabilities of discovering new pools sufficient to maintain an adequate supply of gas for these cities for the next decade or more. Questions concerning drilling, field equipment, repairs, transportation, marketing, amortization, and like matters are left to the mining and other engineers and the business experts, and so also is the serious question of the effect on supplies and prices that may be caused by the competition of Wichita Falls, Waco, Dennison, Gainesville, Sherman, and other cities that may, by reason of more favorable geographic position or by bidding higher, take to themselves a part of the reserve here counted as contributory to Dallas and Fort Worth.

Although the subject of this study touches a matter in which there is local conflict of views, if not of interests, the Survey is concerned only with the problem of ascertaining the adequacy of the gas resources, both developed and undeveloped, in the tributary region.

The thanks of the Survey are due to the gas companies and to all parties interested for cordial and generous submission of data for use in this investigation, which, so far as it assists in ascertaining the extent of the gas deposits already found or in discovering new oil or gas reserves, will be of value to all. In Dallas and Fort Worth and their immediate vicinity the city officials and also Hon. H. W. Sumners, State Senator Bowser, and R. H. Dearing & Sons contributed or put the geologists in touch with those who could contribute many data concerning wells and outcrops. Mr. J. W. Culbertson, of the Wichita Gas Co., in the northern area, was generous in furnishing information concerning the Petrolia field, and Mr. W. P. Gage, vice president and general manager of the Lone Star Gas Co., has courteously contributed not only logs of wells but records of pressures and production. Mr. H. L. Sturm,
Oil Co., and many others assisted in collecting well logs and other
Mr. L. R. Hammond, Messrs. Bean and Gohlke, of the Developers
data. Special acknowledgment is due to Mr. W. E. Wrather, an authority on the geology of many counties in north Texas and long a student of oil and gas problems, who has rendered unstinted assistance in the study of the northwestern part of the area.

For assistance in the work in the southern half of the area examined the Survey, through Mr. Matson, is especially indebted to a large number of citizens who have in many ways given generous assistance and information. Among those to whom special acknowledgments are due are Hon. T. F. Smith, President Wilder, of the Little Giant Oil & Gas Co.; President Nussbaum and Superintendent Anderson, of the Mexia Oil & Gas Co.; Superintendent Faulkner and Local Manager Whitehill, of the Corsicana Petroleum Co.; Mr. F. G. Clapp, manager of the Associated Geological Engineers; Mr. N. E. Ritchie, manager of the Pleasants Gas Co.; and Messrs. Blake Smith, J. T. Leech, T. Bennett, and Robert Jones, of Mexia, Tex.; Mr. C. Y. Welles, of Tulsa, Okla.; and Mr. C. L. Witherspoon, of Corsicana, Tex.

In estimating the quantity of gas, not only in partly developed but in newly discovered fields, the geologists were guided by no precedents known to them, but each, independently of the other, devised the same method of computation. It now appears, however, that a similar method had been used by W. H. Hammen and F. H. Olyphant and had been described by Dorsey Hager.[1] Naturally any estimate of undeveloped territory must start with the study of the underground structure considered with reference to the occurrence of gas, oil, and salt water, and with the mapping, according to the best geologic information, of areas that are probably gas-producing. Starting with this primary basis, Messrs. Matson and Shaw independently worked out the plan of utilizing for the calculation of the extent of a gas pool the geologist's determinations of the average thickness of the gas-bearing sand, the average percentage of pore space in the sands, and the pressures of the gas in the rocks. The results attained are necessarily only approximate, and factors that affect them are discussed by Messrs. Matson and Shaw in their respective papers.

The detailed conclusions reached by the geologists, together with the discussion of the geologic and economic facts, will be found in their reports. Great credit is due to both geologists for the extent and value of the results they have accomplished under conditions that made the preparation of reports, within a period all too short, especially trying.

The answers to the questions as to the extent of the reserves of natural gas in north Texas, so far as they are answered in these reports, may be summarized as follows:

1. The Petrolia field, according to Mr. Shaw's calculations, is about 40 per cent exhausted and now contains 70 billion cubic feet of gas. Although the closed pressures of the wells have declined more than half in the producing area, the field can for a time furnish a much larger monthly and somewhat larger daily output than the maximum it has heretofore been called upon to furnish. Any increase of output, of course, will correspondingly shorten the life of the pool. Taking into account all the factors discussed by Mr. Shaw, the gas reserve in this field is sufficient to meet the normal demands of the cities for three to five years longer, though shortages in cold weather will probably be felt much sooner. After this period the supply, if divided among all the towns drawing on this field, is likely to prove insufficient in winter, even though the field is thoroughly drilled and pumped to the limit of its capacity.

2. The Mexia-Groesbeck gas field, which has been looked upon with the greatest interest as a possible source of supply for Dallas

[1] Hager, Dorsey, Natural gas—its occurrence and properties: Eng. and Min. Jour., vol. 100, No. 24, pp. 959–961, Dec. 11, 1915.

and Fort Worth, is stated, after a thorough and careful study by Mr. Matson, to have an open-flow capacity of 220 million cubic feet a day at the present time. Mr. Matson concludes that, after most unfortunate waste and coincident damage to this field, there remain 31 billion cubic feet of gas (equal in heating value to 43 billion cubic feet of Petrolia gas), of which over 95 per cent may probably be extracted before the closed pressure is reduced to 15 pounds per square inch. The stage of development and the gas pressure in this field are sufficient to supply Dallas and Fort Worth, in addition to the five towns, including Waco and Corsicana, to which gas is now taken from the area, and the quantity is probably sufficient to meet the total normal demand of all these cities for about 3 years provided means can be found to check the present waste, the exact length of period being dependent in turn on economy of marketing, prices, and rates of consumption. Therefore, the practicability of utilizing Mexia-Groesbeck gas in Dallas and Fort Worth is an engineering and economic problem in which the cost to the consumers may be affected by competition between cities.

3. The smaller gas pools of the region tributary to Fort Worth and Dallas, so far as they have been developed or explored, are individually insufficient to supply these cities for any considerable time. None appear to be comparable to the two principal fields already mentioned, but combined they are capable of furnishing a large though at present indeterminable accession. The practicability of assembling the output from these minor scattered fields and conducting it to the two large cities is mainly dependent on equipment costs and selling prices and remains for the consideration of the engineer. Some of these lesser pools lie much nearer than the Mexia-Groesbeck and the Petrolia fields to these cities. If the gas in the better of them can be conserved it will eventually find a profitable market.

4. Besides the scattered oil and gas seeps in the area and the favorable local structures discovered by the geologists in the relatively small portions of the tributary zone they were able to examine thoroughly during the time available, there are in this zone undoubtedly many other areas beneath which the geologic structure is favorable. Not all of these areas by any means will be productive, but some may include gas or oil pools as valuable as the Mexia-Groesbeck, the Corsicana, and the Petrolia. Some of the favorable structures will contain oil, others gas, but more will yield both oil and gas.

5. Near the southern border of the Oklahoma oil fields, according to preliminary examinations made by Mr. Wegemann, gas occurs in amounts sufficient to furnish a supply for Dallas and Forth Worth for a considerable period, though the number of years can not at present be closely calculated. Gas pools of magnitude, as well as many very highly productive scattered wells, have already been discovered,

and the progress of development is constantly increasing the amount of gas in sight, for which there appears to be no present market. Further, it is probable that gas deposits of commercial value will later be found at other points in this region. The utilization of this gas at the present time, in amounts large enough wholly to supply these cities, would probably require branch lines to rather distant pools, and these, together with a long carry to delivery—about twice the distance from Petrolia to Fort Worth—are important factors in the problem of present commercial practicability. It must, however, be borne in mind that, should the need arise, here is to be found a supply that, in spite of its remoteness, is geographically tributary to these cities and will probably be needed later by them unless meanwhile exploration is vigorously prosecuted and new pools thereby found in the nearer zone in Texas.

The cities of north Texas are fortunate in having within reach gas supplies so abundant as to add materially to the comfort and prosperity of their citizens and still more fortunate in their prospects of developing from time to time new supplies in regions relatively close at hand. Nevertheless it is a public duty that may not transgress the propriety of a geological report to urge that a lesson be learned from the history of other cities which have had like resources of natural gas, namely, the lesson of conserving and husbanding this so ephemeral gift of nature for the higher service of the household rather than spending it too freely in industrial promotion.

Too high praise can not be found for the wisdom and progressive spirit shown by the mayors and city commissions of Dallas and Fort Worth in arranging for this investigation of the gas resources tributary to their cities. The wisdom of their action is in contrast with the records of extravagance, waste, and ultimate disappointment of some cities which for a time have enjoyed a cheap natural gas supply. These investigations, provided by the Texas cities, may guide not only to the fullest and best use of the discovered resources, but also, in particular, to the probable discovery and development of new reserves which will bring benefits to the cities that will be realized more and more in years to come.

GAS IN THE AREA NORTH AND WEST OF FORT WORTH.

By E. W. Shaw.

GEOGRAPHY.

Location and general character of the area.—The area covered by this report on the gas resources north and northwest of Fort Worth, Tex., extends from Dallas, Fort Worth, Weatherford, and Strawn northward to Red River. The region is one of rolling prairie, brushy hills, and forests. Some parts, such as that at Montague, underlain by the thick Trinity sand, and that at Palo Pinto, underlain by hard limestone, are rough; other parts, such as the broad divides underlain by shale in Clay County, are nearly flat. The general altitude ranges from 500 or 600 feet near Dallas to 1,400 or 1,500 feet near Palo Pinto, and the highest hills nearly reach 2,000 feet.

In the two months available for the field work most of the area was at least briefly inspected and certain districts were surveyed in detail. The districts to which most attention was given were those which the information in hand or that obtained by the inspection showed to be worthy of immediate attention. Further geologic study may show that other areas are more promising or important than any of these except perhaps the Petrolia field, which is the greatest gas field thus far developed in Texas. Plane-table surveys were made of several areas where outcrops are good in the hope of finding structural features (anticlines and domes) favorable to the accumulation of gas. One of these areas forms a belt along the south side of Wichita River between Red River, east of Byers, and Wichita Falls. Another is in the vicinity of Henrietta.

Supplies and markets.—The commercial geography pertaining to natural gas in the area examined concerns principally the relation of the developed oil and gas fields to markets. The region under discussion lies near the middle of the west side of the great south-central oil and gas region of the United States. The oil and gas fields of Oklahoma lie to the northeast, and beyond them are the gas fields of southeastern Kansas. A hundred and fifty miles east of Dallas are the Caddo, De Soto, and Red River oil and gas fields, and to the southeast and the south are the scattered Gulf coast fields of Louisiana and Texas. Dallas and Fort Worth, which have a combined population of over 200,000, are the largest cities close to the area examined and constitute the largest market for gas. Also, the areas described in this report and the accompanying report by Mr. Matson are the nearest proved or probable gas regions to these cities, and the ones to which they naturally look first for supplies. Other gas-bearing areas are, however, within reach of Dallas and Fort Worth, the most productive being the gas fields of Oklahoma and those in the vicinity of Shreveport, La., though it is doubtful whether the supply of gas near Shreveport is sufficient to warrant the investment necessary for its transportation so far.

AREAL GEOLOGY AND STRATIGRAPHY.

As indicated in figure 1, the geologic formations outcropping in most of this region belong to the Carboniferous and Cretaceous systems. These systems are made up of several series and formations, each of which has its own peculiar kinds and associations of fossils—the remains and imprints of plants and animals that lived at the time it was laid down—by which, as well as by certain other characteristics, it may be recognized. The Carboniferous system, so called because it is the source of a large part of the world's output of coal, is made up of three parts known as the Mississippian, Pennsylvanian, and Permian series. The lowest of these series, the Mississippian, is not exposed in the region examined and has not been reached in many wells. The Pennsylvanian series, next higher, consists mostly of sandstone, bluish shale, thin limestones, and coal beds. It is buried under the Cretaceous along Red River, but it outcrops farther south, beginning near Bowie, and the area immediately underlain by it extends southwestward for 150 miles to Colorado River, gradually becoming wider. All the rocks seen in the vicinity of Mineral Wells, Eastland, and other towns south and southwest of Bowie belong to this series.

The Permian series crops out in an extensive belt that lies just west of the Pennsylvanian area. The principal differences between the Permian and the Pennsylvanian series are that the Permian rocks include little coal and consist largely of red shale. This series is widely known as the "Red Beds," for in most of the areas of its occurrence throughout the world it embraces great amounts of red shale and sandstone. The Permian and the underlying Pennsylvanian have yielded a large part of the oil and gas produced in northern Texas and practically all that is produced in Oklahoma and Kansas. Beds of both these series are also great oil and gas producers in West Virginia, where the Permian contains much less red rock. The Mississippian also yields a great deal of gas and oil in Pennsylvania, Illinois, and other States, and the Carboniferous system is thus the most prolific source of fuels in the United States and probably the most prolific in the world.

Along Red River the lower part of the Permian contains very little limestone or gypsum; the middle part, which outcrops in the vicinity of Electra and Vernon, includes several thin beds of limestone and very little gypsum; and the upper part in areas farther west contains much gypsum. The proportion of limestone in the Permian rocks increases toward the south.

The Cretaceous system contains the oil and gas pools south of Dallas. This and the overlying Tertiary system are the principal sources of gas and oil on the Gulf coast, in California, in Wyoming, and in Colorado, and of coal in the Rocky Mountain States.

The Cretaceous system is made up largely of rather persistent and thick beds of whitish limestone, bluish shale, and poorly consolidated sandstone. Some beds of the limestone, such as those at Weatherford, are so fossiliferous as to be generally called shell rock, and still others, such as those at Benbrook, are hard and brittle. The Cretaceous sandstones consist of little but grains of quartz and are open and porous. Several are sources of water. The Cretaceous rocks contain gas at Corsicana, Mexia, and elsewhere, as is stated by Mr. Matson in his part of this report. The succession of rocks is shown by the following well log:

Log of well at Southern Methodist University, 4 miles northeast of Dallas, Tex.

[See Pl. VII, p. 78.]

	Thickness.	Depth.
Cretaceous system:		
Austin chalk:	*Feet.*	*Feet.*
Soil	6	6
White rock	159	165
Eagle Ford clay:		
Shale	10	175
Limestone	2	177
Shale	44	221
Limestone	6	227
Shale	23	250
Limestone	4	254
Shale	91	345
Limestone	3	348
Shale	10	358
Shale and bowlders	50	408
Gumbo	65	473
Blue shale and bowlders	55	528
Gumbo and bowlders	32	560
Shale and limestone bowlders	49	609
Gumbo and blue shale	63	672
Woodbine sand:		
"First Woodbine sand"	21	693
Limestone, hard	9	702
"Second Woodbine sand"	18	720
Shale	9	729
"Third Woodbine sand" and limestone bowlders	12	741
Gumbo	10	751
Limestone	15	766
"Fourth Woodbine sand"	18	784
Shale and water sand	16	800
Gumbo	15	815
Sand	12	827
Shale	21	848

Log of well at Southern Methodist University—Continued.

	Thickness.	Depth.
Cretaceous system—Continued.		
Woodbine sand—Continued.	*Feet.*	*Feet.*
"Fifth Woodbine sand"	32	880
Shale	18	898
Limestone shell	4	902
Shale	33	935
Broken limestone and "sixth Woodbine sand"	12	947
White rock and water sand	42	989
"Seventh Woodbine sand"	9	998
Washita group:		
Shale	32	1,030
Gumbo	14	1,044
Limestone	14	1,058
Gumbo	5	1,063
White rock	29	1,092
Limestone	22	1,114
"First Weatherford limestone"	25	1,139
Limestone	11	1,150
Gumbo	22	1,172
Limestone	7	1,179
"Second Weatherford limestone," hard	15	1,194
"Third Weatherford limestone"	11	1,205
Limestone	10	1,215
Gumbo and bowlders	22	1,237
Gumbo	16	1,253
Limestone	7	1,260
Gumbo	4	1,264
Limestone, soft	6	1,270
Limestone, hard	4	1,274
Gumbo	8	1,282
Limestone, hard	27	1,309
"Fourth Weatherford limestone"	39	1,348
(Reamed and set 10¼-inch casing.)		
"Fifth Weatherford limestone"	30	1,378
Fredericksburg group:		
Goodland limestone:		
Limestone, hard	36	1,414
Limestone	8	1,422
Gumbo	4	1,426
Limestone	2	1,428
Limestone, hard	30	1,458
"Sixth Weatherford limestone"	10	1,468
Shale	5	1,473
Gumbo and bowlders	15	1,488
Gumbo	4	1,492
Hard limestone	20	1,512
"Seventh Weatherford limestone"	30	1,542
Limestone	16	1,558
Shale	6	1,564
Limestone, hard	8	1,572
Trinity group:		
Paluxy sand:		
??	48	1,620
"First Paluxy water sand"	19	1,639
Limestone	2	1,641
"Second Paluxy water sand"	15	1,656
Gumbo	4	1,660
Water sand	9	1,669
Gumbo	8	1,677
Gumbo, hard	11	1,688
"Third Paluxy water sand"	5	1,693
Water sand	14	1,707
"Fourth Paluxy water sand"	23	1,730
Iron pyrite and sand	12	1,742
Water sand	15	1,757
"Fifth Paluxy water sand"	2	1,759
Water sand	2	1,764
Hard sand	5	1,769
Gumbo	3	1,772
Glen Rose limestone:		
Limestone	14	1,786
(Set 8-inch casing.)		
Limestone	20	1,806
Gumbo	10	1,816
Limestone	30	1,846
Gumbo	7	1,853
Limestone	17	1,870
Limestone and shale	8	1,878
Limestone	9	1,887
Gumbo	6	1,893
Limestone	5	1,898
Sand	10	1,908
Shale and limestone bowlders	14	1,922
Limestone	8	1,930

Log of well at Southern Methodist University—Continued.

	Thickness.	Depth.
Cretaceous system—Continued.		
Trinity group—Continued.		
Glen Rose limestone—Continued.	*Feet.*	*Feet.*
Sand rock	6	1,936
Limestone and shale	9	1,945
Limestone	16	1,961
Limestone, hard	9	1,970
Limestone	22	1,992
Limestone, hard	40	2,032
??	47	2,079
Limestone, hard	19	2,098
??	15	2,113
Limestone	2	2,115
Gumbo	6	2,121
Limestone	6	2,127
??	9	2,136
Limestone, hard	12	2,148
??	12	2,160
Limestone	47	2,207
??	8	2,215
Limestone, soft	5	2,220
Limestone	5	2,225
Limestone, hard	10	2,235
??	7	2,242
Limestone	8	2,250
Travis Peak sand:		
??	46	2,296
Water sand	14	2,310
"First Glen Rose water sand"	6	2,316
Sand	8	2,324
Water sand	18	2,342
??	5	2,347
"Second Glen Rose water sand"	9	2,356
Carboniferous system:		
Pennsylvanian series (?):		
Red gumbo	5	2,361
??	339	2,700

Paluxy water bad; Travis Peak good.

GENERAL STRUCTURE.

The Cretaceous rocks dip rather steeply eastward (see fig. 2), so that the Trinity sand at the base of the system, which comes to the surface at Weatherford and Montague, lies more than 2,000 feet below the surface at Dallas and Sherman and still deeper farther east. On the other hand, the Carboniferous beds that outcrop at Henrietta, Palo Pinto, and elsewhere dip westward, though not so abruptly as the Cretaceous beds dip eastward, and in the western part of the State lie several thousand feet below the surface. Whether or not the Carboniferous rocks dip to the west in the eastern part of this region also, where they are deeply buried under the Cretaceous rocks, is not certainly known, and it is not certain even that they are present beneath Dallas. Perhaps along the eastern border of the region, under Sherman and Rockwall, where they lie several thousand feet below the surface, they dip to the east, so that their general structure in the State is that of a broad anticline or upwarp. In any case the Cretaceous rocks have a general terrace or broad anticlinal structure, for although their dip is so steep in the northeastern quarter of Texas that they all outcrop and their horizon is above the surface west of Bowie and Weatherford, they come down again, as it were, farther west, in the western part of the State. If the strata had no terrace or broad anticlinal structure the beds near the base of the Cretaceous, which outcrop around Fort Worth, would in the western part of the State be many thousand feet above the present surface, but they occur at the surface. It therefore appears probable that the oil and gas in Wichita and Clay counties and in the area extending southward to Eastland occur along the edge of a great structural terrace.

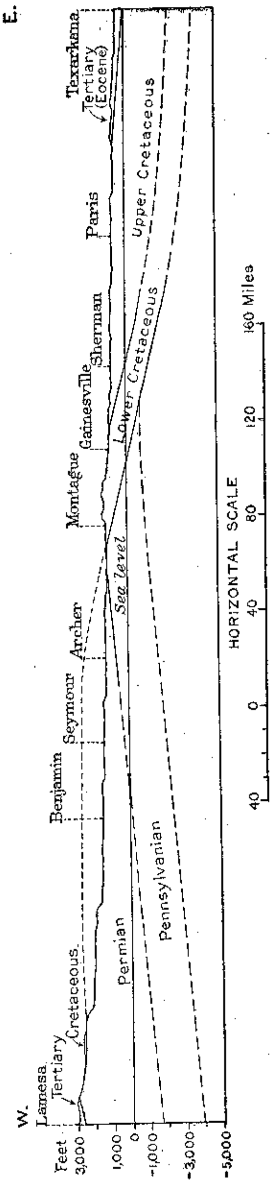

FIGURE 2.—Section across Texas along divide south of Red River from the eastern border of the State at Texarkana to Benjamin and thence southwestward to Lamesa, showing overlap of Cretaceous on Carboniferous formations and general terrace form of structure.

The general terrace form of the structure is not evident except to one who takes a broad view of the region, for the terrace is low compared with its breadth, and the layers of rock are more or less uneven throughout the region and at some places are uplifted into well-developed domes and anticlines. The local dips are nowhere much greater than the general dip and at few if any places exceed 5°. Here and there the rocks have been faulted.

The geology of the Cretaceous part of Texas has been described by Hill.[1]

CONDITIONS OF OCCURRENCE OF NATURAL GAS.

In most of the natural-gas pools of the country the gas is stored under pressure in the pores of sands or sandstones that lie more than 1,000 feet below the surface. Some gas has been found at depths greater than 3,000 feet, and some in other kinds of cavities. The pores of the gas-containing sandstone are commonly less than one-tenth of a millimeter—about $\frac{1}{250}$ of an inch—in diameter, yet the gas flows from them into wells at the rate of millions of cubic feet a day. Most of the pools are found in rocks which have comparatively large communicating pores and which lie near other rocks that contain much carbonaceous matter from which the gas may have been derived.

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

THEORIES OF ORIGIN AND ACCUMULATION OF NATURAL GAS.

The mode of origin of natural gas has never been clearly determined. It has not been possible to prove conclusively that it is either of organic or of inorganic origin, though most investigators agree that the evidence seems to indicate that both gas and oil were once parts of living organisms, and that they have been derived by a long process of distillation from the remains of plants or animals, or both, which have been buried in great bodies of sediment. The remains of plants seem to be a more likely source than the remains of animals. The grounds for these inferences are: (1) Although the hydrocarbons constituting petroleum and gas can be made from certain inorganic materials, such materials are not known to occur in the earth in considerable quantity, and if the gas and oil had been formed from such materials or if they had been original parts of the earth they must have migrated far from their sources, for the pools do not occur in deep-seated rocks but are closely confined in sedimentary strata, thousands of feet thick, which did not form an original part of the earth; (2) any hydrocarbon found in petroleum can be made in the laboratory from either plant or animal matter; (3) carbonaceous remains of plants are abundant in the strata in which oil occurs—more abundant probably than such remains of animals, for plants decay less readily—and fossil plants are generally carbonaceous, whereas animal fossils are rarely so.

Many things remain to be learned regarding the migration and accumulation of gas, but the inference—drawn very early in the history of the oil industry—that most oil and gas is stored in anticlines or upwarps of strata has been well demonstrated, the reason for their position being that they are lighter than water, so that under the water pressures that exist in the earth they tend to migrate to the highest spot attainable.

The exact nature and details of the process by which the gas migrates to the top of the anticline are still under discussion, the most important question being whether or not the salt water that at most places, if not everywhere, surrounds the pools must move and push the oil and gas about to a greater or less extent in order that the gas and oil may reach the top of the anticline. M. J. Munn[1] has argued with much force that such movement of water is necessary. The rock pores are so small that the friction would seem to be too great for the gas to migrate and segregate itself into extensive pools without the help of lateral movements of the water, which would favor this sorting by weight.

[1] Munn, M. J., The anticlinal and hydraulic theories of oil and gas accumulation: Econ. Geology, vol. 4, No. 6, pp. 509–529, 1909.

THE SEARCH FOR GAS.

Natural gas has not been so extensively and vigorously sought as oil, for only in regions in which it is abundant and which are thickly populated or not too far from large towns or industrial centers can it be marketed with profit. Many if not most natural-gas pools have been found in the course of the search for petroleum.

The first knowledge of oil in most regions seems to have been gained either from oil or gas seepages or by accident in drilling for water or coal. Of most pools, however, there were no surface indications before drilling began. The history of oil and gas "wildcatting" is in large part one of blind or even misguided waste, such as might be disastrous were not the gains from the occasional and frequently merely accidental successes so great. It is becoming more and more clearly recognized that in most oil regions of the world oil and gas pools occur in connection with dome, anticlinal, or terrace structures in the strata containing the oil and gas. Usually the gas occupies the upper part or crest of the fold. Accordingly, in his search for new pools or fields, the prospector should first examine the structure. Where anticlines are wanting or poorly developed, the geologic structure map may still be useful, for the strata nowhere lie perfectly flat, and it is everywhere possible to select certain structural features that are more promising than others.

Though the favorable forms of structure, even in oil and gas bearing formations, do not invariably contain pools, the places in which that structure is found are more likely than others to contain gas or oil. The principal unsolved problem concerns the exact places in which the rocks have favorable structure.

The field work requisite to a comprehensive and reliable statement concerning the gas resources available on the north and northwest to Dallas and Fort Worth consisted of—

First, a careful geologic survey of the Petrolia field, which is the present source of gas used by Dallas and Fort Worth. This work included the running of spirit-level lines to every well in the field, a careful study of the outcropping rocks in and near the pools, and the collection of logs of wells and a large amount of other data concerning them. Special attention was given to the details of the structure of the field, the thickness, number, and nature of the sands, and the gas pressures and yields.

Second, a similar though less elaborate and detailed study of other fields having gas wells within reach of the cities.

Third, plane-table stadia surveys of outcropping strata in several districts, made in the hope that structure favorable to the accumulation of gas might be found.

The ordinary method of search for gas pools is almost the same as that for oil pools, the most essential feature of it being the search for anticlines. In Pennsylvania and West Virginia the anticlines nearest the Appalachian Mountains contain the most gas. Gas is generally more abundant in high, sharply defined anticlines than in low, broader structures, which commonly yield much oil. However, the criteria for locating gas pools, as distinct from oil pools, are not yet sufficiently developed to serve as a reliable guide. As all the rocks of the region under discussion may contain oil and gas, the search for new gas pools within reach of Dallas and Fort Worth consisted in hunting for anticlines and other favorable features of structure, especially in places where the underground water conditions appear favorable. The higher folds of the region are more likely to contain gas, but whether any particular fold will be found to contain oil or gas, or neither, can not be certainly foretold.

METHODS OF ESTIMATING GAS RESOURCES.

The estimation of gas resources, though very important, is comparatively new and undeveloped work. Many unknown quantities are involved in the estimates, and great precision in results will doubtless never be attainable. When gas properties change hands there must, of course, be some kind of an estimate of the amount and value of the gas still in the earth. The prices of some gas wells have been determined by the appearance of the well when it was opened. Generally, however, a measure of the closed pressure and a more or less careful estimate of the capacity is made. The common method of determining the capacity is as follows: The well is opened and allowed to blow off freely for 3 to 24 hours. Then a Pitot tube or spring gage is used in measuring the forward or momentum pressure of flowing gas. The opening of a pipe connected with the gage is turned against the stream of gas. The pressure is measured by a column of water or mercury or a spring gage, according to the force of the gas. The pressure reading is then expressed in cubic feet per day by means of a set of tables, the barometric pressure, the temperature, the specific gravity of the gas, and the size of pipe being taken into account.

In determining a proper price for the gas which underlies a farm or group of farms, the acreage of the land and the number of wells are also taken into consideration. These operations, which are applicable to discovered or partly developed fields, involve a large element of chance, but the estimation of gas resources in undiscovered fields is of course far more difficult, so difficult, indeed, that most oil and gas operators regard it as impracticable, and until wells are drilled one tract is regarded as about as valuable as any other that lies at the same distance from a producing field. Nevertheless, estimates vastly better and more reliable may be obtained for such tracts if careful consideration is given to the geologic structure and the general relations of gas to structure in the same region. In the study of the structure attention should also be given to the number, thickness, and porosity of sands and the nature and arrangement of sands that bear salt water. These criteria have been borne in mind in estimating the gas resources about Dallas and Fort Worth. The fact that the Petrolia field is on a high, well-developed anticline may mean that smaller and less sharply defined anticlines in the same region are less likely to contain gas.

METHOD OF MAPPING STRUCTURE.

The problem of representing on a map the precise form of an uneven surface has been solved by the use of contours.

In structure contouring the surface of some bed is chosen and lines are drawn through points of equal altitude on that surface. The result shows the lay of the bed, just as a contour map of the earth's surface shows the lay of the land—that is, the form of hills and valleys, the direction and steepness of slopes, and the altitude of all parts of the surface. Features are shown in greater or less detail, according to the number of contours used and the number and precision of the determinations of altitude.

The method used in making the structure maps included in this report consisted in first looking over a group of outcrops in order to select a bed easily followed and then determining by plane-table and telescopic alidade the course of the outcrop and the altitude of points along it at intervals of a few hundred feet. Often, to afford a check on the results, a second or third bed above or below was traversed at the same time, for in making a structure map the geological surveyor is not limited to one bed, because all beds are nearly parallel and hence the wrinkles on one are generally at the same place and of the same form as those on another. Hence, here and there one bed was dropped and another picked up. Now and then, because of poor outcrops, a tract was altogether passed over, and where such gaps were great a barometer was used for carrying the level line in order to make more rapid progress. As a result the figures shown along outcrops on maps do not show precise altitudes above sea level, but are fairly precise with reference to each other.

In some places valuable inferences concerning structure could be drawn from the surface features. Some long, gentle slopes are immediately underlain by a hard stratum, and the surface thus indicates with greater or less certainty the direction and amount of dip. Elsewhere hard beds make little benches in hillsides, so that even where they are not exposed they may be followed, and in many places a concealed bed may be followed by fragments of the rock in the soil.

The accuracy and reliability of structure contours depend on several factors. In most of the surveys made for this report it was felt that the greatest danger of error was that of mistake in correlation—of following one bed or horizon for a while and then inadvertently shifting to another. This danger is due to the fact that, particularly in Clay County, the beds pinch out and change in character at short intervals. It was necessary to exercise the greatest care to avoid mistakes of this kind, particularly in correlating outcrops separated by short gaps, correlation across long gaps being generally quite impossible. As a result both outcrop lines and contours on the map are commonly represented by dashes, which indicate doubt as to exact position.

The beds are not only discontinuous but their surfaces are not sharply defined, and hence some of the altitudes determined are a little above and some a little below the surface that was followed. No doubt slight errors of this sort affect most of the points determined, but probably few such errors are in excess of 2 or 3 feet. They are not cumulative and hence do not affect the general structural features as shown on the map. Their effect is partly eliminated in drawing the structure contours, and thus the contours shown on the maps do not harmonize in detail with the determined altitudes.

THE PETROLIA GAS AND OIL FIELD.

LOCATION AND EXTENT.

The Petrolia field (see Pl. I) is on a broad, flattish divide between Wichita and Little Wichita rivers, just south of the town of Petrolia, in the northern part of Clay County, Tex. It has often been called the Henrietta field, because at the time it was discovered Henrietta, 12 or 15 miles to the south, was the nearest town. But the town of Petrolia has since grown up on the border of the field and this name is now more appropriate. It covers a somewhat elliptical area about 3 miles from northeast to southwest by 4 miles from southeast to northwest. The limits of the proved field can not be stated with precision, because some dry holes are nearly surrounded by productive wells and one or two productive gas wells are considerably outside of the main field, but an approximate boundary of the developed part of the field is shown on Plate I (in pocket).

STRATA ENCOUNTERED IN DRILLING.

The rocks outcropping in the Petrolia field and a large surrounding territory are widely known as the "Red Beds" and belong to the Wichita formation of the Permian series. They consist of lenticular beds of red shale, soft cross-bedded sandstone, and some blue-gray shale. Their fossils are rare and consist mostly of impressions and remains of plants. The sandstone contains occasional fossil tree trunks and carbonized wood, which is here and there replaced by copper minerals, mainly malachite. There appears to be no limestone near Petrolia, though thin beds of limestone are fairly common in the higher parts of the Wichita formation exposed at Electra and in all parts of the formation at places farther south. Gypsum has been reported in some wells, but, though much gypsum occurs in the Wichita formation 50 to 100 miles to the west, it is doubtful whether any occurs in it in the Petrolia field, for no fragments were found in drill cuttings or slush pits.

The strata penetrated by wells in the Petrolia field, as shown in the following well logs, include several sands that produce oil or gas or both. On the whole, the quantity of gas increases with increase in depth. The sands that lie 150 to 300 feet below the surface contain very little gas, and probably for this reason the oil wells that derive oil from these sands have a low daily production and long life. Practically all the gas marketed comes from a group of sands that lie at a depth of 1,500 to 1,750 feet. This group is made up of three principal and two or three subordinate and lenticular sands.

Driller's log of Wichita Gas Co.'s well, on Felix Webb tract, No. 39, Chilson Neville & Kelley Subdivision, Block No. 13, Clay County, Tex.

[Contractor, M. D. Rowe. Drilled December 29, 1913, to February 5, 1914. Initial production (estimated), 10 million cubic feet of gas. Casing: 10 inch, 54 feet; 6 inch, 1,532 feet set with beveled shoe and cemented on top of sand. Six-inch Darling gate anchored to 10-inch casing.]

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	131	131
Sand	6	137
Shale	50	187
Sand, showing oil	4	191
Gumbo clay	14	205
Shale and thin sandstone	73	278
Sand	47	325
Shale, soft	27	352
Sand, showing oil	8	360
Shale	25	385
Sand rock	35	420
Shale	11	431
Sand rock	11	442
Blue mud	15	457
Sand rock	34	491
Mud	5	496
Shale	7	503
Gumbo	15	518
Lime	6	524
Shale	10	534
Do	10	544
Gumbo	11	555
Shale	10	565
Do	21	586
Shale and shells	87	673
Sandstone, hard	7	680
Mud	27	707
Sand rock	8	715
Gumbo	5	720
Sand rock	8	728
Gumbo	17	745
Streaks of sand, showing oil	57	802
Mud	16	818
Gumbo	22	840
Sand rock	21	861

Driller's log of Wichita Gas Co.'s well—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale and thin sandstone	55	916
Sand rock	10	926
"Slate" and shells	29	955
Limestone	3	958
"Slate" and shells	24	982
Sand rock, hard	5	987
Gumbo and rock	19	1,006
Shale and sand	40	1,046
Mud	36	1,082
Gumbo and sand	36	1,118
Sand and shale	28	1,146
Sand, limestone, and shale	34	1,180
Rock	6	1,186
Sand rock	10	1,196
Gumbo and gypsum	124	1,320
Sand rock, showing water	12	1,332
Gypsum	22	1,354
Sand rock	6	1,360
Gumbo and bowlders	36	1,396
Gumbo, gypsum, and bowlders	88	1,484
Lime	5	1,489
Gypsum and streaks of sand	43	1,532
Sand, showing gas	6	1,538
Shale, blue	15	1,553
Sand, showing gas	14	1,567
Gumbo, tough	24	1,591
Sand, with black streaks, showing gas	10	1,601

Partial driller's log of Wichita Oil & Gas Co. well No. 5 on Culbertson tract, near middle of SW. ¼ block 14, Petrolia gas field, Texas.

[Drilled by Howell, Markowitz & Kell, April 19 to Sept. 2, 1914. Casing 10 inch, 60 feet; 6 inch, 1,545 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
??	1,000	1,000
Sand and bowlders, blue, soft	25	1,025
Gumbo, blue, soft	15	1,040
Gravel, red, soft	10	1,050
Sand rock, gray, hard	5	1,055
Gumbo, blue, tough	20	1,075
Gypsum, white, tough	4	1,079
Shale, blue, soft	21	1,100
Shale, sandy, blue, hard	50	1,150
Water sand, gray, hard	12	1,162
Water sand, gray, soft	200	1,362
Shale, blue, soft	113	1,475
Gumbo, blue, tough	20	1 495
Water sand, gray, hard	13	1 508
Shale, blue, soft	9	1,517
Gumbo, blue, tough	3	1,520
Gas sand, brown, soft	8	1,528
Gumbo, blue, tough	12	1,540
Shale, blue, soft	5	1,545
Gas sand, brown, soft	12	1,557
Gas sand, broken shale, brown and blue, soft	11	1,568
Gas sand, rich brown, hard	11	1,579
Gumbo, blue, tough	5	1,584
Gas sand, broken, and "slate," brown and blue, soft	10	1,594
Gas sand, brown, hard	16	1,610
Gumbo, blue streaks, tough	7	1,617
Cap rock, blue, hard	3	1,620
Gas sand, brown, soft	8	1,628
Lime or granite, red and white, hard	9	1,637
Limestone, brown, oil stain, soft	2	1,639
Limestone, white, hard	5	1,644
Gumbo, blue, tough	21	1,665
Lime, broken, white, hard	5	1,670
Limestone, white and brown, hard	75	1,745
Limestone, white, very hard	19	1,764

Driller's log of Developers Oil Co.'s well No. 12, near middle of NE. ¼ block 9, about 1 mile southwest of Petrolia.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and clay	10	10
Rock	2	12
Hardpan	20	32
Red clay	8	40
Sandstone, soft	3	43
Shale	45	88
Sand, hard	7	95
Gravel and clay	30	125
Shale, soft	70	195
Sand, oil	3	198
Sand, hard	7	205
Shale, soft	200	405
Clay, blue	40	445
Sand rock	35	480
Sand	3	483
Clay	80	563
Clay and rock	6	569
Sand	82	651
Sand rock	15	666
Gumbo	20	686
Oil sand	4	690
Sand rock	6	696
Shale	35	731
Oil sand	3	734
Sand rock	2	736
"Pack sand"	10	746
Shale	60	806
Clay	15	821
Sand rock	32	853
Clay	8	861
Sand rock	20	881
Shale	25	906
Sand rock	12	918
Sand, salt water	34	952
Clay	8	960
Sand rock	9	969
Shale	11	980
Do	15	995
Oil sand	7	1,002
Clay, blue	18	1,020
Shale, soft	20	1,040
Sandstone	17	1,057
Shale	10	1,067
Sand rock	8	1,075
Shale	30	1,105
Shale and clay	15	1,120
Sand rock	16	1,136
Do	27	1,163
Shells and clay	24	1,187
Shale	8	1,195
Sand rock	9	1,204
Clay, blue	18	1,222
Clay	15	1,237
Rock	6	1,243
Shale	20	1,263
Sandstone	6	1,269
Gumbo	5	1,274
Sandstone	10	1,284
Sand rock	2	1,286
Shale	10	1,296
Sand rock	8	1,304
Clay	20	1,324
Shale	20	1,344
Broken rock	16	1,360
Sand rock	(?)	(?)
Sand	(?)	1,395
Clay, blue	30	1,425
Shale	65	1,490
Sand rock	5	1,495
Sand	3	1,498
Clay	12	1,510
Sandy shale	42	1,552
Sand rock	15	1,567
Sand	5	1,572
Rock	3	1,575
Shale	6	1,581
Sand rock	3	1,584
Shale	18	1,602
Sand rock	8	1,610

Driller's log of Developers Oil Co.'s well No. 12—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale	12	1,622
Sand, hard	3	1,625
Clay	17	1,642
Clay, blue	20	1,662
Clay	15	1,677
Shale	20	1,697
Do	15	1,712
Sand, hard	15	1,727
Sand	30	1,757
Shale	6	1,763
Sand (set and cemented, 6-inch casing)	1	1,764
Sand—good gas	2	1,766
Sand, oil spray	7	1,773
Bottom sand	8	1,781
Shale	4	1,785
Sand	3	1,788
Blue mud (bottom of well)	2	1,790

Well completed May 27, 1914. Estimated capacity 12,000,000 cubic feet of gas. Shut in to save gas. Probably good for 5 to 10 barrels of oil.

On account of the high gas pressure and rather large yield of the main gas sands, few wells have been sunk to a greater depth within the proved field. The underlying strata include several layers of sandstone that are inclosed between comparatively impervious beds and that have pore space adapted to make them good oil and gas reservoirs. These deeper sands have been penetrated in wells outside the producing field, as shown in the logs on pages 66–68.

The main gas sands at Petrolia are believed by Prof. Udden[1] to belong in the Cisco formation, which is the uppermost formation of the Pennsylvanian series in this region. On account of the scarcity of fossils, however, it is not yet possible to define with certainty the boundary between this and the lower formations. The importance of carefully preserving shells and other fossils found in drilling is not sufficiently understood by the driller. Gordon's section of the rocks below the Wichita formation is as follows.[2]

Section of Pennsylvanian formations in Wichita region, Texas.

	Feet.
Cisco formation (clay, shale, conglomerate, sandstone, and some limestone and coal)	800
Canyon formation (alternating beds of limestone and clay; some sandstone and conglomerate)	800
Strawn formation (alternating beds of sandstone and clay; some conglomerate and shale; the lower 1,000 feet consists of blue and black clay locally containing beds of limestone, sandstone, or sandy shale, and a coal seam at the top)	1,900
	3,500

[1] Udden, J. A., and Phillips, D. McN., A reconnaissance report on the geology of the oil and gas fields of Wichita and Clay counties, Tex.: Texas Univ. Bull. 246, 1912.

[2] Gordon, C. H., Geology and underground waters of the Wichita region, north-central Texas: U. S. Geol. Survey Water-Supply Paper 317, p. 14, 1913.

STRUCTURE.

As pointed out by Udden and Phillips,[1] the structure of the rocks in the Petrolia gas field is anticlinal. The additional work done by the writer has only served to bring to light further details concerning the structure of the field and the surrounding territory. The more complete structural survey of the field has had the advantages afforded by the records of additional wells combined with plane-table surveys of outcropping rocks on all sides of the field, but especially along the river bluffs that extend from a point a few miles east of Byers west-southwestward nearly to Wichita Falls. These additional data bring out the fact that the oil and gas pools occupy the crest of a large, irregular anticline having a general east-northeast trend. The most important structural features in and near the Petrolia field identified by the present survey consist of a branch anticline extending a mile or two northeast of the middle of the field and a similar structure extending northwest. The form of these features is shown on the structural map. The fold to the northeast was discovered by H. M. Robinson from outcropping beds, and he determined its form so far as possible by a plane-table survey.

PRODUCTION.

The Petrolia field produces both oil and gas, and in recent years its production has increased rather rapidly. It is now yielding about 500,000 barrels of oil a year. Its production in 1912 was less than 200,000 barrels, and for several years before it had been nearly 100,000 barrels. The total amount of oil produced up to the close of 1914 is a little over 2,000,000 barrels, or about 11,200,000 cubic feet.

The annual production of natural gas consumed in Texas amounts to more than 10,000,000,000 cubic feet, and the Petrolia field is by far the largest producer. The production of the State in 1914 amounted to about 13,433,639,000 cubic feet, valued at $2,469,770.

HISTORY.

The first gas well in the Petrolia field was drilled in 1907. For several years before that date it was known as an oil field. The first shipments of oil were made in 1904, though it had produced small amounts of oil for several years before. The oil was first found in water wells, where it and the associated salt water spoiled many wells as producers of drinking water.

During 1904 about 75 oil wells were drilled. The average depth was about 300 feet, and their production ranged from 3 to 40 barrels a day. The oil had a paraffin base and was similar in character

[1] Udden, J. A., and Phillips, D. McN., A reconnaissance report on the geology of the oil and gas fields of Wichita and Clay counties, Tex.: Texas Univ. Bull. 246, 1912.

to that produced at Corsicana, to which place it was shipped for refining. During this year two pipe lines were laid to Petrolia, where loading racks were erected. An analysis of the oil, made at this time,[1] shows naphtha, 9.1 per cent; water-white oil, 54.5 per cent; solar oil, 13.6 per cent; heavy residues, water, and loss, 22.8 per cent.

In 1905, 52 additional wells were drilled, bringing the total number of producing wells up to 135. All were shallow, averaging only about 300 feet in depth. The cost of drilling was low, and 10 to 30 of the wells were operated by one power. During this year over 66,000 barrels of oil were shipped to refineries, nearly 10,000 barrels were used in boilers in the field, and about 26,000 barrels were put in storage. At about this time a large part of the field was "townsited" and offered for sale in small lots, the owners and promoters evidently believing that more money was to be made in this way than by drilling and producing. As a result, much of the field is now cut up into small blocks most of which have changed hands one or more times, a condition that greatly complicates the record of well locations.

By the close of 1907 there were 169 producing oil wells, all of them shallow, and the oil was being piped from the field by the Navarro Refining Co., successor to the Clayco Oil & Pipe Line Co. In October of that year the first gas well was brought in by this company. It was 1,500 feet deep and is reported to have had a 4-minute pressure of 470 pounds to the square inch, and a capacity of 8 to 10 million cubic feet a day. In 1908 two other "gassers" were brought in, the gas being used for domestic purposes in Petrolia as well as for operating boilers and for other purposes in the field.

In 1909 several other gas wells were drilled and the 16-inch pipe line to Fort Worth and Dallas was laid. From this date the number of gas wells has gradually increased until now about 56 produce gas, all of them deep wells. In addition, a smaller but steadily increasing number of deep oil wells have been drilled. Many wells yield little or no salt water, but on the whole the proportion of salt water in both gas and oil wells is increasing, as it commonly does in oil fields. Some of the deep wells yield both gas and oil in proportions that show a wide range, the proportion of oil showing a slight general tendency to increase.

Many of the first deep wells in the field showed closed pressures of more than 700 pounds to the square inch, the highest pressure reported being 740 pounds. The average pressure has gradually decreased and now is less than half as great as at first. (See Pl. II.) Very naturally the capacity of the wells has also fallen off considerably, and on account of the decline in pressure and volume a large

[1] U. S. Geol. Survey Mineral Resources, 1904, p. 715, 1905.

compressor plant furnishing a pressure of about 300 pounds to the square inch has been built by the Lone Star Gas Co., the principal gas producer in the field. When the pipe line was installed and for the following two or three years the pressure and volume of the wells were great enough to maintain this 300-pound flow pressure, which was necessary to force the gas to Fort Worth and Dallas in sufficient quantity to meet the demand. In fact, at first the requisite amount could be delivered at the cities by using only a few wells and allowing them to flow into the pipe line for only a part of the time, but since then the consumption has greatly increased and the capacity and pressure of the wells has decreased, so that the installation of the compressor plant was necessary. A large pipe line or additional pipe lines would have made it possible to furnish the requisite amount of gas for a year or two longer without compression, but the building of the compressor plant could not have been long postponed.

EFFECT OF METHOD OF DRILLING ON DISCOVERY AND PRODUCTION.

The wells of the Petrolia field are bored to the supposedly productive sands by rotary drills, but as the mud used with these drills may so mask the sands as to obscure to a greater or less extent their capabilities for producing oil or gas and may even totally conceal rich oil and gas sands, it is the common practice to drill the sands with cable tools. These tools are installed after the hole has been sunk with the rotary drill nearly to the top of the sand which is expected to be productive.

Drilling is done in a way more favorable to the development of oil wells than of gas wells, on account of the fact that an oil well is worth in general much more than a gas well. The attempt is thus generally made to make an oil well if possible. When a gas sand is found the operator attempts to drill through it, in the hope of finding oil in paying quantities beneath the gas. Thus it happens that much gas has been allowed to go to waste, and many gas wells have been "killed," because they were considered not worth caring for. Oil operators commonly have an arrangement with a gas company to sell to it all gas wells as fast as drilled, so when the attempt to make a well an oil well fails on account of the abundance and high pressure of gas, the well is turned over to the gas company. The gas company commonly finds it convenient to give a purchased well a new number or designation, and this practice leads to confusion in names of wells.

After it is finished each well has its own history, which differs more or less from that of any other, not only in geologic but in technologic detail. Some wells are short lived and others maintain a large yield for many years. Some become bridged over or are in other ways troublesome; others require very little care.

GAS RESOURCES.

Distribution of gas wells.—As shown by the map (Pl. I), the gas wells, about 56 in number, are fairly evenly distributed throughout the Petrolia field. Very few unsuccessful deep wells have been drilled within the field. Many that are called oil wells are in fact capable of producing considerable gas also, the general practice being, as noted above, to make as many oil wells as possible. In the northwest corner of the field in particular efforts to this end have been very successful. Here, especially in blocks 9 and 13, the gas sands of the central part of the field contain a great deal of oil. Though most of the wells here produce gas, in only a few does gas preponderate to such an extent as to cause them to be rigged up as gas wells.

The limits of the Petrolia gas field are generally considered to be pretty well determined by the drilling so far done. Most of the deep wells within a fairly well defined boundary (see line on Pl. I) are productive, and those outside are nonproductive, though the Morgan Jones No. 1, of the Ninety-nine Pumping Co., is a notable exception. This well has not so large a capacity as most wells in the field, but though it is more than a mile west of the nearest gas well in the field, it is a very good gas well.

Depth of wells.—Most wells over 1,000 feet deep yield more or less gas, and the big gas wells range in depth from 1,500 to 1,750 feet. Contrary to a prevalent opinion, the sands do not lie almost perfectly horizontal but have dips which in a few miles cause considerable differences in their altitude. The dips are much less than the general slope of the surface of the region, though they are sufficient to carry the beds down or up scores of feet within a mile.

Closed pressure and capacity of wells.—The initial closed pressure of the first few gas wells drilled in the Petrolia field ranged from 600 to 740 pounds to the square inch. Since these wells were drilled their closed pressures have not only decreased but the initial pressures of other wells drilled later have been lower than that of earlier wells, some of the latest wells drilled having recorded initial pressures of less than 300 pounds to the square inch. The initial pressure depends in part on the stage of development of the field and in part on the surrounding producing wells—whether they are numerous or few, distant or near by, old or recently drilled, or have been much or little used. The following table, showing the rate of decrease of closed pressure as ascertained by monthly gaging of most of the gas wells in the field, is compiled from records kindly furnished by the Lone Star Gas Co. These monthly gagings were begun in January, 1913, and have been continued to date.

Rock pressures of gas wells at Petrolia, Tex., belonging to Lone Star Gas Co., 1913–1915.

[Figures show line pressure at well mouth, in pounds to the square inch.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1913.												
Byers 1	[a]725	[a]730	[a]730	[a]725	[a]595	——	——	——	——	——	——	——
Byers 4	[a]710	[a]710	[a]710	[a]715	[a]715	[a]665	[a]660	[a]670	[a]675	[a]665	[a]665	[a]670
Byers 5	[a]640	[a]650	[a]640	[a]630	[a]630	[a]360	[a]560	[a]555	[a]550	[a]220	490	[a]475
Byers 6	635	[a]640	630	620	610	[a]535	[a]540	[a]525	[a]520	480	445	415
Byers 12	......	......	......	......	(335)	(315)	(330)	(325)	(325)	(345)	(375)	(315)
Byers 15	......	......	......	......	......	......	......	......	......	[a]470	[a]445	[a]390
Holt 1	[a]615	[a]615	[a]615	[a]615	[a]630	[a]570	[a]560	[a]560	[a]550	445	480	530
Matlock 1	[a]565	[a]560	[a]565	[a]565	[a]585	430	425	[a]485	440	435	420	475
Landrum 1	[a]635	[a]640	[a]640	[a]655	[a]650	[a]590	[a]590	[a]585	[a]585	[a]575	[a]545	[a]575
Schnell 1	[a]720	710	[a]710	[a]705	[a]720	[a]655	[a]650	645	655	[a]665	665	[a]660
Schnell 2	[a]570	530	[a]560	[a]560	[a]565	[a]505	[a]495	[a]500	[a]490	[a]495	[a]450	[a]435
Brick & Tile 1	485	——	——	——	——	——	——	——	——	——	——	——
Brick & Tile 2	520	505	435	505	510	430	440	435	445	480	445	460
Miller 1	580	570	560	555	560	540	525	460	455	430	455	425
Smith Webber 1	520	[a]530	[a]560	[a]555	[a]560	[a]505	[a]500	[a]510	[a]505	[a]510	430	420
Smith Avis 1	[a]655	[a]650	[a]655	[a]660	[a]650	[a]615	[a]610	[a]645	[a]620	[a]625	[a]615	[a]605
Lockridge 1	[a]660	[a]655	[a]655	[a]665	[a]685	[a]635	[a]625	[a]635	[a]640	[a]635	[a]630	[a]615
Panhandle 1	595	[a]595	[a]590	[a]590	[a]585	[a]580	[a]570	540	525	515	505	490
Clayco Stine 1	645	[a]650	[a]650	[a]660	[a]670	[a]610	[a]605	[a]610	[a]615	[a]650	[a]630	[a]615
Holloway 2	(315)	(310)	(310)	(275)	(290)	(295)	(315)	(315)	(315)	(315)	(315)	[a]410
Holloway 4	[a]615	[a]615	[a]635	[a]640	[a]620	[a]590	[a]590	575	510	515	——	——
Taylor 2	(325)	(320)	(325)	(285)	(300)	(315)	(325)	(325)	——	——	——	——
Skelly 1	[a]675	[a]590	[a]590	[a]585	[a]595	[a]565	510	[a]530	[a]430	[a]525	[a]515	480
Skelly 4	......	......	......	......	......	......	......	......	......	......	......	475
C. P. Stine 1	......	......	......	[a]605	[a]565	[a]355	[a]365	——	——	——	——	——
Skelly 2	650	585	590	(415)	(420)	(395)	(410)	300	——	——	([a][b])	......
Total number wells	22	22	22	23	24	24	24	24	24	25	24	25
Total number off test	2	3	3	4	5	6	5	6	7	7	7	6
Total number tested	20	19	19	19	19	18	19	18	17	18	17	19
Average per well	621	617	622	621	615	540	538	553	541	518	519	506

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1914.												
Byers 1	——	——	——	——	——	——	——	——	——	......	——	——
Byers 4	655	670	625	560	575	......	515	505	500	......	465	510
Byers 5	440	410	375	342	345	......	340	340	340	......	300	305
Byers 6	(365)	370	325	307	300	......	295	305	[a]300	......	300	240
Byers 12	(325)	——	290	——	——	......	——	[a]185	[a]180	......	200	140
Byers 15	350	350	310	——	——	......	280	[a]275	[a]265	......	240	230
Byers 17	......	......	......	......	......	......	270	[a]255	[a]285	......	250	230
Byers 19	......	......	......	610	555	......	510	490	495	......	——	505
Byers 20	......	......	......	......	......	......	575	550	575	......	500	520
Holt 1	510	505	460	450	440	......	400	405	395	......	350	350
Matlock 1	440	435	420	375	360	......	340	325	335	......	310	350
Landrum 1	555	510	450	420	395	......	420	420	380	......	320	365
Schnell 1	680	675	635	630	590	......	540	525	600	......	——	——
Schnell 2	480	480	435	425	425	......	395	385	390	......	355	350
Brick & Tile 1	——	——	——	——	——	......	350	335	335	......	335	290
Brick & Tile 2	425	415	385	360	390	......	330	320	335	......	310	250
Miller 1	(350)	——	——	——	——	......	——	——	——	......	——	——
Smith Webber 1	475	450	400	400	390	......	360	350	355	......	315	305
Smith Avis 1	585	555	507	487	480	......	450	450	460	......	420	415
Lockridge 1	595	480	425	375	360	......	275	265	250	......	360	365
Panhandle 1	470	460	425	400	400	......	375	375	355	......	310	310
Clayco Stine 1	585	570	530	507	507	......	480	470	420	......	420	440
Holloway 2	475	480	420	(280)	465	......	280	425	375	......	355	[b]505
Holloway 4	——	——	——	——	——	......	——	405	420	......	365	355
Taylor 2	——	——	——	——	——	......	——	——	——	......	——	——
Skelly 1	——	455	415	——	400	......	——	——	360	......	320	315
Skelly 4	465	465	420	405	400	......	370	365	360	......	335	325
C. P. Stine 1	——	——	——	——	——	......	——	——	——	......	420	——
Brotherton 1	......	......	......	......	......	......	......	......	......	......	320	315
Holmes 1	......	......	......	......	......	......	......	......	......	......	......	320
Total number wells	25	25	25	25	26	......	28	28	28	......	29	30
Total number off test	9	7	6	8	8	......	7	5	4	......	5	5
Total number tested	16	18	19	17	18	......	21	23	24	......	24	25
Average per well	511	485	434	431	432	......	388	379	377	......	341	344

[a] Wells not in use.
[b] Closed 16 hours before test.

Figures in parentheses are estimates, the wells being impossible to shut in for test.
A dash (——) indicates that well was in bad order and no test was made.
Totals do not include records in parentheses.

Rock pressures of gas wells at Petrolia, Tex.—Continued.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1915.												
Byers 1	—	—	—	—	—	—	—	—	—	—	—	......
Byers 4	485	425	435	480	455	465	455	450	440	435	430	......
Byers 5	245	280	265	240	240	240	240	240	230	225	225	......
Byers 6	195	185	175	155	150	185	175	170	160	155	130	......
Byers 12	175	150	130	135	100	100	55	—	—	—	—	......
Byers 15	180	165	145	145	145	150	140	130	110	120	110	......
Byers 17	175	160	115	140	135	135	65	—	—	—	—	......
Byers 19	465	475	465	455	435	435	420	410	400	390	385	......
Byers 20	530	530	475	455	445	445	430	420	400	345	335	......
Holt 1	360	355	350	330	320	325	325	320	305	300	300	......
Matlock 1	310	345	335	335	320	320	330	335	320	315	315	......
Landrum 1	355	350	345	325	335	325	325	310	295	310	300	......
Schnell 1	—	—	—	—	—	—	—	—	—	—	—	......
Schnell 2	355	345	335	335	315	325	310	320	310	310	310	......
Brick & Tile 1	295	265	275	285	250	310	285	260	235	240	255	......
Brick & Tile 2	240	235	210	205	185	265	290	300	295	290	290	......
Miller 1	320	300	305	305	300	300	285	300	300	300	300	......
Smith Webber 1	295	290	300	290	280	280	295	285	290	285	285	......
Smith Avis 1	405	415	410	415	390	395	395	390	385	375	370	......
Lockridge 1	—	—	—	—	—	395	400	390	370	355	335	......
Panhandle 1	315	325	320	310	305	300	310	305	295	295	280	......
Clayco Stine 1	425	445	425	435	420	420	415	410	400	385	370	......
Holloway 2	410	460	420	340	440	350	455	470	460	265	290	......
Holloway 4	345	345	335	335	335	335	335	335	330	320	315	......
Taylor 2	......	......	Disconnected.		......	......	......	......	......	......	......	......
Skelly 1	310	315	300	310	305	300	310	295	290	285	280	......
Skelly 4	315	315	315	315	295	295	300	295	280	295	290	......
C. P. Stine 1	—	—	—	—	—	—	—	—	—	—	—	......
Brotherton 1	250	280	255	285	290	255	200	160	150	135	155	......
Holmes 1	240	280	255	285	290	255	195	155	150	120	145	......
Culbertson 1	240	245	195	225	260	240	190	155	130	95	—	......
Hammond 1	350	350	340	325	320	320	325	320	300	305	305	......
Patterson 1	......	......	305	290	285	290	290	280	260	265	265	......
Beatty 1	......	......	440	420	400	400	395	360	350	330	320	......
Minnick 1	......	......	......	—	—	—	—	—	—	—	—	......
Landrum 2	......	......	Not in use.		......	[a] 325	325	320	305	310	300	......
Smith Webber 2	......	......	......	......	......	......	200	180	—	—	150	......
Brotherton 2	......	......	......	......	......	......	Plugged; mudded up.			......	......	......
O. G. Stine 1	......	......	......	......	......	......	......	......	175	175	165	......
Myers 1	......	......	......	......	......	......	......	......	215	205	205	......
Total number wells	32	31	33	34	34	35	37	37	39	39	39	......
Total number off test	5	4	4	5	5	4	5	7	8	8	8	......
Total number tested	27	27	29	29	29	31	32	30	31	31	31	......
Average per well	318	320	309	307	302	306	296	302	288	275	274½	......

[a] Wells not in use.

The average closed pressure of these wells is shown diagrammatically in Plate II.

The capacity of the wells—that is, the quantity of gas which they are capable of yielding per day—has not been so carefully measured as the closed pressure. The tests are more difficult to make and involve considerable loss of gas. The individual wells had an estimated initial capacity of 10,000,000 to 40,000,000 cubic feet of gas a day and a "settled" capacity of 5,000,000 to 35,000,000 cubic feet. Estimates as to settled production are unsatisfactory, not only because they are rarely based on careful tests but also because there is no such thing as a fixed settled production. The capacity decreases continuously, and though not so rapidly after a year or two as at first, the decline continues at a perceptible rate.

The facts that Dallas uses only about 12,000,000 cubic feet of gas a day and that the 50 wells of the Petrolia field are reported to have capacities of 10,000,000 to 40,000,000 cubic feet each may seem to the casual reader incompatible with any suggestion of shortage. The fact is, however, that the capacities of the wells are not so great, and for various reasons it is not possible to market all or even a large part of the capacity of wells. The general conditions should be regarded by all as calling for taking good care of the supplies available.

Number, thickness, and extent of the sands.—Three principal and several subordinate sands, all more or less lenticular, yield gas in the Petrolia field, the three principal sands being more than 1,500 feet below the surface. As reported in the logs of wells, the average thickness of sand, exclusive of dry, oil, and water sands, is about 30 feet. However, many wells have not been sunk through all of the pay sands, and hence the average "pay" penetrated in the wells is only about 25 feet.

The volume of pay sand in the Petrolia field can not be determined with great precision, but a fairly accurate estimate may be made from the average total thickness of pay sands and the area of the field. If the boundary of the field be defined as shown on the map (Pl. I), so as to include the main mass of productive wells, its area is a little over 7½ square miles. This boundary, however, leaves out the "Ninety-nine" well, which is just outside the area mapped, and no doubt considerable areas underlain by gas-bearing sand. The full extent of the gas pool is probably about 15 square miles, an area indicated by the fact that the favorable structure extends beyond the borders of the field as now developed, by the relation between closed pressures and amount of gas produced, and by the application of the doctrine of chances to the percentage of successful wells about the margin of the present field. If 15 square miles be taken as a minimum and the average thickness of pay sand 30 feet, the total volume of pay sand is about 12,545,000,000 cubic feet.

Pore space of the sands.—Fragments of the producing gas sand large enough for tests of pore space are difficult to obtain, but a few fragments one-quarter to one-half inch and one 2 inches in diameter were procured. Some of these were tested by C. E. Van Orstrand and some by the writer and their pore space was found to range from 18.5 to 27 per cent. The results are not so satisfactory as they would have been if more and larger specimens had been available, but it is fairly safe to assume that the average pore space of the sand is at least 20 per cent and not more than 25 per cent. At 20 per cent the total volume of pore space occupied by gas in the known gas field would be about 2,509,000,000 cubic feet.

Original amount of gas.—The quantity of gas originally in the Petrolia field may be computed roughly from the total volume of pore space in the gas-bearing rock and the gas pressure at the time the first gas well was drilled. If the average original pressure was 725 pounds to the square inch the gas would have occupied a little more than one-fiftieth of the space it would have occupied at 8-ounce pressure. If the area originally underlain by the gas were 15 square miles, the average thickness of pay sand 30 feet, the average pore space 20 per cent, and the pressure 725 pounds per square inch, the original quantity of gas would have been 120,432,000,000 cubic feet, which, if all recovered and used at an average rate of 10,000,000,000 cubic feet per year, would last 12 years. The production could not, of course, be kept up at this rate until the gas had been exhausted, so there would be a gradual decline in the production and the life of the pool would be somewhat longer.

Quantity of gas thus far produced.—The quantity of natural gas produced in Clay County from 1907, the year the first well was drilled, to 1915 is about 37,000,000,000 cubic feet. This figure is based on the statistics showing the quantity of gas marketed. An estimate based on the pressure gradient and the thickness, volume, and percentage of pore space of the sand gives, however, a considerably larger figure, and it seems that the field has been depleted by about 50,000,000,000 cubic feet, the difference being the wasted and other unmarketed gas.

Quantity of gas remaining.—Estimates of gas in the earth, based on pressure curves, depend for accuracy largely on the fact whether or not water follows up the gas in the sand as fast as the gas is removed. If the water does not follow up the gas in the sand then the difference in closed pressure from time to time should indicate rather accurately the amount of gas that has been removed, because if the volume of gas remains stationary Boyle's law demands that the quantity must decrease about as the pressure decreases.[1] If, however, as the pressure decreases water flows into the sand because it has access and is under great pressure, the closed pressure will not decrease so rapidly as the volume in the sand decreases on account of production. If a very large volume of water under the same pressure as the original gas pressure in the pool had free access to the sand, and if the gas were removed from a well in the middle of a pool, it is conceivable that water might follow up and keep the pressure practically as high as the initial pressure until the pool was exhausted. In the Petrolia field water has apparently followed up the gas to an appreciable though small extent so that the closed pressures are not a close index of the rate of depletion, but, on account of discontinuity of sands and consequent lack of free access of water, the pressures have no doubt fallen off nearly as rapidly as the volume

[1] R. F. Earhart and S. S. Wyer, in manuscript to be published by the American Society of Mechanical Engineers, state that Boyle's law is not closely applicable to natural gas. Samples of gas were found to expand more rapidly than the pressure decreases. Presumably this does not imply that Boyle's law needs revision, but it does imply a molecular rearrangement in some of the constituent gases; also, as has long been known, many gases do not expand precisely as pressure decreases, even though apparently no molecular rearrangement takes place.

has decreased. The basis for this inference is (1) that the pressures have fallen off in nearly the same proportion as the depletion of the field, as indicated by the statistics of production, probable waste, and computations of the original volume of pore space, and (2) the marginal wells have not yet shown a much greater tendency to "go to water" than wells in the middle of the fields. Of course, it is not to be expected that there should be a regular dropping out of wells from the margin toward the center of pools, because water may take the place of gas in a well in the middle of a field on account of unusually open sand about the well or because an unusual quantity of gas may be taken from the well, for water generally has access to the pay part of the gas sand from below as well as from the sides. Other factors also may prevail to keep a well productive or to render it unproductive notwithstanding its location.

An important factor in the length of life of any gas pool is the completeness of extraction which is possible. Because of irregularities in composition and structure of sand, obviously not every atom of gas can be taken from the sand, and many pools have been abandoned which may still contain a considerable quantity of gas. However, on account of the great original pressure and the consequent relatively small original volume of the gas, together with its elasticity, it is apparent that when the pressure in a well has been reduced nearly or quite to zero, the percentage of the original amount of gas remaining in the sand and having access to the well must be low.

Possibility of extension of field.—A most interesting question concerning any discovered gas or oil field is whether or not the producing area may be extended, either by discovering that the sands continue, under favorable structural relations, into neighboring areas, or by finding new sands in the areas that are already producing from other sands. The average of all opinions, estimates, and guesses is generally well reflected in the prices asked and given for property in and about the margins of the pool, and it is interesting to compare such opinions with those based on a geologic survey. Judging by real estate values the operators in the Petrolia field do not seem to expect any great extension. Land about the margin of the productive area is almost as cheap as land at some distance from it, and the prices of oil and gas land within the area seem to depend largely on the quantity of oil or gas now being produced. Indeed, it may be said that a gas well in the middle of the field will not bring a much higher price than the cost of drilling and equipping the well.

On the other hand, the results of geologic work indicate that the field is likely to spread laterally in one or two directions. The attitude of the rocks is favorable to an extension of the field a mile or two beyond the limits of the proved area both to the east-northeast and to the west-northwest. A favorable structure in the area to the east-northeast is indicated by outcropping beds, the altitudes of which at many points were determined by H. M. Robinson. Contours based on these altitudes are shown in Plate I. The inferences formed concerning structure in the area to the west-northwest are based on well logs, which indicate that the contours open out in that direction. The outcrops in this area are not sufficient for satisfactory structural work, so the precise attitude of the rocks is not known, but there is good reason to expect an extension of the field in that direction.

The stratigraphy of the Permian and Pennsylvanian formations indicates that they include many beds of sandstone, which are pretty well distributed from top to bottom and many of which are adapted to form good oil and gas reservoirs. Below the bottom of the deepest well yet drilled in the Petrolia field there are several sands that may form good oil and gas reservoirs. This conclusion is further supported by the logs of the deepest wells drilled in surrounding territory. For example, in the well drilled to a depth of nearly 4,000 feet on the Halsell farm, near Henrietta, sands are reported at fairly short intervals to a depth of 2,400 feet, and occasional thin layers of sand are reported at greater depths. The well recently drilled a few miles southwest of Waurika, still nearer the Petrolia field, shows also numerous sands down to 2,000 feet, some of which would make good oil reservoirs were the structure and other conditions favorable. The log of the Halsell well, samples from which were studied by Professor Udden, is given in his report on this region and also in M. J. Munn's report on the Grandfield district, Oklahoma. The log of the lower part of the Waurika well is given below. One or more of these deeper sands may contain gas in paying quantities, despite the fact that one or two lower sands already penetrated in wells within the proved field are barren. One of these barren sands in particular is known to some drillers as the "Gulf of Mexico," because it yields immense quantities of salt water. The fact that its yield of salt water is so great may indicate that a short distance away there is a gas pool under great pressure which forces the water out of the sand and causes the wells tapping it to flow copiously.

The history of most gas fields justifies the inference that deeper productive sands may lie below sands now producing. This inference does not apply to some fields, such as certain Illinois oil fields, where the productive sand is underlain by formations that do not contain porous strata. In many apparently exhausted pools, however, deeper drilling has struck lower productive beds. The development of important though not great extensions of the producing areas in the sands now tested may therefore be expected, and also the finding of some gas in underlying sands not yet touched in the structurally higher parts of the pool. Since as a general rule the deeper the gas sand the more the gas is compressed, any gas found below the sands now producing is likely to be under high pressure.

Probable life of the field.—By plotting the average closed pressure of all the wells of the field month by month in the form of a curve, the pressures being shown as abscissas and the time as ordinates, a formula may be deduced from which the probable life of the field may be estimated by extrapolation or by extending the curve according to the formula. An estimate of the length of life of the Petrolia field made in this way indicates that the closed pressure will reach zero in 5 or 10 years.

For practical purposes three additional facts must be taken into consideration. One, which has already been noted, is that the pressure curve is probably not declining quite so rapidly as the loss of supply, because water and oil follow up the gas to a certain extent and keep the pressure higher than it would otherwise be. The second is that when gas is under high pressure in the presence of oil a considerable quantity dissolves in the oil and is given off when the pressure is relieved, so that really the pool originally contained and still contains more gas than would be indicated by the pressure and the amount of pore space. The third is that some time before the pressure reaches zero it will become impracticable to market the gas unless some special device is used to make complete extraction possible, in which event the life of the field will be lengthened but the daily output greatly diminished.

The problem may be approached in still another way. Comparison may be made with other gas pools now abandoned which had similar areas, sands, pressures, and market demands. Of course every pool is to a certain extent unique, so the results of such a comparison can not be precise. The approximation has, however, much value, and if the length of life of the Petrolia field as now developed be estimated in this way, the conclusion is reached that the pool will last five or six years longer.

The above figures are independent of the probable extension of the field, both as to area and as to number of producing sands. When allowance is made for these facts the figures are increased by 40 to 50 per cent, and after making proper allowances and adjustments the author reaches the conclusion that the Petrolia field will produce gas from 8 to 12 years longer, but that several years before the end of this period the annual yield will begin to fall off, notwithstanding the fact that new wells will be brought in and that powerful pumps will be used to keep the production up, so that much sooner the cities of Dallas and Fort Worth will need to look to other fields for an adequate supply for even domestic use.

Quality of gas.—The chemical constitution and heating value of the gas in the Petrolia field are shown by the following typical analyses:

Analyses of three samples of gas from Petrolia field.

[Nos. 6751 and 6752 are from Wichita Falls Gas Co.'s No. 1 Matlock well, which supplies the town of Petrolia; the third sample (X) is from Beatty No. 1 well, and the figures were furnished by the Lone Star Gas Co. Bureau of Mines, Nov. 19, 1915; G. A. Burrell, analyst.]

	6751	6752	X
CO_2	Trace.	0.2	0.2
O_2	.0	.0	.0
CH_4	48.5	48.4	52.7
C_2H_6	12.8	12.8	9.3
N_2	38.7	38.6	37.8
Total	100.0	100.0	100.0

6751 and 6752. Specific gravity (air=1), 0.78; heating value per cubic foot at 0° C. and 760 millimeters pressure, 755 British thermal units.
X. Specific gravity (air=1), 0.76; heating value, 734 British thermal units.

The most striking and important characteristic is the high nitrogen content of the gas. On account of the large percentage of this inert element the heating value is only 755 British thermal units, or about the same as that of artificial coal gas, whereas the Mexia and many other natural gases show over 1,000 British thermal units. Another interesting character is the presence and quantity of the ethane (C_2H_6) reported by the Bureau of Mines—a gas that has a heating value of more than 1,700 British thermal units and a specific gravity nearly twice that of methane (CH_4). It has also a much greater illuminating value than methane. The ethane suggests a relation between the gas and associated oil and next to the nitrogen constitutes the most important point of difference between the Petrolia and the Mexia gas. The fact that it is possible to extract considerable gasoline from the gas, one small plant for this purpose being already in operation, suggests that the part reported as ethane includes other substances.

Numerous tests made by the city of Dallas seem to show an increase in heating value of the gas since the compressor plant was built at Petrolia, the rise being from about 750 British thermal units to about 800 British thermal units based on a freezing point temperature and 30 inches of atmospheric pressure.

OTHER KNOWN GAS FIELDS IN TEXAS NORTH AND WEST OF FORT WORTH.

ELECTRA-BURKBURNETT FIELD.

The oil-producing sands of the Electra-Burkburnett field are probably not a potential source of natural gas, though some wells in it have capacities of more than a million cubic feet, but it is possible that small pools of gas exist in deeper sands not yet penetrated. The pertinent facts are that the structure in the Electra-Burkburnett field is favorable to the accumulation of both oil and gas, though more favorable to oil, that the formations are such as yield gas elsewhere, and that sands suitable for gas reservoirs have not yet been reached by the drill in many parts of the producing field, and some have not been reached anywhere within it. There is no reason to expect that the field will ever produce much gas, though it may produce enough to be worth piping to some nearby towns.

STRAWN OIL AND GAS FIELD.

The Strawn oil and gas pool lies just west of the town of Strawn, in the southwest corner of Palo Pinto County. The most thickly drilled portion of the field is about 2 miles west of the town, where most of the wells are oil wells. Most of the gas wells are 1 to 2 miles south of the main oil area, though there are some gas wells among the closely spaced oil wells. Other oil and gas wells are scattered over an area 2 or 3 miles from east to west and 9 miles from north to south, and among them are several dry holes. The field is only about a year and a half old, but about 100 wells, most of which are producing, have been drilled. Many of these wells are productive, and the output of oil is now said to be 400 or 500 barrels of oil a day. The combined capacity of the gas wells is probably about 50,000,000 cubic feet per day. Most of the wells are between 800 and 1,000 feet deep and have been drilled with Star machines. Gas was found some time before oil.

The rocks at Strawn belong to the Canyon and Strawn formations (Pennsylvanian), and the pool, like the one at Moran, though stratigraphically considerably lower, is in strata which are favorable to the formation and accumulation of both oil and gas. The beds are of the same age as others that contain oil and gas elsewhere, they are carbonaceous, they have numerous sands of varying porosity, and they have not been tilted about and disrupted until the oil, gas, and salt water have been washed out or allowed to escape. The structure, as determined by H. M. Robinson and C. W. Hammen, and shown in Plate III, is roughly that of a dome on a terrace and is favorable to the accumulation of oil and gas. The dome is, however, flat or low—much lower than that at Petrolia—and this fact, together with the well data, suggests that the volume of oil in the sands is greater than that of gas. The general dip is northwest about 70 feet to the mile. The field is little more than half as far from Fort Worth and Dallas as the Petrolia field and is a possible source of gas for those cities, but the present capacity of the field is not nearly great enough to warrant piping so far, and it is somewhat doubtful whether even if it were entirely drilled the field would furnish so great a quantity of gas as to warrant piping to Fort Worth.

Logs of two wells showing the number, thickness, and distribution of the sands are given below.

Log of Palo Pinto Oil Co.'s well No. 5, on the Swenson farm, 2 miles west of Strawn, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and clay	10	10
Water, sand, and gravel	10	20
Shale, blue	50	70
Lime, hard	27	97
Shale, blue	113	210
Shale, hard, and bowlders	12	222
Shale, blue	38	260
Red rock	25	285
Shale, blue, and bowlders	285	570
Sand	5	575
Shale, blue	19	594
Sand	10	604
Shale, blue, and bowlders	161	765
Gas sand	5	770
Shale, blue	45½	815½
Sand, broken	22½	838
Hard water sand	1	839
Oil sand	4	843
Sand, blue	1	844

Log of Bendrum & Trees well No. 1, on Ackermann tract, in southwest corner of Palo Pinto County.

	Thickness.	Depth.
	Feet.	*Feet.*
Sandstone	44	44
Limestone, hard	41	85
Shale, blue	315	400
Red rock	15	415
Limestone, hard	9	424
Shale, blue	476	900
Limestone and sandstone	18	918
Shale, blue	27	945
Sand, hard, gray	19	964
Shale, blue	41	1,005
Sand, hard, show of oil	17	1,022
Limestone shell	8	1,030
Shale, blue	30	1,060
Limestone shell	6	1,066
Shale, blue	39	1,105
Limestone, blue	4	1,109
Shale, blue	56	1,165
Sand, close, show of oil	10	1,175
Sand and shale	7	1,182
Sand, hard, red, show of gas	6	1,188
Sand, water	37	1,225
Shale, blue	45	1,270
Shale, sandy	10	1,280
Shale, blue	25	1,305
Shale, sandy	69	1,374
Sand, water	9	1,383
Shale, blue	9	1,392
Sand, water	9	1,401
Limestone shell	3	1,404
Shale, blue	31	1,435
Shale, sandy	11	1,446

Some small faults have been observed near Strawn. In the Mount Marion mine a fault trending N. 75° W. and having a downthrow on the southwest side of 15 feet has been traced for 3,000 feet.

A generalized section of the rocks exposed in the Strawn field has been compiled by H. M. Robinson and is given below:

Generalized section of rocks exposed in Strawn oil and gas field, Texas.

	Feet.
Conglomerate, chert, and quartz pebbles, with siliceous cement; pebbles average one-fourth inch in diameter, fairly well rounded	1
Limestone, weathers gray; fresh surface shows numerous calcite veinlets; contains a bed of conglomerate 1 foot thick; makes top of Loyd Mountain	45
Shale, gray	10
Limestone, sandy; numerous crinoid stems and other fossils	5
Clay, bluish gray; numerous white streaks and blotches	5
Shale, sandy	5
Sandstone, buff, loosely cemented, irregularly bedded; cross-bedding common	15
Shale and clay, bluish gray	15
Sandstone and sandy shale; sandstone is buff and on the whole is irregularly bedded; cross-bedding common	55
Interval for most part grassed; presumably made up mostly of shale; some sandy shale and one or two limestones each about a foot thick	110
Limestone, resistant, exposures poor; estimated thickness	2
Shale and shaly sandstone; exposures poor	20
Sandstone, light brown, massive, thick bedded, grains medium size and fairly well rounded; weathers to dark rusty brown, massive, irregular blocks; generally closely cemented	3
Sandstone, brown, massive, loosely cemented in some portions; some portions very friable, slightly coarser grained than member immediately above. Grains mostly quartz. Pore space comparatively large in some parts of the member. In some places minute cross beds less than an inch thick are evident. Olive-colored specks as large as a small pea and imperfect cross bedding are common in lower part. Cross beds average about 1 foot in thickness	50
Sandstone very similar to that above but contains much more iron. Apparently because of irregularity in distribution of the cementing material, the sandstone weathers into very irregular shapes. In lower portion of member are some light-brown specks and streaks which are probably $FeCO_3$	10
Interval of grassy slope, more gentle than the upper concealed interval, probably friable sandstone, light gray	12
Limestone, very arenaceous. This member forms the top of the first terrace below top of the main ridge in the field. Light gray, weathering darker, fine-grained, fairly well cemented, weathered surface hard and smooth. This member contains a resistant ledge just above the fossil horizon, which is the key rock used for the structure map (see Pl. III)	10
Limestone, light gray, beds rather thin, averaging 1 to 2 inches. Highly fossiliferous. Abundant crinoid stems, Productus (?), and Bryozoa (?); breaks with an irregular fracture	12
Sandstone, cream-colored, very fine grained. Calcareous. Bedding fairly well developed; beds average about 4 inches thick; well cemented. Weathers darker in color	7
Shale, sandy at base and top, light buff	8

	Feet.
Sandstone, very calcareous; abundant crinoid stems; some as large as 1 inch in diameter and several inches long	1
Shale, sandy, and thin sandstone beds 2 inches to 1 foot thick; tan-colored in the main	60

The quality of the gas is shown by the following analyses:

Analyses of two samples of gas from Strawn oil and gas field.

[No. 6838 is from Stuart Bros.' well No. 10 (Texas Pacific Coal Co. No. 37), from pipe line one-fourth mile from well. No. 6839 is from Texas Pacific well No. 15, from pipe line 1 mile from well. Collector, H. M. Robinson. Bureau of Mines, Dec. 17, 1915. G. A. Burrell, analyst.]

	6838	6839
CO_2	0.00	0.00
O_2	.00	.00
CH_4	79.00	78.20
C_2H_6	13.90	12.90
N_2	7.10	8.90
	100.00	100.00
Specific gravity (air=1)	0.65	0.66
Heating value at 0° C. and 760 millimeters pressure per cubic foot	1,100	1,072

MORAN OIL AND GAS FIELD.

The Moran oil and gas field lies southeast of Albany, near the southeast corner of Shackelford County. The 40 or 50 producing wells are, as at Strawn, scattered over an area 2 or 3 miles across, and among them are occasional dry holes. Most of the oil wells are from 1 to 2 miles west of the town, and the gas wells, which are much less numerous, are to the east of the oil wells. The yields of the wells, even of wells that are close together, differ greatly. One 5-barrel well is only one location from a 600-barrel well, which is only two locations from a dry hole, and one location farther there is a well which at first yielded only a show of oil, then 25 barrels a day and a good showing of gas, and then went dry. Another well is reported to have made 3,000,000 cubic feet of gas for about four days and then to have changed abruptly to an oil-water well.

It has been known for years that the field contained natural gas in paying quantities, but active drilling did not begin until 1913. Exciting interest in the field began when the No. 1 Wild came in with a reported yield of 20 to 30 barrels of oil at the start and 40 to 50 barrels a little later. The No. 1 Edwards yields 100 to 200 barrels of light-gravity oil, reported to be 45° Baumé, from a depth of a little more than 2,500 feet.

The facts concerning the Moran field that are of principal interest to the people of Dallas and Fort Worth are that the geology of the district appears to be favorable to the existence of a valuable pool of oil and gas; that the rocks, except those near the surface, belong to the Pennsylvanian series, which commonly contain much gas; that the beds are carbonaceous, as they commonly are in oil and gas regions; and that the sands are lenticular and have not been so disturbed as to cause the oil, gas, and salt water to be washed out of them.

The field is evidently capable of producing considerable gas, though the present indications are that its yield will not be great enough to pay for a pipe line to Fort Worth and Dallas, which are farther from it than from Petrolia. Several logs showing the approximate number and thickness of sands and other features of the stratigraphy in various parts of Shackelford County are given below:

Driller's log of well No. 1 on Terry farm, Shackelford County, Tex., southeast corner SW. ¼ block 47, Lunatic Asylum land.

[Drilled August 1 to December 5, 1912.]

	Thickness.	Depth.
	Feet.	*Feet.*
"Surface"	130	130
Shale, blue	50	180
Red mud	20	200
Limestone, gray	10	210
"Slate," white	40	250
Red mud	25	275
Limestone	10	285
Red mud	15	300
Shale, blue	25	325
Shale, dark	25	350
Red mud	30	380
Limestone	5	385
Red mud	15	400
Limestone	10	410
"Slate," white	40	450
Shale, red	20	470
Sand, gray	5	475
Limestone, blue	15	490
Limestone	10	500
Shale, red	5	505
Red rock	45	550
Shale, blue	25	575
Limestone, gray	10	585
"Slate," white	15	600
Limestone	5	605
Shale, dark	10	615
Shale, light	25	640
Limestone	5	645
Shale, white	15	660
Sand, blue	10	670
Red rock	5	675
Sand, show oil	2	677
"Slate," black	3	680
Limestone, gray	5	685
Red rock	10	695
Brown shells	5	700
Pink shells	25	725
Lime, gray	25	750
Shale, gray	50	800
Red rock	30	830
Sand, water	20	850
Shale, gray	120	970
Shale, brown	30	1,000
Shale, gray	80	1,080
Shale, brown	20	1,100
Shale, gray	40	1,140
Limestone, gray	10	1,150
Shale, gray	40	1,190
Sand, salt water	50	1,240
Shale, gray	5	1,245
Limestone, gray	5	1,250
Sand, gray	5	1,255

Driller's log of well No. 1 on Terry farm, Shackelford County, Tex.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
"Slate" and shells	95	1,350
Limestone, white	130	1,480
"Slate," black	50	1,530
Sandy limestone and water	5	1,535
Limestone, white	145	1,680
Limestone, blue	80	1,760
Limestone, white	20	1,780
Water	10	1,790
6-inch casing	5	1,795
Limestone, blue	10	1,805
Limestone, crystalline	25	1,830
"Slate"	10	1,840
Limestone, white	70	1,910
"Slate," white	90	2,000
Limestone, white	10	2,010
"Slate," blue	6	2,016
Sand, water	4	2,020
6-inch casing	25	2,045
Limestone, blue	25	2,070
Limestone, white	10	2,080
Limestone, black, water	65	2,145
"Slate," black	5	2,150
Limestone, white	60	2,210
"Slate," black	5	2,215
Sand, white	20	2,235
Sand, black	35	2,270
Sand	15	2,285
Show of oil at 2,280–2,285 feet.		
Sand, white	15	2,300
4½-inch casing set at 2,300 feet.		
"Slate," black	50	2,350
Limestone, white	10	2,360
"Slate," black	40	2,400
Limestone, white, shells	40	2,440
"Slate," black	10	2,450
Limestone, white	40	2,490
Limestone, white, gritty	25	2,515
Red shell and cave	5	2,520
Limestone, white	10	2,530
"Slate," black	5	2,535
Limestone, white	15	2,550
Shale, blue	80	2,630
Limestone, white	5	2,635
Shale, blue	110	2,745
Sand, dark gray, hard, no water	20	2,765
Shells	30	2,795
Limestone, white, gritty	....	2,795
Water filled up hole 500 feet.		

Log of Corsicana Petroleum Co.'s well No. 1 on the Weddington farm, in Shackelford County, Tex.

[Contractor, J. W. Dyson. Drilled April to August, 1912. Casing: 13 inch, 416 feet; 10 inch, 1,116 feet; 8 inch, 1,520 feet; 6 inch, 1,785 feet; 5 inch, 2,720 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Shale, red	30	30
Limestone	4	34
Shale, dark	40	74
Limestone	5	79
Shale, white	50	129
Shale, red	21	150
Limestone, soft	35	185
Shale, white	10	195
Lignite, black	5	200
"Slate," black	15	210
Sand (6 boilers of water)	35	255
"Slate," white	50	300
Limestone	5	305
Coal	5	310
"Slate," black	20	330
"Slate," white	10	340

Log of Corsicana Petroleum Co.'s well No. 1 on the Weddington farm in Shackelford County, Tex.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand	35	375
Shale, white	10	385
Sand, white	20	405
"Slate," white	5	410
Limestone	10	420
"Slate," white	40	460
Limestone	10	470
"Slate," black	80	550
Limestone	15	565
"Slate," white, and limestone	20	585
"Slate," black, and limestone	25	610
"Slate" and limestone	25	635
"Slate" and shell	80	715
Limestone, sandy	15	730
"Slate," black	40	770
Sand	15	785
"Slate," black	60	845
Limestone	6	851
"Slate," white	50	901
Limestone	9	910
"Slate," white	20	930
Red cave	15	945
"Slate" and limestone	110	1,055
Black cave	40	1,095
"Slate," white	10	1,105
Sand	12	1,117
"Slate," black	5	1,122
Sand and shale	28	1,150
Limestone	15	1,165
Shale, black	4	1,169
Limestone	160	1,329
Sand, white	60	1,389
"Slate" and shells	135	1,524
"Slate," white	10	1,534
Limestone	11	1,545
"Slate," black, and shells	80	1,625
Limestone, sandy	50	1,675
"Slate" and limestone shells	110	1,785
Shale, black	90	1,875
Limestone and slate	50	1,925
Shale, pink	55	1,980
Limestone	20	2,000
"Slate"	80	2,080
Limestone	80	2,160
Limestone, sandy	40	2,200
"Slate" and shells	425	2,625
Limestone, sandy	10	2,635
"Slate" and shell	40	2,675
Limestone, hard	8	2,683
"Slate"	12	2,695
Limestone, hard	5	2,700
"Slate," white	10	2,710
Sand, white	9	2,719
"Slate"	6	2,725
Limestone, black, hard	5	2,730
"Slate," black	35	2,765
Limestone, sandy	40	2,905
"Slate" and shell	80	2,985
"Slate"	49	3,034
Bottom dry.		

Log of Reynolds No. 1 well, 3 miles north and half a mile west of Albany, Shackelford County, Tex.

[Drilled from Sept. 23, 1913, to Mar. 22, 1914.]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface	40	40
Limestone	12	52
Shale, white	13	65
Shale, pink	10	75
Shale, blue	20	95

Log of Reynolds No. 1 well, 3 miles north and half a mile west of Albany, Shackelford County, Tex.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Limestone and shells and white "slate"	85	180
Rock, red	45	225
Shale, blue	35	260
Shale, pink	10	270
Shale, blue	15	285
Shale, gray	135	420
Limestone	25	445
Shale, blue	10	455
Rock, red	12	467
Limestone shells	18	485
Shale, gray	40	525
Rock, red	15	540
Shale, white	20	560
Limestone	25	585
Shale, gray	5	590
Limestone	10	600
Shale, gray	25	625
Slate, black	10	635
Limestone	25	660
Slate, gray	35	695
Rock, red	20	715
Limestone	15	730
Rock, red	30	760
Shale, black	30	790
Limestone	15	805
Shale, brown	35	840
Rock, red	10	850
Shale, brown, show of oil	10	860
Shale, white	15	875
Shale, brown	35	910
Shale, blue	30	940
Limestone	15	955
Rock, red	5	960
Limestone	10	970
Shale, white	55	1,025
Limestone, white	95	1,120
Rock, red	5	1,125
Shale, white	65	1,190
Limestone, white	20	1,210
Shale, white	40	1,250
Rock, red	10	1,260
Shale, white	30	1,290
Water sand	40	1,330
Shale, white	10	1,340
Limestone, white	85	1,425
Shale, black	75	1,500
Limestone	60	1,560
Lime, sandy	7	1,567
Shale, black	28	1,595
Limestone, hard, shell	5	1,600
Shale, soft, dark	85	1,685
Limestone shells	10	1,695
Shale, gray	5	1,700
Limestone shells	10	1,710
Shale, soft, dark	60	1,770
Do	20	1,790
Shale, sandy, and water	25	1,815
Water sand	20	1,835
Limestone shells and sand	40	1,875
"Slate," sandy, very hard	20	1,895
Limestone, very hard	45	1,940
Shale, gray	10	1,950
Limestone	10	1,960
Shale, dark	35	1,995
Limestone, hard	5	2,000
Rock, red	20	2,020
Limestone shell	5	2,025
Shale, gray	5	2,030
Limestone	35	2,065
Shale, blue	25	2,090
Shale, dark	15	2,105
Water sand	30	2,135
Limestone, sandy	15	2,150
Shale, blue	40	2,190
Shale, gray	15	2,205
Shale, dark	35	2,240
"Slate," dark	10	2,250
Limestone (3 boilers water per hour)	20	2,270
Shale, dark	25	2,295

Log of Reynolds No. 1 well, 3 miles north and half a mile west of Albany, Shackelford County, Tex.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand, dry, gray	9	2,304
Limestone	9	2,313
Shale, dark	282	2,595
Limestone	5	2,600
Sand, gray, dry	5	2,605
Limestone	20	2,625
Lime, sandy, water	2	2,627
Lime	38	2,665
Sand, dry	5	2,670
Lime	87	2,757
Sand	20	2,777
Shale, black	83	2,860
Limestone, black	5	2,865
Shale, black	35	2,900
Limestone, water 4 boilers	5	2,905
Shale, black (top)	7	2,912
Lime	13	2,925
Shale, gray	87	3,012
Limestone	73	3,085
Shale, blue	35	3,120
Limestone, blue	30	3,150
Water sand	7	3,157
Limestone	....	....

Log of well on Cauble ranch, in Shackelford County, Tex., near northeast corner of county (north of Clear Fork).

[Drilled May 31 to Sept. 16, 1912.]

	Thickness.	Depth.
	Feet.	*Feet.*
"Cellar"	10	10
Clay, red	80	90
?	10	100
Shale	40	140
Limestone, white	5	145
Shale, white	13	158
Limestone, hard	3	161
Shale, white	94	255
Rock, red	5	260
Sand, white, salt water	25	285
Limestone, white, soft	35	320
Rock, red, top	50	370
Limestone, white	10	380
Shale, white	55	435
Limestone, black, hard	10	445
Shale, white	50	495
Rock, red	25	520
Sand, gray (little gas)	10	530
Shale, white	70	600
Rock, red	12	612
Limestone, white	18	630
Shale, white	20	650
Limestone, white, hard	10	660
Shale, white	30	690
Sand, gray, dry	10	700
Rock, red	30	730
Shale, white	70	800
Sand, white (salt water)	25	825
Shale, white	75	900
Shale, black, soft	20	920
Shale, white	150	1,070
Rock, red	5	1,075
Sand, black	52	1,127
Shale, black	11	1,138
Limestone shells	24	1,162
Limestone, white	22	1,184
Rock, red	36	1,220
Sand (salt water)	18	1,238
Shale, white	46	1,284
Limestone, white	4	1,288

Log of well on Cauble ranch, in Shackelford County, Tex.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Rock, red	42	1,330
Limestone, dark	20	1,350
Rock, red	35	1,385
Limestone, gray	25	1,410
Limestone, black	30	1,440
"Slate," white	50	1,490
Sand, black	40	1,530
Shale, black	139	1,669
Limestone, white	21	1,690
Shale, black	270	1,960
Limestone, gray, little water	6	1,966
Limestone, white	34	2,000
Limestone, black	12	2,012
Shale, black	28	2,040
Limestone, hard, gray	160	2,200
Shale, black	40	2,240
Limestone, hard, shells	12	2,252
Shale, black	26	2,278
Limestone, gray, and hard shells	6	2,284
Shale, black	11	2,295
Sand, black, salt water	18	2,313
Limestone, white, hard	17	2,330
Shale, black	35	2,365
Limestone, gray	12	2,377
Shale, black	63	2,440
Limestone, gray	6	2,446
Shale, black	9	2,455
Limestone, gray	25	2,480
Shale, black	20	2,500
Limestone, gray, hard	60	2,560
Shale, black	15	2,575
Limestone, black, top	4	2,579
Shale, white	61	2,640
Limestone, gray, hard	130	2,770
Shale, blue	37	2,807
Limestone, gray, shells	18	2,825
Shale, black	20	2,845
Limestone shells	30	2,875
Shale	42	2,917
Top sand	31	2,948
Sand, black	30	2,978

Log of Nelson No. 1 well, 3 miles north and 1 mile west of Moran, Tex., 200 feet north of south line and 800 feet west of east line Nelson lease.

[J. M. Guffey Petroleum Co. (½), Treat Crawford (¼), Lone Star (¼). Contractors, Halfest & Easton. Drilled Nov. 16, 1914, to Feb. 11, 1915. Casing: 12½ inch, 455 feet; 10 inch, 1,092 feet; 8 inch, 1,550 feet; 6 inch, 1,897 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface soil	35	35
Shale, blue	10	45
Rock	5	50
Limestone shell	3	53
Brown mud	5	58
Limestone shell	7	65
Brown mud	20	85
Limestone shell	5	90
Shale, blue	5	95
Rock, red	5	100
"Slate," white	20	120
Shale, blue	10	130
Limestone	6	136
Shale, blue	19	155
Limestone	10	165
Shale, white	35	200
Sand, show of oil	10	210
Rock, red	20	230
Brown mud	10	240
Rock, red	10	250
Brown mud	10	260
Limestone	15	275
Shale, brown	20	295

Log of Nelson No. 1 well, 3 miles north and 1 mile west of Moran, Tex.—Con.

	Thickness.	Depth.
	Feet.	*Feet.*
Rock, red	5	300
Shale, white	35	335
Limestone	5	340
Sand	10	350
"Slate," white	5	355
Limestone	27	382
Shale, black	18	400
Shale, light	30	430
Sand, salt water (hole full)	30	460
Brown mud	10	470
Shale, blue	10	480
Shale, brown	15	495
Shale, blue	5	500
Limestone	6	506
Shale, dark	12	518
Limestone	17	535
Shale, dark	15	550
Shale, light	5	555
Limestone	5	560
Shale, dark	55	615
"Slate"	5	620
Limestone	5	625
Shale, dark	25	650
Limestone	10	660
Slate, white	5	665
Shale, dark	15	680
Sand, salt water (hole full)	20	700
"Slate," dark	50	750
"Slate," white	30	780
Shale, dark	10	790
Shale, brown	42	832
Shale, dark	48	880
"Slate," white	20	900
Shale, light	20	920
Limestone	8	928
Shale, dark	72	1,000
Shale, black	5	1,005
Shale, white	20	1,025
Sand	30	1,055
Water at 1,032 feet.		
Shale, white	90	1,145
Do	7	1,152
Limestone ("big lime")	43	1,195
Shale, light	50	1,245
Limestone	40	1,285
Water at 1,255–1,285 feet.		
Shale, black	15	1,300
Limestone	153	1,453
Water at 1,342–1,372 feet.		
Slate, white	5	1,458
Lime, sandy	15	1,473
Shale, dark	27	1,500
Limestone	8	1,508
Limestone, sandy, water	4	1,512
Limestone	45	1,557
Shale, light	23	1,580
Sand, water	10	1,590
Shale, light	15	1,605
Shale, dark	95	1,700
Limestone shells	5	1,705
Shale, light	37	1,742
Limestone	5	1,747
Shale, blue	45	1,792
Limestone	23	1,815
Sand (hole full of water)	22	1,837
Shale, light	60	1,897
Limestone	33	1,930
Shale	13	1,943
Limestone	12	1,955
Shale, white	7	1,962
Shale, black	6	1,968
Slate, dark	32	2,000
Shale, light	25	2,025
Shale, dark	45	2,070
Limestone shells	3	2,073
Shale, light	32	2,105
Sand	15	2,120
Hole full of water. Abandoned.		

PALO PINTO GAS SHOWINGS.

The possibility of developing gas or oil in the region north of Palo Pinto has recently been discussed by Wegemann,[1] who suggested that tests be made of deeper sands in the vicinity of the Dalton well on the Kyle Mountain anticline. The structure of the region, including a plunging anticline and minor lateral folds, was correctly described by Mr. Wegemann though, through inadvertence, it was erroneously contoured on the map. A revision of the contouring has recently been published by L. J. Pepperberg.[2] Mr. Wegemann suggests a test of a small anticline 4 miles north of the Brazos River bridge on the Palo Pinto-Graford road, should an adequate test of the Kyle Mountain anticline prove successful.

Gas showings of greater or less size have been found in various parts of Palo Pinto County. A good showing of both gas and oil has been found in a 2,600-foot well recently drilled on the Frank Corn land in the southeast part of the county. The first notable showing in the county is said to have been found in a water well 4 miles north of Palo Pinto. A good oil well and also a gas well having a capacity of 500,000 cubic feet were reported in December, 1915.

A log of a recently drilled deep well to illustrate the strata encountered in drilling in this county is given below.

Log of well No. 1 on Holt ranch, 6 miles southwest of Salesville, Sykes & Palaint, operators.

[Contractor, L. C. Hevick. Drilled September, 1915.]

	Thickness.	Depth.
	Feet.	*Feet.*
Red dirt	4	4
Shale in small shell	46	50
Shale, blue	40	90
Shell, lime	10	100
Shale, blue	40	140
Shell	8	148
Shale	47	195
Shell	5	200
Shale, blue	45	245
Lime shell	10	255
Shale, blue	125	380
Water sand, fresh	20	400
Shale	20	420
Water sand, fresh	20	440
Shale	120	560
Lime shell	12	572
Water sand	283	855
"Slate"	39	894
Water sand, salt	136	1,030
"Slate"	75	1,105
Water sand, salt	10	1,115
"Slate"	55	1,170
Lime shell	6	1,176
"Slate"	29	1,205
Shale, sandy	20	1,225
Shale, blue	10	1,235
Shale	140	1,375

[1] Wegemann, C. H., A reconnaissance in Palo Pinto County, Tex., with special reference to oil and gas: U. S. Geol. Survey Bull. 621, pp. 51–59, 1915.

[2] Pepperberg, L. J., Western Engineering, vol. 6, No. 6, pp. 252–254, San Francisco, Dec., 1915.

Log of well No. 1 on Holt ranch, 6 miles southwest of Salesville—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand	25	1,400
Do	40	1,440
Do	130	1,570
"Slate"	60	1,630
Water sand	8	1,638
Shale, sandy	65	1,703
Shelly lime	37	1,740
Sand, show of oil	5	1,745
Shelly lime	45	1,790
Shale	15	1,805
Shell	5	1,810
Shale	85	1,895
Sand, dark, dry	20	1,915
Shale	12	1,927
Sand, with little water	19	1,946
Shale	56	2,002

SCATTERED SMALL GAS POOLS AND SHOWINGS.

Small showings of gas have been found in a great many wells in the region north and northwest of Fort Worth, but most of these probably have no connection with any considerable gas pool. The experience of the prospectors justifies this inference. It is commonly remarked that little puffs of gas may come from any well drilled in northern Texas, but that they have no significance. At several places, however, noteworthy quantities of gas have been found, though further prospecting has shown that the pools are small.

A brief examination was made of a small area just north of Mankins, about 20 miles southwest of Wichita Falls, where two or three showings of oil are reported in the log of an 850-foot well, but no good indications of a gas reservoir were found. Dundee, 15 miles farther southwest, where a 2,000-foot dry hole was recently drilled, was also visited. The rock outcrops a few miles south of Dundee are much better than at Mankins, and apparently the beds at both places lie nearly flat.

At Graham, in Young County, some gas was found only a few hundred feet below the surface, and as a consequence several deep test wells were sunk, the log of one of which is given below.

Driller's log of Corsicana Petroleum Co.'s well No. 1 on C. N. Keen farm, in Young County, Tex.

[Contractors, Halfest & Easton. Drilled July 4 to Oct. 5, 1912. Casing: $13\frac{1}{4}$ inch, 415 feet; 10 inch, 840 feet; $8\frac{1}{4}$ inch, 1,022 feet; $6\frac{1}{2}$ inch, 1,762 feet; $5\frac{3}{16}$ inch, 2,024 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Sand	30	30
"Slate"	75	100
Sand	35	145
"Slate"	35	170
Sand	20	195
"Slate"	105	305

Driller's log of Corsicana Petroleum Co.'s well No. 1 on C. N. Keen farm, in Young County, Tex.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Red rock	75	375
Coal	5	380
White cave	35	415
"Slate"	55	470
Sand	40	510
"Slate"	33	543
Sand	15	558
"Slate"	212	770
Sand	20	790
Cave	50	840
"Slate"	115	955
Limestone	25	980
Sand	12	992
Cave	30	1,022
"Slate"	60	1,082
Do	48	1,130
Limestone	40	1,170
"Shell"	5	1,175
Limestone	8	1,183
"Slate"	229	1,412
Limestone	13	1,425
"Slate"	10	1,435
Limestone	15	1,450
"Slate"	55	1,505
Limestone	45	1,550
Sand	70	1,620
"Slate"	30	1,650
Sand	25	1,675
"Slate"	10	1,685
Sand	35	1,720
"Slate"	10	1,730
Sand	10	1,740
"Slate"	85	1,825
Sand	8	1,833
"Slate"	17	1,850
Sand	25	1,875
"Slate"	10	1,885
Sand	15	1,900
"Slate"	540	2,440
Limestone	10	2,450
"Slate"	69	2,519
Sand	20	2,539
"Slate"	41	2,580
Limestone	10	2,590
"Slate"	23	2,613
Limestone	10	2,623
"Slate"	2	2,625
Limestone	11	2,636
"Slate"	124	2,760
Sand	10	2,770
"Slate"	5	2,775
Sand	21	2,796
Bottom dry. Abandoned.		

Strong showings of gas are reported from depths ranging from 255 to 696 feet in a 2,171-foot well drilled by the Producers Oil Co. on the R. F. Arnold farm 3½ miles south of Newcastle in Young County. The gas showings here and in the Murry well, about 8 miles distant, are said by some to have been decidedly the best so far found in Young County.

Several wells in Archer County have yielded small quantities of gas. At one well the gas is reported to have caught fire and burned with a flame many feet high, but these reports were not confirmed.

Showings of oil have also been reported in some test wells, the logs of three such wells being as follows:

Log of Corsicana Petroleum Co.'s well No. 1 on R. J. Garvey farm, in Archer County, Tex.

[Contractors, J. W. Dyson & Co. Drilled May 11, 1912, to July 12, 1912. Casing: 13¼ inch, 385 feet; 10 inch, 810 feet; 8¼ inch, 1,306 feet; 6⅝ inch, 2,325 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Red mud	20	20
Sand, white	10	30
Blue mud	30	60
Red mud	20	80
Sand	20	100
Blue mud	40	140
Red mud	25	165
Sand	10	175
Blue mud	70	245
Red mud	15	260
Sand	40	300
Red mud	10	310
Blue mud	30	340
Shale	25	365
Red mud	20	385
??	60	445
Shale	65	510
Limestone, white	15	525
Shale	25	550
Sand	30	580
Red mud	25	605
Sand	5	610
Limestone, hard	50	660
Shale	30	690
Do	50	740
Limestone	20	760
Sand	10	770
Shale and mud	60	830
Sand, show of oil and gas	20	850
Shale, white	60	910
Shale, sandy	30	940
Shale, dark	70	1,010
Shale, white	30	1,040
Shale, dark	50	1,090
Sand, white	20	1,110
Limestone	40	1,150
Shale	90	1,240
Limestone and shale	45	1,285
Limestone	30	1,315
Shale and limestone	240	1,555
Limestone	20	1,575
Shale	30	1,605
Limestone	10	1,615
Shale, dark	150	1,765
Shale, white	50	1,815
Sand, dark	10	1,825
Shale	85	1,910
Shale, sandy	140	2,050
Shale, dark	140	2,190
Shale, white	90	2,280
Limestone, dark	20	2,300
Shale	20	2,320
Sand	5	2,325
Shale	5	2,330
Sand	20	2,350
Shale	27	2,377
Bottom dry. Abandoned July 13, 1912.		

Driller's log of Corsicana Petroleum Co.'s well No. 3 on M. P. Andrews farm, in Archer County, Tex.

[Contractor, E. W. Morgan. Drilled September 3 to November 10, 1912. Casing: 13$\frac{1}{4}$ inch, 430 feet; 10 inch, 898 feet; 8 inch, 1,315 feet; 6 inch, 1,600 feet; 5$\frac{3}{16}$ inch, 2,100 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Red mud, sand, etc.	180	180
Sand, water	20	200
Red rock	90	290
Sand, water	20	310
Red rock	40	350
Sand, water	80	430
Shale, light	10	440
Red rock	15	455
"Slate," blue	95	550
Sand, dry	20	570
"Slate," blue	10	580
Sand, dry	10	590
"Slate," light	50	640
Limestone	15	655
"Slate," light	5	660
Sand, dry	30	690
Shale, light	20	710
Sand, water	40	750
"Slate," light	25	775
Sand, water	15	790
Shale, light	102	892
Limestone, hard	6	898
Shale, light	13	911
Sand, oil	13	924
Red rock	11	935
Sand, dry	10	945
Red rock	15	960
Shale, light	290	1,250
Sand, water	60	1,310
"Slate," white	90	1,400
Limestone	10	1,410
"Slate," blue	20	1,430
Shale, light brown	10	1,440
Limestone, white	10	1,450
Shale, blue	10	1,460
Limestone	6	1,466
Shale, blue	10	1,476
Limestone, white	20	1,496
Shale, light	29	1,525
Sand, water	30	1,555
Shale	10	1,565
Sand, water	115	1,680
Shale, light	30	1,710
Limestone	15	1,725
Shale, light	45	1,770
Limestone	25	1,795
Shale, light	165	1,960
Sand, water	80	2,040
Shale, light blue	10	2,050
Sand, water	10	2,060
Shale, light	30	2,090
Shale, sandy	110	2,200
Shale, dark	150	2,350
Shale, light	50	2,400
Limestone	5	2,405
Shale, light	10	2,415
Sand, dry	5	2,420
?, light	95	2,515
Sand, water	5	2,520
Dry. Abandoned May, 1913.		

Driller's log of Corsicana Petroleum Co.'s well No. 2 on Cora Harmonson farm, in Archer County, Tex.

[Contractors, J. W. Dyson & Co. Drilled July 28 to Dec. 12, 1912. Casing: wooden conductor, 357 feet; 13¼ inch, 357 feet; 10 inch, 711 feet; 8 inch, 1,332 feet; 6⅝ inch, 1,356 feet; 5$\frac{3}{16}$ inch, 1,590 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface	90	90
Sand, gray	10	100
Red rock	85	185
Sand, gray	20	205
Red rock	45	250
Slate	55	305
Red rock	2	307
Sand, water	83	390
Shale, blue	15	405
Red rock	10	415
Shale, blue	8	423
Red rock	7	430
Sand, gray, and coal	25	455
Red rock	85	540
Sand, gray	10	550
Sand, water	65	615
"Slate," white	5	620
Limestone	20	640
"Slate," gray	5	645
Sand, water	35	680
"Slate," gray	6	686
Limestone	66	752
"Slate," gray	123	875
Limestone	10	885
Shale	31	916
Sand (show of oil)	5	921
Shale	9	930
Limestone	5	935
Shale	17	952
Limestone	5	957
Shale and water	118	1,075
Sand	10	1,085
Shale	60	1,145
Sand	8	1,153
Shale, blue	72	1,225
Limestone	5	1,230
"Slate"	8	1,238
Sand, water	22	1,260
"Slate"	5	1,265
Sand, water	5	1,270
Limestone	8	1,278
Sand, water	37	1,315
"Shale"	82	1,397
Limestone	13	1,410
"Slate"	30	1,440
Limestone	10	1,450
"Slate"	5	1,455
Limestone	10	1,465
"Slate"	5	1,470
Limestone	25	1,495
Shale	25	1,520
Sand	40	1,560
Shale	155	1,715
Limestone	12	1,727
Shale	43	1,770
Limestone	15	1,785
Shale	15	1,800
Limestone	35	1,835
Shale	25	1,860
Limestone	15	1,875
Shale, blue	63	1,938
Abandoned May 1, 1913.		

Small showings of both gas and oil in Montague County have been reported, and a deep well has recently been sunk north of the town of Montague. A log of this well is given below.

Log of C. B. Shaffer well No. 1 on J. D. Jameson farm, Montague County, Tex.

[Drilled in 1915 with cable tools. Contractor, C. A. Steelsmith. Casing: 12½ inch, 638 feet (underreamed from 512 feet); 10 inch, 1,101 feet (underreamed from 780 feet); 8 inch, 1,704 feet (underreamed from 1,253 feet); 6⅝ inch, 22 feet (underreamed from 1,943 feet).]

	Thickness.	Depth.
	Feet.	*Feet.*
"Cellar" (sandy soil), soft	7	7
Sand, hard	3	10
Red rock, soft	15	25
"Slate," soft, white	50	75
Shale, soft, blue	90	165
Sand, soft, gray, much fresh water	45	210
Shale, soft, red	15	225
Shale, soft, blue	55	280
Sand, soft, gray, a little fresh water	10	290
"Slate," soft, white	10	300
Shale, soft, red	5	305
"Slate," soft, white	5	310
Sand, soft, gray, a little fresh water	5	315
Shale, soft, red	20	335
"Slate," soft, white	20	355
Sand, soft, gray, a little fresh water	15	370
Shale, soft, blue	10	380
Sand, soft, gray, a little fresh water	15	395
Shale, soft, blue	35	430
Sand, soft, gray, a little fresh water	10	440
Shale, soft, blue	70	510
Sand, soft, gray, a little fresh water	20	530
Shale, soft, blue	40	570
"Slate," soft, white	30	600
"Slate," soft, black	10	610
Shale, soft, blue	23	633
Limestone shell, hard, white	7	640
Shale, soft, blue	20	660
Sand, soft, gray, a very little fresh water	15	675
Shale, soft, pink	15	690
Shale, soft, brown	10	700
Shale, soft, blue	65	765
Sand, soft, gray, much fresh water	25	790
Shale, soft, blue	15	805
Shale, soft, pink	25	830
Shale, soft, red	20	850
Shale, soft, blue	10	860
Sand, soft, gray, much fresh water	20	880
Shale, soft, blue	10	890
Twelfth sand, soft, gray, fresh water	35	925
Shale, soft, blue	5	930
Thirteenth sand, soft, gray, fresh water	30	960
Shale, soft, blue	25	985
Shale, soft, red	25	1,010
Fourteenth sand, soft, gray, fresh water	25	1,035
Shale, soft, blue	5	1,040
Fifteenth sand, soft, gray, fresh water	45	1,085
Shale, soft, blue	5	1,090
Sixteenth sand, hard and sharp, gray, fresh water	10	1,100
Shale, soft, gray	5	1,105
Seventeenth sand, soft, gray, fresh water	10	1,115
Shale, soft, blue	15	1,130
Eighteenth sand, soft, gray, brackish water	35	1,165
Shale and limestone shells, soft and hard, gray	15	1,180
Nineteenth sand, soft, gray, brackish water	25	1,205
Shale, soft, blue	20	1,225
Twentieth sand, soft, gray, salt water	20	1,245
Shale, soft, blue	30	1,275
Twenty-first sand, soft, gray, slight salt water	30	1,305
Shale, soft, blue	25	1,330
Twenty-second sand, soft, gray, dry and coarse	8	1,338
Shale, soft, blue	17	1,355
Twenty-third sand, soft, gray, dry and coarse	8	1,363
Shale, soft, blue	82	1,445
Twenty-fourth sand, soft, gray, dry	7	1,452
Shale, soft, blue	48	1,500
Twenty-fifth sand, soft, gray, salt water	25	1,525
Shale, soft, blue	70	1,595
Twenty-sixth sand, soft, gray, salt water	20	1,615
Shale, soft, blue	60	1,675
Twenty-seventh sand, soft, black, dry and coarse	20	1,695
Shale, soft, black	15	1,710
Lime, black, hard	20	1,730
Shale, soft, black	35	1,765
Lime, hard, gray	10	1,775

Log of C. B. Shaffer well No. 1 on J. D. Jameson farm, Montague County, Tex.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale, soft, blue	55	1,830
Twenty-eighth sand, soft, gray, slight salt water	15	1,845
Shale, soft, blue	10	1,855
Lime, hard, white	20	1,875
Shale, soft, gray	40	1,915
Lime, hard, white	10	1,925
Shale, soft, gray	30	1,955
Lime, hard, white	15	1,970
Shale, soft, gray	50	2,020
Twenty-ninth sand, soft, gray, much salt water	20	2,040
Shale, soft, gray	35	2,075
Lime, hard, white	10	2,085
Shale, soft, gray	15	2,100
Lime, hard, white	10	2,110
Shale, soft, gray	20	2,130
Thirtieth sand, hard, gray, much salt water	10	2,140
Shale, soft, gray	20	2,160
Thirty-first sand, soft, gray, much salt water	15	2,175
Shale, soft, gray	5	2,180
Thirty-second sand, soft, gray, much salt water	40	2,220
Shale, soft, gray	5	2,225
Thirty-third sand, hard, gray, much salt water	15	2,240
Shale, soft, gray	5	2,245
Thirty-fourth sand, soft, brown, much salt water	1	2,246

Small showings of both oil and gas are reported from Cook and Denton counties and a well 2,365 feet deep has recently been sunk about 6 miles south of Denton by J. S. Darnall, of Denton, and P. L. Tippett, of Gainesville. These men are drilling another well between Myra and Red River in Cook County.

Small showings of oil are reported in some wells in the eastern part of Dallas County, but on the whole the sands underlying Dallas and Tarrant counties seem to have lost all the oil, gas, and salt water they ever had and are now filled with fresh water. A mile east of Paradise in Wise County good showings of oil are reported and a log of one well follows:

Driller's log of well 1 mile east of Paradise.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	5	5
Quicksand	35	40
Sand, white, water	20	60
Sand and shells	10	70
Sand, water	10	80
"Gipp rock"	4	84
"Trivally" sand	14	98
Sand rock	2	100
Pack sand	10	110
Gumbo, red	6	116
Sand rock	6	122
Sand rock, "crystallized"	3	125
Pack sand	1½	126½
Gumbo	1½	128
Shale, blue	6	134
Pack sand; set 10-inch casing at 154 feet	20	154
Sand rock	3½	157½

Driller's log of well 1 mile east of Paradise—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Pack sand	3	160½
Gumbo	4½	165
Sand rock	5	170
Gumbo	3	173
Sand rock	8	181
Gumbo	9	190
Shale, blue	56	246
Sand rock, hard, brown	26	272
Shale, blue	20	292
Gumbo, blue	5	297
Shale, blue	12	309
Sand rock	1	310
Shale, blue	18	328
Lime rock, blue	2	330
Gas rock	3	333
Shale, blue	7	340
Gumbo, blue	4	344
Sand rock	29	373
Gumbo	1	374
Sand, salt water	2	376
Sand rock, hard	23	399
Gumbo	4	403
Shale, blue	4½	407½
Lime rock	253	660½
Chalk (No. 1)	13	673½
Sand, blue	2½	676
Shale, blue	10	686
Sand, showing oil	30	716
Gumbo	26	742
Lignite	4	746
Shale, blue, dark color	2	748
Sand rock, gray	12	760
Shale, blue	7	767
Sand, salt water; set 8-inch pipe	1	768
Sand rock, hard, white	46	814
Gumbo	34	848
Shale, blue	8	856
Shale, blue, with streaks blue sand	10	866
Sand, blue	5	871
?	46	917
Sand, hard packed	3	920
Sand rock, hard	3	923
Packed sand	3	926
Sand rock, gray (soft place in sand)	2	928
Lime rock, soft	6	934
Shale, hard, gray	7	941
Sand rock, gray, and show of gas	7	948
Packed sand, hard	20	968
Shale, hard, blue	144	1,112
Sand rock	4	1,116
Shale, blue, and lime shells	114	1,230
Soft coal (like asphalt)	1	1,231
Shale, blue	9	1,240
Sand rock, gray	6	1,246
Shale, hard, blue	44	1,290
Sand rock, soft, gray, and quartz	6	1,296
Shale, blue, hard	24	1,320
Sand rock, gray	2	1,322
Shale, blue	2	1,324
Sand rock, hard, gray	8	1,332
Shale, hard, blue	3	1,335
Coal, cannel	2	1,337
Shale, blue	5	1,342
Shale and sand shells	6	1,348
Shale, blue	39	1,387
Shale, hard, gray	4	1,391
Sand rock, gray	16	1,407
Shale, hard, blue	26	1,433
Sand rock, soft, gray	3	1,436
Shale, hard, blue	4	1,440
Sand rock, gray, and gas (very porous rock)	16	1,456
Shale and hard limestone shells	14	1,470
Shale, gray	10	1,480
Sand, soft, white	5	1,485
Shell, hard, limestone	10	1,495
Shale, blue	5	1,500

In the southwest corner of Throckmorton County a gas well reported to have a capacity of 20,000,000 cubic feet is 1,060 feet deep. Several other wells have been drilled, some to much greater depth, but none have been successful.

UNDISCOVERED POOLS.

Geologic indications.—The geology of the region extending north and west of Dallas and Fort Worth for 150 miles is, as already stated, generally favorable to the origin, accumulation, and preservation of gas and oil pools. All considerations, both practical and theoretical, point to the existence of undiscovered pools both of gas and of oil in the region. The favorable geologic conditions may be summarized as follows:

1. The rocks of the region belong to the Carboniferous and Cretaceous systems, which contain much gas and oil in other regions. Such rocks as the pre-Cambrian, which nowhere contain valuable pools of gas or oil, are not found, or lie so far below the surface that they may be left out of consideration.

2. The general structure is favorable. The layers of rock have the form of a broad, shallow basin or geosyncline, and most of the gas and oil of the world occur in such general basins. The rocks lie nearly flat and at some places, particularly between Fort Worth and Red River, have a broad terrace form.

3. The details of structure are locally favorable. Though the beds lie nearly flat, their general attitude is at many places modified by irregularities of various kinds, and here and there they are undoubtedly arched up into well-developed domes and anticlines, as has been shown by observations made in similar basins elsewhere and by the conditions existing in those parts of this basin that have been tested.

4. The chemical composition of the rocks shows that they may have been the source of large quantities of oil and gas. Carbonaceous sediments, including coal, though not so abundant as in some other regions, are very common.

5. The physical nature of the rocks also shows that they are well suited to accumulate and retain gas and oil pools. They include many layers of open-textured sand of various degrees of porosity, in more or less lenticular beds. These sands make up less than half of the rock, a fact favorable to their retention of pools of oil and gas, because it makes the washing out of the beds with fresh water difficult or impossible.

6. The history of the rocks has been favorable to the accumulation and retention of pools. With the exception of those underlying Dallas, they have apparently not been tilted back and forth until

all the original fluids in the sands have migrated elsewhere. Salt water, which is considered an indication of slight or no underground circulation, is found almost throughout the region, and it may be fossil sea water which has not been shifted far since the beds were deposited.

7. The rocks have been under sufficient pressure to induce the degree of metamorphism required to separate the hydrocarbons that make up gas and oil, but have not been so much compressed as to drive these fluids out of the region and leave nothing but carbonized remains. David White, in discussing this subject recently, has pointed out that the quality of gas and oil found in any rocks shows a relation to the stresses to which the rocks have been subjected and has suggested that gas pools are likely to be most numerous on the sides of an oil region that lie nearest to regions in which the rocks have undergone greater stresses. According to this principle, gas pools should be most numerous on the east side of this oil and gas region.

The discovery of new pools may undoubtedly be hastened by careful studies of the rocks, made to determine the most promising places for drilling. Without such assistance in finding pools, the cities of Fort Worth and Dallas will probably fail to obtain abundant supplies of natural gas unless they draw supplies from Oklahoma or other distant fields. As the country is developed, and as the oil and gas resources gradually become exhausted, more wildcat wells will no doubt be drilled and greater care will be taken to drill them in the most favorable places. The search for gas and oil pools should begin with domes and anticlines, for they are by far most likely to contain such pools. Later explorations should extend to structures less favorable, and finally to regions in which the underground structure can not be determined because significant outcrops are poor or are lacking.

Inferences based on experience and on the doctrine of chances.—The proportion of wildcat wells that have been successful in the region under discussion indicates that if it were practicable to make tests of each square mile, a good many more gas pools would be found. Such a series of tests is, of course, as yet out of the question, but illuminating inferences may be drawn from the results of the somewhat random wildcatting and the proportion of successful wells. The importance of these tests becomes more obvious when the law of probabilities is applied to them and the fact is remembered that in some counties, especially Parker, probably not a single deep test well has been drilled. If a township were known to contain a pool of oil a mile across, the chances of finding that pool by a random well would, of course, be 1 in 36. If a county covering 1,000 square miles contains one pool 3 or 4 miles across or having an area of 10 square miles the chances of finding the pool by a random test are 1 in 100. Other considerations, of course, enter into the problem, such as the fact that the well must be sufficiently deep and drilled with sufficient care to make an adequate test; nevertheless a single unsuccessful wildcat well

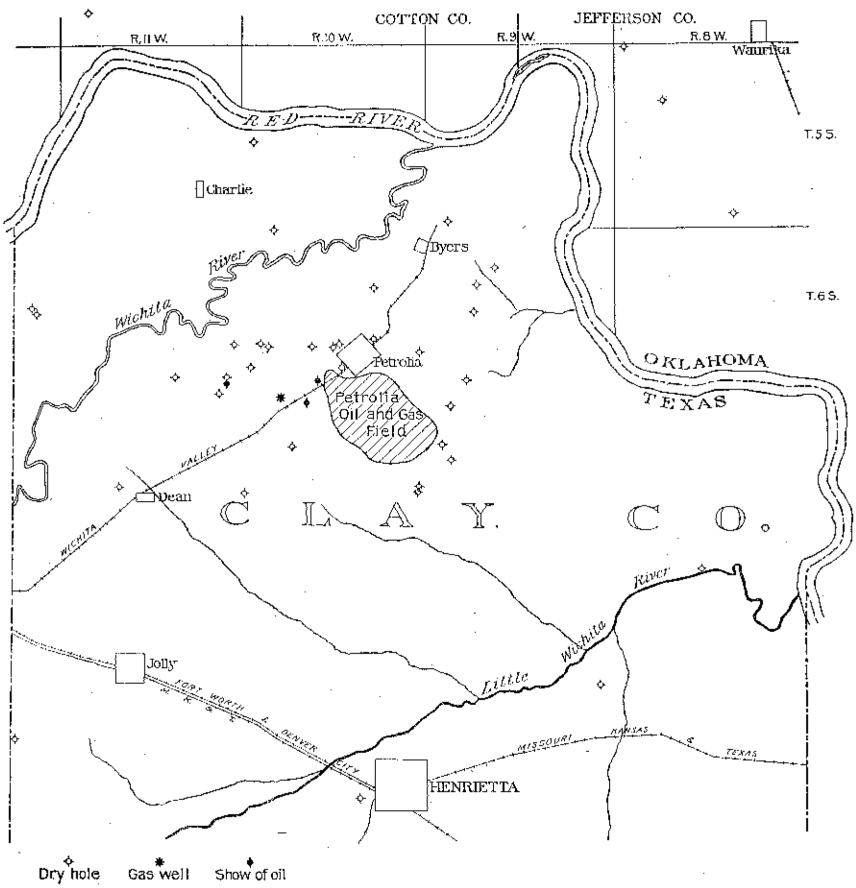

FIGURE 3.—Map showing distribution of deep wells in the northern half of Clay County and the degree of thoroughness of the testing, independent of geologic conditions.

drilled at random does not throw a great deal of light on the existence of gas and oil pools in a considerable area.

Figure 3 shows the distribution of deep tests in the northern half of Clay County, where such tests are unusually abundant. It should be observed that even in this region, which has been rather fully tested by wells, there are large areas in which no test wells have been drilled.

AREAS SURVEYED TO FIND FAVORABLE STRUCTURE.

BETWEEN WICHITA VALLEY RAILWAY AND WICHITA RIVER.

A plane-table survey (see Pl. IV) of a belt extending from a point northeast of Byers to Dean, which, however, shows some gaps where exposures are poor, was made by H. M. Robinson and the writer. The survey consisted principally in running lines of levels along outcropping contacts of sandstone and shale, the sandstone being the upper member in some places and the lower member in others. Account was also taken of dips, of benches made by hard layers, and of fragments of rock in the soil at places where outcrops were poor or lacking. Where the beds at the horizon contoured were concealed it was traced by means of outcropping beds above or below.

The rocks near Byers dip, on the whole, to the northeast; those north of Petrolia to the north, and those near Dean to the northwest. In other words, the general dips of the strata are away from the Petrolia field. The general dips are modified, as shown in Plate IV, by local dips in various directions, but no well-developed anticlines, domes, or other structures favorable to the accumulation of gas were found anywhere in the belt examined. Nowhere in the belt is there a pronounced dip opposite the main dip. Some places, however, are more promising than others, and if, in addition to the several unsuccessful tests made in this belt, most if not all of which are indicated on the map, other wells were to be sunk it would seem wise to sink them 1 to 2 miles north of Petrolia, 1 to 2 miles west of Dean, and 3 to 4 miles west of Petrolia. The strata and physiographic features at the place last named show that the rocks on the north dip to the north and those on the west dip to the west. A fairly well developed basin lies about 2 miles north of this place.

Apparently, the Petrolia anticline involves not only the rocks in the oil and gas field but also those in a large surrounding territory, for the search for other anticlines along the south side of Wichita River was not only fruitless but the strata everywhere rise toward the oil and gas field. The anticline 5 miles east of Byers, described by Wegemann,[1] may be the east end of the Petrolia anticline and may be lower than the part in the oil and gas field, for a well recently drilled 3 miles southwest of Waurika, near the crest of the east end of this anticline, was unsuccessful. A log of this well and a log of a well northeast of Waurika, which shows much less red rock, are given on page 66. The log of a deep well near Byers is also given, and these three and the wells in the Petrolia oil and gas field form a row of wells along the axis of the anticline.

[1] Wegemann, C. H., Anticlinal structure in Cotton and Jefferson counties, Okla.: U. S. Geol. Survey Bull. 602, p. 98, 1915.

Log of lower part of well 3 miles southwest of Waurika, Okla., in SE. ¼ sec. 8, T. 5 S., R. 8 W.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale, blue	3	1,113
Shale, red	12	1,125
Shale, blue	10	1,135
Shale, sandy	10	1,145
Shale, red	60	1,205
8-inch casing set at 1,204 feet.		
Shale, blue	10	1,215
Sand, water	10	1,225
Shale, blue	15	1,240
Shale, red	25	1,265
Shale, blue	10	1,275
Red bed	35	1,310
Shale, blue	29	1,339
Sand	15	1,354
Shale, blue	34	1,388
Sand	21	1,409
Shale, blue	8	1,417
Sand	3	1,420
Shale, blue	4	1,424
Sand, salt water	10	1,434
Shale, blue	13	1,447
Sand	4	1,451
Shale, red, gumbo	7	1,458
Shale, brown	3	1,461
Shale, brown, sandy	24	1,485
Limestone	4	1,489
Shale, blue	11	1,500
Shale, sandy, blue	5	1,505
Sand	12	1,517
"Slate," black	27	1,544
Shale, blue	11	1,555
Sand, dry	20	1,575
Shale, white	5	1,580
Sand, dry	5	1,585
Shale, blue	15	1,600
Sand, water	7	1,607
Limestone, hard	21	1,628
Shale, black, hard	4	1,632
Sand, water	2	1,634
Limestone, sandy	9	1,643
Sand, white	11	1,654
"Slate," black	4	1,658
Shale, blue	20	1,678
Sand, oil, and water (10 barrels oil)	10	1,688
Shale, black	22	1,710
Shale, blue	155	1,865
Sand, water, and showing of oil	111	1,976
Shale, black	16	1,992
Limestone, sandy	13	2,005
Sand, fine	15	2,020
Cave shale, blue-gray, and sandstone	10	2,030
Similar but pinkish	10	2,040
Shale, gray	20	2,060
Shale, hard, gray, with fossil shells	40	2,100
Shale, sandy, gray (fine drilling, no caving)	150	2,250
Shale, sandy		

Began to get loadstone at 400; tools showed strong magnetization.

Partial log of Kauerauff well, in SW. ¼ sec. 11, T. 4 S., R. 8 W., northeast of Waurika, Okla.

	Thickness.	Depth.
	Feet.	*Feet.*
Red bed	30	30
Shale, sandy	10	40
Shale, blue	30	70
Sand	5	75
Shale, mixed	45	120
Sulphur	1	121
Shale, blue	8	159
Sand, dry, show of gas	3	162

Partial log of Kauerauff well, in SW. ¼ sec. 11, T. 4 S., R. 8 W., northeast of Waurika, Okla.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale, blue	5	167
Rock	1	168
Shale, blue	10	178
Sand, gas	6	184
Shale	8	192
Gumbo	30	222
Shale, mixed brown and blue	28	250
Shale, blue	40	290
Shale, blue and black	44	334
Sand, show of oil	8	342
Shale, hard	1	343
Shale, blue	33	376
Shale, mixed blue and brown	40	416
Shale, dark brown	20	436
Shale, mixed blue and brown	50	486
Shale, dark blue	14	500
Limestone, soft	2	502
Shale, blue	19	521
Shell, limestone	1	522
Shale, blue	50	572
Shale, hard, dark blue	21	593
Shale, mixed blue and brown	20	613
Shale, blue and black	37	650
Limestone	1	651
Sand, show of gas	8	659
Shale, blue	29	688

Log of Byers Oil & Gas Co.'s well No. 1, 2 miles northeast of depot at Byers, Tex.

[Drilled in 1913.]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface	30	30
Red rock	10	40
Shell	5	45
Red rock	230	275
Shale, blue	20	295
Red rock	55	350
Water sand	15	365
Red rock	65	430
Sand, salt water	7	437
Red rock	28	465
Shale, red and blue	30	495
Red rock	40	535
Shale, blue, shelly	10	545
Red rock	100	645
Shale, red and blue	5	650
Red rock	10	660
Shale, blue and red	27	687
Sand, salt water	8	695
Shale, blue and red	90	785
Sand, salt water	30	815
Red rock	30	845
Sand, salt water	30	875
Shale, blue	10	885
Sand, salt water	5	890
Red rock	5	895
Sand, salt water	15	910
Red rock	25	935
Shale, blue	60	995
Sand, salt water	15	1,010
Shale, blue	25	1,035
Sand, salt water	40	1,075
Shale, blue	10	1,085
Sand, salt water	60	1,145
Shale, blue	7	1,152
Red rock	8	1,160
Shale, blue and red	10	1,170
Red rock	20	1,190
Shale, blue	10	1,200
Sand, salt water	20	1,220

Log of Byers Oil & Gas Co.'s well No. 1, 2 miles northeast of depot at Byers, Tex.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Red rock	15	1,235
Shale, blue, shelly	20	1,255
Sand, dry	7	1,262
Shale, blue	15	1,277
Sand, salt water	8	1,285
Shale, blue and red	15	1,300
Shale, blue	15	1,315
Red rock	7	1,322
Sand, salt water	11	1,333
Red rock	9	1,342
Shell	5	1,347
Red rock	13	1,360
Shell	10	1,370
Red rock	15	1,385
Shale, blue	17	1,402
Sand, salt water	10	1,412
Red rock	8	1,420
Shale, blue and red	30	1,450
Shale, blue, shelly	20	1,470
Red rock	5	1,475
Shale, blue and red, very shelly	35	1,510
Shale, blue	20	1,530
Sand, salt water	10	1,540
Shale, blue	35	1,575
Sand, salt water	15	1,590
Red rock	5	1,595
Shale, blue	5	1,600
Sand, salt water	60	1,660
Shale, blue	5	1,665
Shell, hard	10	1,675
Sand, salt water	15	1,690
Shale, blue, very shelly	30	1,720
Red rock	15	1,735
Shale, blue	2	1,737
Sand, salt water	23	1,760
Shale, blue	56	1,816
Sand, salt water	4	1,820
Shale, blue	5	1,825
Shell	10	1,835
Shale, blue	5	1,840
Shell	5	1,845
Shale, blue	40	1,885
Sand, salt water	15	1,900
Shale, blue and red	7	1,907
Sand, salt water	3	1,910
Shale, blue	5	1,915
Shell	3	1,918
Shale, blue and red	4	1,922
Sand, salt water	3	1,925
Shale, blue	10	1,935
Shell, hard	3	1,938
Shale, blue	7	1,945
Shelly	10	1,955
Shale, sandy, blue	45	2,000
Sand, salt water	30	2,030
Shale, black (oily black)	5	2,035
Shale, sandy, blue	40	2,075
Sand, salt water	7	2,082
Shale, sandy, blue, and gas bubbles	178	2,260
Shale, blue	5	2,265
Shale, brown	5	2,270
Sand, salt water	5	2,275
Shale, blue	5	2,280

STRUCTURE IN THE VICINITY OF HENRIETTA.

The results of a stadia traverse of the outcrops in the vicinity of Henrietta made by H. M. Robinson are shown in Plate V. The general dip, amounting to about 40 feet to the mile, is to the north. The structure is, however, irregular, and at some places, as in the southwest part of Henrietta and half a mile farther southwest, the strata are slightly uplifted, so that they form low domes. The facts that the domes are very low and that the strata south of them continue to rise rather steeply make them seem unpromising for oil or gas, and one 2,000-foot dry hole has been sunk on one dome. The other structural features of the area surveyed appear still more unpromising for gas or oil. The anticlines and domes, as well as the more irregular features, are so flat or low as apparently to be of no consequence. The district surveyed may be on the north limb of a broad, irregular anticline, for the general dip observed can not continue far to the south. In territory south of the region surveyed the dip must either swing to the east or to the west or the strata must come down again so as to form an anticline. The strata studied are shown in the following section, which crops out between Henrietta and Little Wichita River, to the north:

Section of rocks of Wichita formation exposed in north part of Henrietta, Tex.

	Feet.
Sandstone capping the hill on which Henrietta is built	15–25
Conglomerate, clay pebble, very lenticular, pebbles mostly less than half an inch	0–2
Sandstone, olive-gray, laminated	1–4
Conglomerate like bed above, but pebbles somewhat larger; weathers into large resistant blocks	0–4
Clay shale, brownish red	8–12
Sandstone, olive-gray, open textured, soft, cross laminated	8–10
Shale, red, and sandstone in irregularly arranged lenses	8–12
Sandstone, gray, soft, open textured, cross-bedded	8+
	60±

STRUCTURE IN THE VICINITY OF BENBROOK.

The general eastward dip of the Cretaceous strata between Fort Worth and Weatherford is modified at Benbrook by a terrace or an asymmetric anticline. The results of a reconnaissance survey of this feature are shown in figure 4. Apparently it plunges to the north, but its precise form was not determined. A cross section of the terrace may be seen from a Texas & Pacific Railway train, for along the south side of the valley up which this railroad passes through Benbrook there are fairly good exposures of a bench-making limestone belonging in the Goodland limestone of the Cretaceous system. In the bottom of the valley of Trinity River, 6 miles southwest of Benbrook, there is a water well which occasionally gives off gas bubbles. The terrace may be the cause of this gas seep. The general nature of the rocks exposed in this vicinity is shown in the following section:

Generalized section of rocks of Goodland limestone (Lower Cretaceous) exposed near Benbrook, Tex.

	Feet.
Limestone ("fence rock"), flaggy, few fossils; breaks into slabs suitable for building rough stone walls and hence before the days of barbed wire was used commonly for fences	20±
Limestone ("broken rock"), rather soft and thick bedded	20±
Limestone, hard and thick bedded	25±
Limestone ("cement rock") showing much solution and cementation	10±
Limestone ("wolf dirt"), earthy, weathers rapidly to brownish earth, which is called wolf dirt because it is easy digging for wolves and, on account of the hard overlying bed, is attractive to them for making dens	15±
Limestone ("shell rock") very fossiliferous	10±

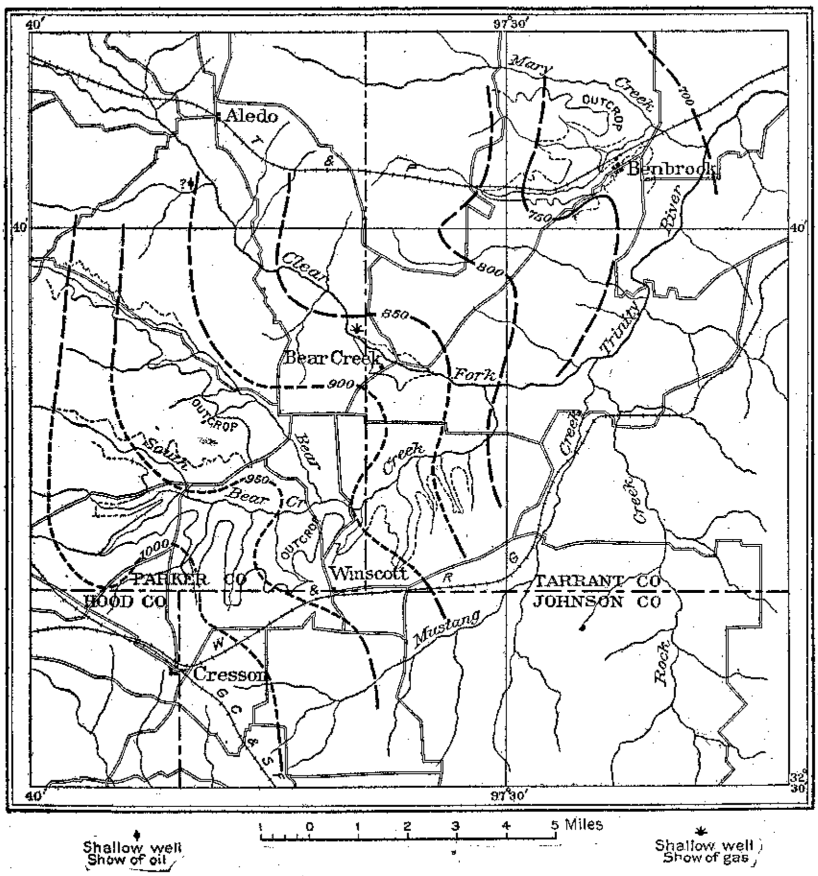

FIGURE 4.—Sketch map showing probable main features of geologic structure in the vicinity of Benbrook, Tex., based upon determinations of altitudes and dips by hand level and aneroid barometer. The thin lines show outcrops of certain limestone beds. Heavy lines are structure contours on the top of bench-making limestone. Dashed lines indicate doubt, the short dashes signifying greater doubt than the long dashes.

REPORTED INDICATIONS OF GAS.

A large number of places at which indications of gas were reported were examined. Among these was one on the Jackson farm, northwest of Dallas, where a peculiar welling up of very fluid mud was inspected and found to be due to causes other than pressure of natural gas. Several reported gas seeps also were visited and the gas of most of them was found to be marsh gas, which, though an excellent fuel, is in the places examined of surficial origin and does not indicate the presence of deep-seated and large pools of natural gas.

Several water wells from which bubbles of gas are reported to escape were visited, but natural gas was actually escaping from very few. Such seeps, unlike most of those of marsh gas at the surface, are likely to be true indicators of natural-gas pools. Puffs of natural gas are not at all uncommon in water wells in the region about Dallas and Fort Worth, but probably only a few of them are really near important pools. One of these gas seeps, which is about 8 miles a little west of north of Weatherford, is so copious that a structural survey of the surrounding area has been made by Mr. Robinson to see whether or not the geologic conditions, particularly the lay of the beds of rock, are favorable to the accumulation of a pool. The results of this survey show that the rocks have an almost uninterrupted northerly dip and are therefore not very favorable to the accumulation of a pool. The rocks at the surface here belong near the base of the Cretaceous, though the bottom of the well, 90 feet below the surface, probably does not reach the underlying Pennsylvanian.

Another class of indications considered worthy of examination are oil shows, for oil is very commonly associated with gas, but a great many of the oil seeps reported are in fact seeps of water containing iron hydroxide—a substance very similar to iron rust—which is common in marshy places. The iron makes an iridescent film on the surface of the water which to an unpracticed eye looks very much like oil. Iron hydroxide will not burn, however, and in a true oil seep it is generally possible to collect a sufficient amount of oil to show that it will burn.

Oil in water wells is generally worth careful study, for "the best sign of oil is a little oil." Small showings of oil and gas also are not at all rare in Clay County and elsewhere. Showings of oil are reported in several wells, about 70 feet deep, on the W. G. Smith place, at the northwest corner of the Charlton Thompson tract, 15 miles south-southwest of Henrietta. A brief inspection of the geology suggests that the structure near this place may be favorable to the accumulation of a pool. On the Calloway place, 4 miles southwest of Henrietta, a water well 60 feet deep showed a little oil and bubbled with gas for several days. On the north edge of Henrietta, northeast of the standpipe, a well drilled for water is said to have bubbled with gas. On the Arthur farm, about 4 miles east of Henrietta, in the east half of block 11, oil is said to have ruined a water well. On the Harker farm, 3 miles east of Henrietta, a small showing of oil is said to have been found in a 200-foot well drilled as an oil test. It is rumored that small showings of oil were found in the very deep Halsell well, 6 miles west of Henrietta, and also in the three deep wells on the Raht farm, 20 miles south of Henrietta.

INCREASE OF MARKETED PRODUCTION BY CONSERVATION.

In recent years considerable thought has been given to the avoidance of waste in natural gas, with manifestly good results, but the losses are still great and are incurred at many stages in the recovery and marketing of gas. Gas pools are abandoned before they are exhausted, though, on account of the great elasticity of gas, their abandonment is not so regrettable as the failure to exhaust oil fields. The greatest loss arises from the fact that gas is harder to store and market than oil, and because of this and other facts, the desire among operators for oil wells is much greater than for gas wells. Hence drilling is commonly continued as long as possible in the search for oil, though in the meantime gas sands are tapped and much gas is allowed to escape into the air. Much gas is also allowed to go to waste while oil is being pumped. The yield of oil wells is more rapid, though shorter, from sands that contain considerable gas under high pressure—conditions that mean quick returns to the oil operator—but the question may be seriously raised whether he might not profit more by preserving the gas, which, as Johnson and Huntley[1] have recently pointed out, would make possible the recovery of a great deal more oil from each pool before it is abandoned.

Another kind of loss takes place within the well and consists of the escape of gas from an important gas sand up through the well to another sand, into which, under certain circumstances, it passes and becomes so widely disseminated that much or all of it is lost. This kind of loss occurs in closed wells in which sands above the gas sand are not cased off. In the Petrolia field the losses of this sort have not been great, for few wells have been left shut in for long periods. Most wells are cased with sufficient care to shut off higher sands, and there are not many or extensive higher sands which are capable of absorbing considerable quantities of gas.

Gas is also allowed to escape into the air for other reasons. Some wells, such as the famous Miller well, in the Petrolia field, have gone

[1] Johnson, R. H., and Huntley, L. G., The influence of the Cushing pool in the oil industry: Eng. Soc. Western Pennsylvania Proc., vol. 31, pp. 460–487, 1915.

wild, and many millions of cubic feet of gas have thus escaped. Other wells have been opened in order to reduce the head for one reason or another. Wells are commonly opened and allowed to blow in order to clean themselves, and some are opened to blow off accumulated salt water. Other losses are incurred by breaks and leaks in lines, uneconomical management, and other causes. The losses are of course comparatively greater in small fields that are without good marketing facilities than in large fields. In the Petrolia field it might be possible through conservation to increase the output by 10 or 20 per cent but probably not more. There can be little doubt that if gas were more valuable the ultimate total yield of the field would be considerably greater than it is likely to be under present conditions.

SUMMARY OF CONCLUSIONS.

The results of a geologic study of the gas resources available to Dallas and Fort Worth in the region north and west of those cities may be summarized as follows:

PETROLIA FIELD.

Original quantity of gas in the field.—The volume of pore space occupied by gas and the original rock pressure and also the relation between decline in pressure and percentage of depletion indicate that the original quantity of gas in the Petrolia field, measured at 8 ounces above atmospheric pressure, was about 120 billion cubic feet.

Ratio between percentage of depletion and amount marketed.—Statistics of production indicate that about 37 billion cubic feet of gas from the Petrolia field have been delivered to consumers. This quantity is about 75 per cent of the reduction of supply in the ground. The question whether or not this percentage should be larger is beyond the scope of this report, but it may be remarked that many gas fields show a greater waste.

Present capacity.—The Petrolia field as now drilled and equipped is capable of producing more gas per day than it has ever been called upon to produce. The limit of its daily capacity depends in part upon engineering considerations not discussed in this report, such as the handling of wells and pipe lines, but it is probably at least twice that of any demand which has been made upon it.

Capacity in near future of the field as now drilled.—The daily capacity of the wells in the field is steadily decreasing, and indeed the field as a whole is doubtless rapidly approaching its limit in rate of production. While the demands upon it have been steadily growing its capacity has been diminishing because of reduction of supply and pressure, and before many years have passed the supply will no longer meet the demand.

Capacity in distant future of the field as now drilled.—If no new gas wells were drilled the production would not only fall below the demand in a few years but in ten years the output would probably be too small to be worth transporting.

Increase of capacity through new wells to known sands in the proved field.—The capacity of the field may be kept up for a few years by new wells drilled to known sands within the proved field, but the present wells are rather evenly distributed and closely spaced, so that increase of output through new wells can not be great.

Increase of capacity through finding new sands in the proved field.—More gas can probably be found in some parts of the field by drilling deeper, for sands having favorable structure, texture, and stratigraphic and lithologic relations lie below the sands now producing. A few small gas-bearing lenses of sand lie above the producing sand, and though these lenses contain much less gas than the so-called deep sands they should not be overlooked.

Increase of capacity through finding new productive area adjoining the field.—The daily capacity of the field may be increased by new wells drilled outside the proved field to sands now producing. The structure of the field indicates that the actual area of the gas pool is probably twice that of the area now producing, though a part of the new area may yield oil instead of gas. The production can not, of course, be doubled by simply doubling the producing area, for gas has been slowly moving from the undrilled ground to the producing wells, so that throughout most if not all of the undrilled parts of the pool the original gas content and pressure in the sands have been reduced, though not so greatly reduced as in the developed part of the pool.

Increase in marketed supply through greater care in handling wells.—The depletion of the original supply of gas at Petrolia is evidently considerably greater than the quantity of gas marketed, the loss incidental to the production of oil being especially noteworthy. The output could be increased by handling the wells somewhat differently, but the work of properly caring for the natural supply must be left to the engineers.

Life of the field.—If all the gas at Petrolia could be delivered to consumers in Dallas and Fort Worth and other cities now drawing on the Petrolia supply it would probably last them, at the present rate of consumption, about 6½ years. If an estimate is made of the increase in consumption that will probably occur if the supply is adequate and no advance is made in the price, proper deduction being made for necessary losses in production and marketing, the estimate of 6½ years must be reduced to about 4 or 5, and if further allowance be made for unnecessary losses it must be reduced to 3 or 4 years, and a shortage will be felt in cold weather still sooner.

OTHER FIELDS.

Other discovered pools northwest and west of Dallas and Fort Worth, particularly those at Strawn and Moran, have noteworthy quantities of gas, though not so much as Petrolia, and these supplies would be available to the cities if the pools were near to each other or to the existing pipe lines.

Undiscovered pools of gas and oil undoubtedly exist in the area described in this report, and some of them will probably be large enough to warrant the building of individual pipe lines. If several of them were developed at once, however, sufficient gas would be made available to justify the construction of lines to groups of pools. The search for new pools must be pushed with vigor if the present output is to be maintained or increased.

GAS PROSPECTS SOUTH AND SOUTHEAST OF DALLAS.

By George Charlton Matson.

GEOGRAPHY.

In the autumn of 1915 the writer made detailed examinations of the geology and natural-gas resources at Mexia and Groesbeck, Tex., as well as a rapid reconnaissance of a narrow area extending from a point near Thornton northward nearly to Greenville. This area has a length of 110 miles and an average width of about 20 miles, and includes a belt of black clay lands that are locally covered by a few feet of sand and gravel. A more general reconnaissance was extended across the area from Greenville to Dallas and Fort Worth.

Gas has been developed in commercial quantities at Groesbeck, Mexia, Corsicana, and Chatfield, and oil has been exploited in the vicinity of Corsicana. The Mexia-Groesbeck gas field (Pl. VI, in pocket) is now supplying gas to Waco, Mart, Groesbeck, Mexia, Teague, Tehuacana, Wortham, Richland, and Corsicana. The Corsicana and Chatfield areas formerly supplied Corsicana but are not now being utilized. The areas comprised in these fields are approximately as follows: Mexia-Groesbeck, 11.8 square miles; Corsicana and Chatfield, 6 or 8 square miles.

The surface of this part of Texas has only a moderate relief, generally from 50 to 150 feet, though the extreme differences in elevation are somewhat greater. This surface is a product of the erosion of the underlying formations and of the local deposition of thin beds of sediments that form broad, level terraces along the streams. There are five distinct terraces, which are separated by more or less definite scarps having steep slopes. The original level surfaces of some of the higher and older terraces have been partly obliterated through erosion by small streams.

The terraces are of little importance in connection with oil and gas resources except where their level surfaces, formed by thin veneers of younger sediments, obscure the older formations and interfere with the geologist's determination of their character and structure. The terraces have a distinct economic bearing on the development of the region, however, because they furnish level areas suitable for agriculture and favorable for lines of transportation along easy gradients.

In general, the terraces have an indirect bearing on the development of oil and gas because of the character of the roads that cross them. Where clay soils are exposed the roads are exceptionally good during the dry season and very muddy and difficult to travel during wet weather. The sands of the terraces produce a condition just the reverse of that produced by the clays. They are much more difficult to traverse in dry than in wet weather, and in the Mexia-Groesbeck field especially they add to the cost of transporting machinery and materials required for drilling wells and constructing pipe lines. The larger cities in the region have recently constructed gravel or rock roads to facilitate transportation, and the network of these highways now makes travel easy between most of the principal cities and towns.

GEOLOGY.

The areas covered by the general examination are underlain by rocks of several geologic formations that are assigned to the Tertiary and Cretaceous systems. Only the lower part of the Tertiary extends into the region, and the formations represented are of no commercial importance. The formations belonging to the Upper Cretaceous series are the source of all the oil and gas that have been developed in commercial quantities in the area examined by the writer and they supply large quantities of oil and gas in Louisiana.

CRETACEOUS SYSTEM.

The Cretaceous system is divided into two major subdivisions, the lowermost known as the Comanche series, or Lower Cretaceous, the uppermost the Gulf series, or Upper Cretaceous. The distribution of these two series is shown in figure 1. The series are divided into formations, but it is impracticable to represent all these minor subdivisions on a map of so small a scale, and in this report some of the formations will be discussed in groups. The general sequence of the Cretaceous formations is as follows, the youngest formation being given at the top (see also Pl. VII):

- Gulf series (Upper Cretaceous):
  - Navarro formation, including Nacatoch sand member.
  - Taylor marl.
  - Austin chalk.
  - Eagle Ford clay.
  - Woodbine sand.
- Comanche series (Lower Cretaceous):
  - Washita group:
    - Denison formation.
    - Fort Worth limestone.
    - Preston formation.
  - Fredericksburg group:
    - Edwards limestone. } Goodland limestone in northern part of area.
    - Comanche Peak limestone. } Goodland limestone in northern part of area.
    - Walnut clay. } Goodland limestone in northern part of area.

Comanche series (Lower Cretaceous)—Continued.
Trinity group:
Paluxy sand.
Glen Rose limestone.
Travis Peak sand.

COMANCHE SERIES (LOWER CRETACEOUS).

Trinity group.—The Trinity is the oldest and lowest group belonging to the Comanche series. In Oklahoma and northern Texas it consists of coarse light-gray or white quartz sands with local layers and lenses of gravel. Farther south, especially along Brazos River, marl and sandy limestone occur interbedded with the sands, and the Trinity becomes a group divisible into three formations—the Paluxy sand (at top), Glen Rose limestone, and Travis Peak sand. In general the upper part of the Trinity is finer grained and contains more marl and clay than the lower part. The Trinity group is generally rather loose or only slightly indurated and is referred to by the well drillers as pack sand, though at some places, especially where exposed, it is a hard sandstone.

Fredericksburg group.—The Fredericksburg group consists largely of chalky limestones, though its basal part includes more or less impure marl and calcareous clay, the Walnut clay.

Washita group.—The Washita group consists of alternate beds of marly clay and soft limestone. At some places the limestone predominates; at others the clay. Thin layers and lenses of sand occur, especially in the upper part of the group, and most of the limestones are impure, containing both sand and clay.

The materials range in color from dark gray near the base of the group to light gray near its top. On weathering they become yellow or red, the more pronounced colors being found in the upper formations, which contain a larger percentage of the iron compounds that form the coloring matter.

GULF SERIES (UPPER CRETACEOUS).

Woodbine sand.—The Woodbine sand consists of medium to fine-grained sand containing many layers and laminæ of clay. Thin beds and partings of lignite occur in this formation, and it contains fossil plants which, together with the lignite, indicate an abundant flora and form a probable source of gas and oil.

The sands composing the Woodbine formation are generally light gray and friable. Locally they are cemented into hard layers which the well drillers call "shells." At many places a large amount of shale and clay is interlaminated with the sands, but two or more porous beds are usually found in the formation. These are good water-bearing beds and are apparently very persistent, because they are the source of water for many artesian wells.

Eagle Ford clay.—The Eagle Ford clay consists of light to dark-blue laminated clay, which is locally more or less calcareous and contains thin layers of very hard limestone. This limestone is generally earthy and at many places contains large numbers of shells of marine organisms. In northwestern Louisiana and the adjacent part of Texas there is a bed of sand at the top of the Eagle Ford clay that contains laminæ and layers of clay. This sand, however, which is known as the Blossom sand member, does not extend into the area covered by this report except in the vicinity of Cooper.

Austin chalk.—The Austin chalk consists of massive light-gray to white chalky limestones containing some hard layers. Locally thin beds of clay are found in this formation, especially at the east end of the area here discussed, in the vicinity of Terrell and Greenville. Farther east the lower part of the limestone is so impure that it loses its distinctive characteristics and becomes a marl—the Brownstown marl—and the overlying chalk is known as the Annona chalk.

Formations overlying the Austin chalk.—Above the Austin chalk are beds of dark-gray marl and shale and thin layers and lenses of sand. These beds have been divided into two formations—the Taylor marl, immediately overlying the chalk, and the Navarro formation. More recently Deussen [1] has used the name Nacatoch sand for one of the sand beds in this part of the Upper Cretaceous of eastern Texas, and in this report it is called the Nacatoch sand member of the Navarro formation. In general it is probable that the Taylor formation should be restricted to the more calcareous beds overlying the Austin chalk and that the clays, shales, and sands that overlie the Taylor should be placed in the Navarro formation. The shales above the Nacatoch may be the equivalent of the Arkadelphia clay of Arkansas and northeastern Texas, but detailed information for exact correlation is not yet available. Two fragments of valves of a fossil oyster were obtained from the gas sand of the Mackey well, near Mexia. These were identified as *Ostrea owenana* Shumard by L. W. Stephenson, who states that

> This species occurs in the Navarro formation in the vicinity of Corsicana and Chatfield, Tex., and in the Nacatoch sand of southwest Arkansas. The stratum from which this fossil was obtained in the Mackey well probably corresponds in age to and may be physically continuous with the Nacatoch sand.

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[1] Deussen, Alexander, Geology and underground waters of the southeastern part of the Texas Coastal Plain: U. S. Geol. Survey Water-Supply Paper 335, pl. 7, 1914.

Mr. Stephenson also says that the matrix is a glauconitic sand similar to the Nacatoch sand of Arkansas. He gives the following list of localities where this species of Ostrea has been found:

Nacatoch sand:

U. S. G. S. collection 7465. Cut of St. Louis & San Francisco Railroad, west of McNab station, Ark.

U. S. G. S. collection 7463. West bank of Little Missouri River at Nacatoch Bluff, Ark.

Navarro formation:

U. S. G. S. collection 7567. Chatfield road, 7 or 8 miles north of Corsicana, Navarro County, Tex. Fossils collected in the road and in a small branch just east of the road.

U. S. G. S. collection 763 (U. S. Nat. Mus. catalogue No. 29876). Near Corsicana, Navarro County, Tex. Collected by T. W. Stanton.

U. S. G. S. collection 762 (U. S. Nat. Mus. catalogue No. 21089). Near Chatfield, Navarro County, Tex. Collected by T. W. Stanton.

Navarro formation (Nacatoch sand member):

Mackey well No. 1 of Peoples Gas Co., 2 miles northwest of Mexia, Limestone County, Tex., at a depth of 785 feet. Matrix a gray glauconitic sand. Collected by G. C. Matson.

The Taylor marl consists of dark-gray calcareous clays containing more or less carbonaceous matter, interbedded with lighter-colored clays and marls. In general the formation contains a small percentage of very fine sand, which is distributed through the clays in the form of very thin laminæ. Rounded and oval calcareous concretions occur at many places and in different parts of the formation. These are the bowlders mentioned in the logs of the well drillers. After exposure to the weather the Taylor marl changes to a dark-gray or black calcareous clay that is very plastic and sticky when wet.

The Navarro formation, including the Nacatoch sand member, consists of dark-gray and black clays containing more or less calcium carbonate, interbedded with thin layers of fine sand. These sand beds include thin partings and lenses of clay. Some layers of calcareous marl occur throughout the formation, and at many places there are concretions similar to those found in the Taylor marl.

The Nacatoch sand is typical of the sands found in the Navarro formation and is therefore worthy of special mention. It is composed of light-gray quartz sand containing some grains of glauconite. It is fine textured and is locally cemented into firm sandstone, especially near the top, thus forming a cap rock for the gas sand. It ranges in thickness from 40 to slightly more than 65 feet and in places contains partings of shale 3 to 4 feet thick, or rarely 8 to 10 feet. This sand has been studied very carefully, and its texture and porosity are described in detail on pages 92–93.

TERTIARY SYSTEM.

EOCENE SERIES.

Rocks of Tertiary age rest on the uppermost Cretaceous formation and possibly overlap some of the older formations of the Upper Cretaceous series. These deposits are the oldest and lowermost of the Tertiary system and belong to the Eocene series.

Midway formation.—The oldest of the Eocene deposits—the Midway formation—rests upon the Cretaceous in eastern Texas. This formation lies at the surface in the Mexia-Groesbeck gas field and extends both northward and southward in a narrow belt on the east side of the boundary line between the Upper Cretaceous and the Eocene, as shown in figure 1. The Midway formation consists of clays and some layers of fine sands and sandy clays. When fresh these materials are blue or gray, but on exposure to the air they become yellow or black. From the vicinity of Corsicana southward beyond a line drawn eastward from Hearne a series of limestone beds occur in the Midway formation. These limestones may be seen on the east slope of Pisgah Ridge at Tehuacana, at Horn Hill, on the road from Hearne to Thornton, and at many other places. They are conspicuous at several points in the Mexia-Groesbeck gas field, the best exposures being at the Reunion ground and near Springfield. Their average thickness is about 40 feet and their maximum thickness about 60 feet. The limestones are gray where freshly exposed, but on weathering they become yellow or brown. When partly dissolved they become deeply pitted. Fossils are abundant in some beds of the limestone.

NATURAL GAS.

OCCURRENCE.

Practically all the rocks of the earth's crust contain crevices or pores, the presence of the crevices being obvious wherever hard rocks are exposed to view, but the aggregate volume of openings of this kind is small when compared with that of the minute openings called pores. The average porosity of rocks of different kinds has been carefully studied, and though it varies greatly it amounts to a large percentage of the total volume of all rocks except the most compact. Among the most porous rocks are sandstone and coarse shales, though many limestones are nearly as porous as some sandstones.

In the study of the occurrence of natural gas the pores of the fine-grained rocks, such as shale and clay, even where their aggregate volume is very large, are of little importance, because in general the gas that occurs in the minute pores of these sediments is so widely diffused that it can not be readily recovered. The important reservoirs of natural gas are sands and sandstones, though in a few places, including some comparatively large areas in Ohio and Indiana, porous limestones have supplied large quantities of gas. The gas in the sands and sandstones and in the porous limestones fills the pores of the rock and is commonly under considerable pressure.

CAP ROCK.

The gas is confined by a relatively impervious formation (cap rock), which prevents its migration toward the surface. The material that most commonly forms a cap above gas sands is a bed of fine shale, though very fine grained sandstones serve the same purpose because the pores between the grains are small. This was illustrated by an examination of a portion of the cap rock from the Mexia-Groesbeck gas field, which, with an aggregate pore space of 34.4 per cent of the total volume of the sample, contained such minute individual openings that C. E. Van Orstrand, who made the examination, decided that with the presence of a small amount of liquid the great resistance offered to free movement of gas was sufficient to make the rock an efficient cap. Impervious beds below the gas sand are not everywhere required to confine the gas, for in many gas fields the downward migration of the gas is prevented by water.

PRESSURE.

The term rock pressure, as applied to natural gas, is commonly used to designate the pressure under which the gas occurs in the earth. It is determined by means of a gage placed on the gas well and read when the maximum pressure is attained after the well has been closed to prevent the escape of gas. In general the gas is associated with salt water, and the initial rock pressure in any well is approximately equal to the hydrostatic pressure of a column of water with a height equivalent to the depth of the well. It therefore varies with the depth of the gas sand below the surface.

The rock pressure represents the maximum closed pressure of a gas well, but determinations are also made by permitting the well to flow freely and measuring the pressure of the flowing gas. This is designated as open-flow pressure. After a well has been permitted to flow in the air for some time, it may be closed and the pressure read at intervals, usually at the expiration of succeeding minutes. This is called minute pressure.

The open-flow pressure is an index of the volume of the well, and tables have been constructed for the estimation of volume from the open-flow pressure. Minute pressures are used for the same purpose, but it is necessary to know the exact diameter and depth of the well in order to estimate the amount of gas that enters the well from the sand between the intervals of reading the pressure.

It is sometimes assumed that a well which has a very high rock pressure must necessarily have a large volume or rate of flow, but this assumption is not warranted, though the rock pressure is one of the factors that controls the volume. It is also sometimes assumed that when gas wells have declined in volume and pressure they will recover if they are closed temporarily. This is true in so far as rock pressure is concerned, the recovery being due to the movement of water or oil or both into the gas sands, reducing the bulk of the gas and thereby increasing the pressure. It is not true that the total quantity of gas in the sand will be increased by this process, for it is simply a matter of concentration of the gas already in the sand. This process, however, by increasing the rock pressure increases the volume of the gas that can be obtained from the well and thus increases the open-flow pressure. The life of many wells may also be prolonged in this way.

ACCUMULATION.

Gas rises because it is of lighter gravity than the water in the porous formations, the most favorable place for its accumulation being the higher portions of an upward arch (anticline or dome) of the gas sand. The quantity of gas found in any anticline depends on the original quantity in the formation and the percentage of it that has accumulated in the anticline. Another favorable position for gas to accumulate is where the general inclination or dip of the gas sand is interrupted or lessened in a flat terrace. A slight upward bend in this terrace will form a low fold similar, in many respects, to an ordinary anticline. If the water, with which the gas was originally associated, is in motion this may facilitate the migration of the gas and its accumulation in the anticlines or domes. The mode of accumulation is shown graphically in figure 7 (p. 94).

STRUCTURE.

GENERAL CAUSES AND FORMS.

The attitude of the strata is usually discussed under the term structure. Most sedimentary beds were originally almost horizontal, but many have been disturbed by forces that altered their attitude, producing structural features 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 of such disturbance of the original attitude of deposits is pressure, by which 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. 5) shows simple types of folds, the upward bends being known as anticlines and the downward as synclines.

Many types of folds and faults have been described, but most of them are not represented in the Mexia-Groesbeck gas 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.

The steep dips of the gas sand in the Mexia-Groesbeck field show that the forces which produced the anticline were concentrated in a

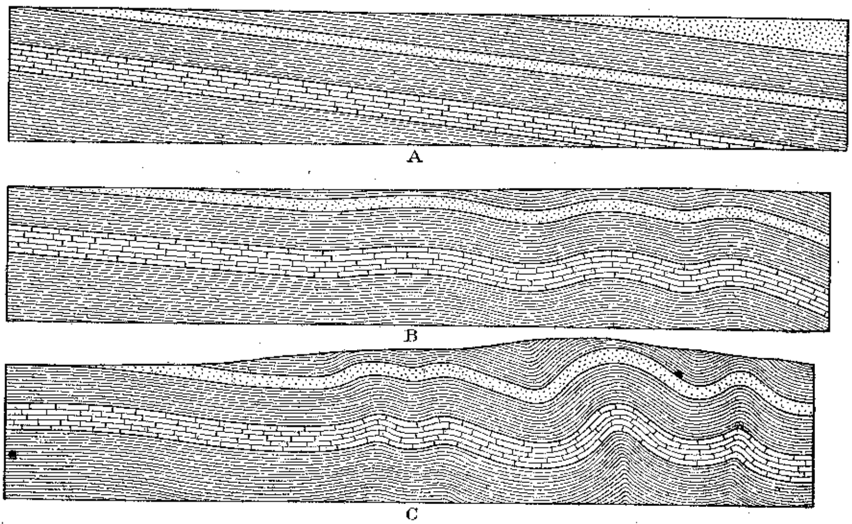

FIGURE 5.—Sections showing simple types of structure. A, Sedimentary beds with gentle dip; B, the same beds gently folded; C, the same beds more intensely folded.

small area that was subjected to vigorous disturbance. It is probable that this intense deformation of the strata was accompanied by some faulting, but no conclusive evidence of the existence of faults in the gas field was obtained. If there are faults in the field, they are doubtless of small throw and extent.

METHODS OF REPRESENTATION.

Structure may be represented diagrammatically, as in figure 5, or by means of contour lines, as in Plate VI. These lines are represented as connecting points, on the top or bottom of a stratum of rock, that lie at the same distance above or below a given horizontal plane, generally sea level. When contour lines are thus drawn, indicating every 10 feet, say, of difference in elevation, or any other definite interval (called contour interval) 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 in any part 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 on the amount and accuracy of the information available and the refinement in the contouring that can be based on it. The elevation of the stratum at any point 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 area represented. Contours possess the advantage of showing the structure over the entire area represented 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 and gas fields persistent coal beds have been used for the purpose of constructing contour maps, but in the Mexia-Groesbeck field the cap rock of the gas sand is the only formation that could be used for this purpose except the sand itself. Inasmuch as the cap rock is merely the upper portion of the sand, which has been consolidated to varying depths, its upper surface is considered the most trustworthy key to the structure. The contours on the structure map of the Mexia-Groesbeck field (Pl. VI, in pocket) are based on the top of the cap rock and show its depth below sea level. The contour map represents the key rock as it would appear if all overlying formations were removed. The position of the contours has been determined by subtracting the elevation of the surface at the well from the depth to the cap rock.

The degree of accuracy in drawing structure contours depends in part on the accuracy of measurement of the depth to the key rock, and in part on the number and distribution of the wells showing the depth to the key rock. In general, it is believed that the measurements used for the accompanying map are reasonably exact and that the wells are sufficiently numerous and distributed over enough of the territory to permit accurate contouring. In a portion of the field where information is lacking the structure has been represented by dotted lines drawn on the basis of surface observations on outcrops of limestone, together with the knowledge of the character and general trend of the anticline that is shown by the contours. In order to show more clearly the structure of the Mexia-Groesbeck field a profile showing the elevation of the apex of the anticline has been included (fig. 6).

MEXIA-GROESBECK GAS FIELD.

LOCATION.

The Mexia-Groesbeck gas field is in the east-central part of Limestone County, Tex., where it occupies a long, narrow area, having an approximate length of 12¼ miles and an approximate width of 0.9 mile. The map of this field (Pl. VI, in pocket) shows the area that it occupies and its relation to the towns of Mexia and Groesbeck. The present developments are comprised in an area extending from a point near Mexia southward to Navasota River, and in another area extending from the south side of the river to a point a short distance southwest of Groesbeck. It is entirely probable that the actual distribution of gas is such as to join these fields through the strip about 0.9 mile wide that now lies between them.

CONSUMPTION OF GAS.

The present consumption of gas from this field amounts to more than 4,000,000 cubic feet a day, which is drawn from about 20 wells, but there are at present more than 40 wells in the field that are capable of supplying gas to pipe lines. In addition, several wells that are now in so bad a condition that they can not be utilized could probably be made to supply gas by removing the accumulated shale and sand.

PRODUCTION.

The total possible production from the Mexia-Groesbeck field has been determined by gaging all the wells that could be allowed to flow open for a long enough time, usually 45 minutes or more. A few wells were connected

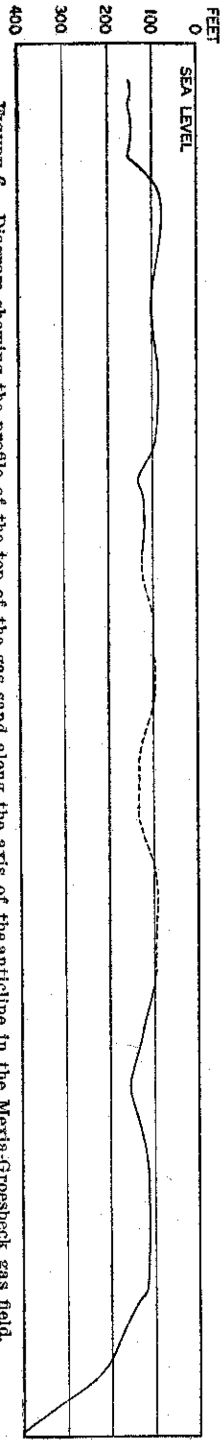

FIGURE 6.—Diagram showing the profile of the top of the gas sand along the axis of the anticline in the Mexia-Groesbeck gas field.

with pipe lines in such a way that it was impossible to open them without interfering with the consumption of the gas, and they were not gaged in this investigation; but reliable information concerning the volume of most of them was obtained from records of earlier gaging. In addition, some wells were found to be so badly clogged with shale and sand that gaging was impossible. The original volumes of these wells were ascertained from the most reliable sources, and after making due allowance for depreciation, an estimate was made of their possible present volumes, provided they were cleaned out and connected for use. The details of the methods of measurement and results are given in another section, and it is sufficient to say here that the present open-flow volume of this field is about 220,000,000 cubic feet a day.

HISTORY.

The beginning of active drilling in the vicinity of Mexia dates from the first operations by the Mexia Oil & Gas Co. under the active management of J. B. Smith. Ten wells were drilled before a successful dry gasser was obtained, and this well, drilled in 1912, made the first production in the field. Prior to the drilling of these wells gas had been known in a few shallow water wells west of the field and had been exploited in the vicinity of Corsicana. Wells showing considerable volumes of gas had also been drilled between Corsicana and Mexia, but salt water interfered with development.

After the first successful well was completed operations were much more active, with the result that seven successful wells had been drilled by July 25, 1913. Eight or nine other wells were completed before the end of 1913, and more than 30 were added to this number during 1914. The ratio of successful wells and dry holes may be judged from the examination of the map (Pl. VI) which shows the location of the wells and indicates their character.

During 1914 pipe lines were laid to connect the field with the larger towns, among them being Mexia, Groesbeck, Waco, Mart, and Corsicana; and these towns, together with some smaller communities, are still being supplied with gas from this field.

STRATA ENCOUNTERED IN DRILLING.

MIDWAY FORMATION.

The wells in the Mexia-Groesbeck gas field pass through the lower Eocene Midway formation and penetrate a portion of the Upper Cretaceous Navarro formation. The exact thickness of the Midway formation in the wells can not be determined with accuracy because the descriptions of the materials encountered in drilling are not complete enough to enable a geologist to distinguish between the Midway and the Navarro. The Midway formation consists of clay, limestone, and sand that form the upper 50 to 200 feet recorded in the well logs. The limestone varies greatly in hardness and ranges in thickness from 40 to 60 feet. It is interbedded with clay and where it is soft it is often described as clay. Local hardening of the limestone has caused the abandonment of many wells that might have been successful if they had been drilled through the rock to the gas sand.

Layers of the limestone are exposed on eroded surfaces, and where the surface is level the successive layers form bands that are roughly parallel. Such layers show the strike of the beds, and two of them, known as the east and west ledges, happen to be so situated that nearly all the wells drilled between them have been successful. By following these ledges, which have the same trend as the structure, it has been possible to develop the gas field across the uplands both north and south of Navasota River, but some trouble was experienced south of the river because a layer of limestone lying stratigraphically higher than those north of the river is exposed west of Groesbeck. This limestone was erroneously thought to be the same as one of the ledges north of the river, and the mistake led to the drilling of two or three wells where the gas sand was so low on the anticline that it contained very little gas.

NAVARRO FORMATION.

The upper portion of the Navarro formation, which underlies the Midway, is composed of clays and shales with thin beds of sand and sandstone. It is in most places so easily penetrated with a rotary drill that a few wells in which no hard rock was encountered in the Midway formation were completed in two or three days. The clays and shale of the Navarro formation range in color from dark gray to black, except 20 to 60 feet of shale immediately overlying the gas sand, which is light gray.

The gas sand of the Mexia-Groesbeck field has been called the Nacatoch sand member of the Navarro formation, and in the general discussion of the geology (p. 80) the evidence is presented for the correlation of this sand with the Nacatoch sand of northwestern Louisiana and southwestern Arkansas. The Nacatoch sand of the Mexia-Groesbeck field consists of light-gray fine quartz sand with many dark grains of glauconite. The upper part of this sand is cemented into a hard sandstone which is known to the drillers as the cap rock. This cap rock is much denser than the gas sand and has a thickness ranging from 1 to 10 feet and averaging about 5 feet. Beneath the cap rock the sand is porous except where there are layers and lenses of clay. That the clay forms a negligible portion of the Nacatoch sand is shown by its absence in 48 wells out of a total number of more than 50 wells. In the Mexia-Groesbeck field the Nacatoch sand has a maximum thickness of more than 65 feet and an average thickness, if the cap rock is not included, of more than 40 feet.

GAS-BEARING SAND.

AREA.

Measurements of the limits in depth of the gas-bearing sand are essential in order to estimate the area underlain by sand that will be productive. Several careful computations were made to determine to what depth the sand is filled with gas. Some of the wells in the north end of the field were still in dry sand at depths of slightly more than 200 feet below sea level, farther south salt water was encountered at about 198 feet below sea level, and in the south end of the field salt water was encountered at about 207 feet below sea level. In order to make a safe estimate the margin of the gas-bearing area was drawn at a depth of 200 feet below sea level, or, as the cap rock, upon which the contours are drawn, has an average thickness of 5 feet, at the 195-foot contour.

EFFECT OF CURVATURE ON THE AREA AND QUANTITY OF THE GAS SAND.

An examination of the map showing the structure of the Mexia-Groesbeck field (Pl. VI, in pocket) will show that the surface of the gas sand is not horizontal but is bent upward in the form of an anticline. In considering the productive area and the quantity of gas sand that might be expected to contain gas, it was thought that this curvature might have an important bearing on the results, and in order to determine whether the curvature was important E. L. McNair made computations based on profiles of the top of the sand across different portions of the anticlines, so selected that the maximum and minimum curvatures and the mean curvature might be included.

From the profiles made from these cross sections the actual rise was computed for 10 different grades, the maximum grade being 8 per cent and the minimum 0.8 per cent, with an average of about 3.7 per cent. For the maximum grade the increase in area of the gas-bearing sand on 1 square mile resulting from the upward slope of the strata is 0.64 per cent, which is equivalent to an increase of about 2 inches in thickness. For a 5 per cent rise the increase in area is only 0.25 per cent, which is equivalent to an increase of 0.8 inch in thickness. It is apparent that the curvature of the sand is a factor too small to make any appreciable difference in the results and need not be considered in computing the areas and volumes of productive sand, and the computations here given are therefore based on the area that the sand would occupy if it were horizontal. Measurements of the area of sand included in the contour of 195 feet below the sea gave 4,094 acres of proved territory north of Navasota River and 2,360 acres south of the river, with an intermediate area of 1,124 acres unproved but probably gas bearing.

THICKNESS OF THE SAND.

Very few of the gas wells in the Mexia-Groesbeck field reach the base of the gas sand, and it is therefore difficult to determine the exact thickness of the sand. Many of the wells on the higher part of the anticline penetrate the sand to a depth of more than 20 feet, and oral reports have been given of thicknesses greater than 43 feet. Evidently, therefore, the thickness is considerably greater than is indicated in the gas wells. On the eastern margin of the field the Harden well encountered 40 feet of sand. The Munger Oil & Cotton Co.'s well, on the Hickman lease, showed the following section: Sand, 15 feet; gumbo, 10 feet; sand, 40 feet. One of the Stitt wells showed the following section: Sand, 15 feet; gumbo, 10 feet; sand, 50 feet. There is no reason to doubt that these beds maintain a similar thickness throughout the gas field, though variations from the sections given above are to be expected. Apparently the gumbo of the Hickman and Stitt wells is lenticular, because it was not encountered in the Harden well, and many of the gas wells that penetrated the sand to depths of more than 20 feet did not encounter gumbo. A moderate estimate of the average thickness of sand in the field, exclusive of the cap rock, is believed to be 40 feet.

QUANTITY OF THE GAS SAND.

The computations made to determine the area of producing gas sand in the Mexia-Groesbeck field gave a total of 7,568 acres—4,094 acres of developed territory north of Navasota River, 2,360 acres of developed territory south of the river, and 1,124 acres of undeveloped territory between the two tracts.

On the higher parts of the anticline in the Mexia-Groesbeck field the gas would occupy the pores in the entire thickness of the sand, and this condition would prevail down to a depth of 200 feet below sea level. As the gas-bearing sand has a thickness of 40 feet, the area in which all the sand contained gas would be inclosed by the 155-foot contour and would amount to 34 per cent of the developed area north of Navasota River, 50 per cent of the developed area south of the river, and 35 per cent of the undeveloped territory.

With a thickness of 40 feet, this portion of the field contains about half the gas-bearing sand in the developed areas and more than half the gas-bearing sand in the undeveloped area. The gas would occupy only a portion of the total thickness of the sand in an area where the base of the sand was below the level of the salt water, which rises to 200 feet below sea level. The area containing gas-bearing sand would be bounded by the 195-foot contour, because, with an average thickness of 5 feet for the cap rock and a salt-water level at 200 feet below sea level, no gas in commercial quantities could be expected beyond that contour, though small pockets might be found where the bottom of the cap rock is uneven or where there are local flexures in the sand. The areas of gas sand included between the 155-foot and 195-foot contours are 66 per cent of the developed territory north of Navasota River, 50 per cent of the developed territory south of the river, and 65 per cent of the undeveloped territory. In these areas the thickness of the sand that lies above the level of salt water and contains gas ranges from practically nothing to 40 feet, with an average of 20 feet. With this thickness, the volume of the gas-bearing sand amounts to half the quantity in the developed areas and to less than half the quantity in the undeveloped area.

The total volume of the gas-bearing sand in the field would be 9,141,400,000 cubic feet, 85 per cent of which is in the developed territory and 15 per cent in the undeveloped territory.

PORE SPACE.

Samples of the gas sand from the Mexia-Groesbeck field were submitted to C. E. Van Orstrand, of the United States Geological Survey, to determine the amount of pore space they contained. His determinations showed from 16.6 to 34.2 per cent of pore space, with an average of 25.5 per cent, which would amount to 2,331,057,000 cubic feet. Only a small part of that amount belongs to the undeveloped area, the largest part of it being in the developed areas. There can be no doubt that the entire pore space of the gas sand was occupied by gas, because the pressure when the field was first developed, 276 pounds to the square inch, was sufficient to force the gas into even the most minute pores. It might be contended that the average porosity of the sand may not continue throughout the gas field, but such a contention would not agree with the generally uniform decline of pressure throughout the field, which indicates uniform porosity, for if there were obstacles to free movement of gas in the sand in the form of fine-grained portions of the sand or beds of shale there should be much greater variations in the pressure of wells that are close together because of unequal rates of decline. Moreover, the relatively large volume of the wells, even of those drilled only a few feet into the sand, indicates that the sand must be very porous, because the volume depends largely on the rock pressure and the porosity of the sand, and with a present average rock pressure of 200 pounds to the square inch the average volume of 36 wells is over 5,000,000 cubic feet a day.

DISTRIBUTION OF THE WELLS.

Nearly 50 producing gas wells have been drilled in an area having an average length of about 16¼ miles and an average width of 0.8 mile. The locations of the wells in all except the south end of the field have been controlled chiefly by the requirements of the leases that contained drilling contracts and to a certain extent by the desire to offset wells of competing companies.

The developed portion of the field contains approximately 6,454 acres, and the number of wells actually drilled in this area is as great as would be required to drain the gas from the entire field, including the undeveloped territory. For comparison it may be stated that in some localities it has been held that only one gas well should be drilled to each 800 acres. It is doubtful, however, if any limiting area can be chosen that will be satisfactory for all gas fields, because the acreage required will vary with the structure of the gas field, the relation of the gas to the salt water, and the size of the pores and consequent freedom of movement of gas in the sand. An ideal arrangement of wells in the Mexia-Groesbeck field would be to space them at such distances from the sides of the gas-bearing area that they would have equal quantities of gas on each side. The distribution of the wells along the longer axis of the anticline should be controlled by the variations in the width of the fold, and the spacing between two adjacent wells should not be greater than one-half the average width of the fold in the vicinity of the wells. If spaced at greater intervals the wells will not drain all the gas from the sand. For a full utilization of the available supply the distance between any two wells should be equal to the shortest distance from either of the wells to the margin of the gas-producing area. This distance would be less than one-half the average width of the field near the wells, and where so spaced the wells might be expected to interfere with each other, but this interference would work no injury to the field and would merely diminish the daily yield of each well.

In the south end of the field the wells are distributed in such a way as to leave an interval of about half a mile between them. This interval is probably a little too great for the full utilization of the gas. Under the existing conditions all the gas in this field can be utilized only by controlling the yield of some of the wells that are too near the margin. This statement is best explained by reference to figure 7, *a*. To draw too heavily upon wells A and C will raise the level of the salt water and cut off from the main body of the gas a portion of that which is contained in the sand farther down the dip. By checking the flow of these wells nearly all the gas in the sand at lower levels than those at which they penetrate it may be recovered. Well B, drawing from the sand at a point where there is no salt water, will have a much longer life and supply a much greater total quantity of gas because it will continue to flow after the salt water has migrated upward beyond wells A and C.

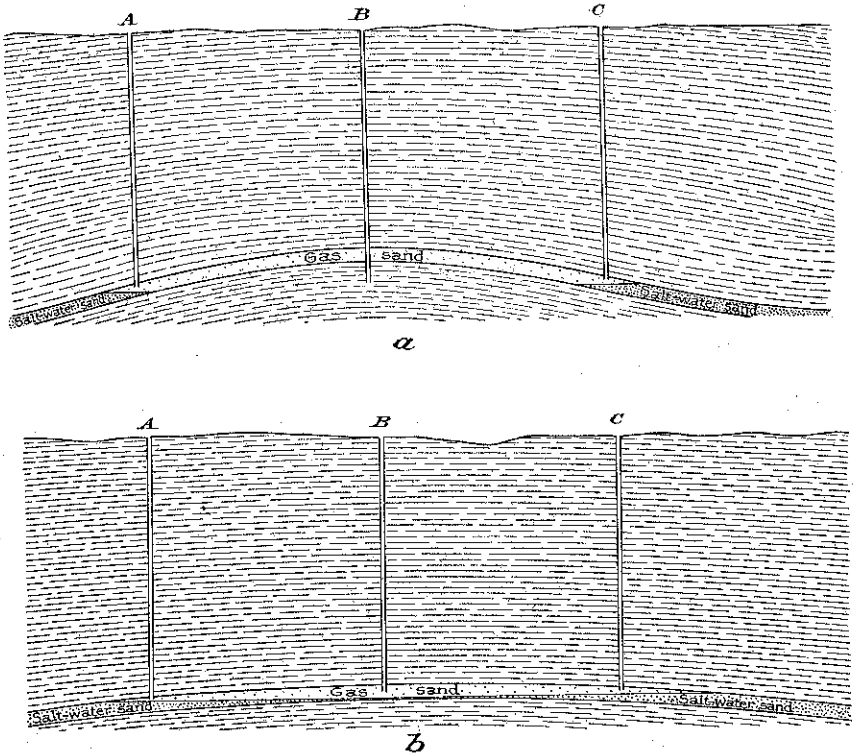

FIGURE 7.—Diagrams showing the occurrence of gas and salt water in different folds and their relation to the production of gas wells. *a*, Portion of the sand entirely filled with gas; *b*, salt water extending beneath the entire body of sand containing gas.

In those portions of the field where the sand lies so low that the conditions represented in figure 7, *b*, prevail the flow of gas from all the wells situated like those shown in the diagram will need to be controlled carefully in order to prevent the salt water from rising to the top of the sand in the vicinity of the wells before the total quantity of gas has been utilized.

DETERMINATIONS OF PRESSURE.

In determining the rock pressure of the wells in the Mexia-Groesbeck field three separate gages were used. These gages belonged to Supt. Anderson, of the Mexia Oil & Gas Co, Mr. F. G. Clapp, and Mr.

R. L. Underwood. The determinations with these gages did not agree very closely. Those made with the gages of Mr. Underwood and Supt. Anderson checked within 1 or 2 pounds of each other, but those made with Mr. Clapp's gage were from 5 to 12 pounds less than the pressures shown by the others. It was not practicable to have these gages tested by a machine company, and they were therefore checked with the Foxboro line gage of the Mexia Oil & Gas Co. The readings of the line gage and Mr. Clapp's gage showed a difference of 12 pounds at the time the test was made, and subsequent comparisons of Mr. Clapp's gage with those of Mr. Underwood and Supt. Anderson showed a similar difference. Corrections in accordance with these differences were applied to readings that were made with Mr. Clapp's gage alone.

The 37 wells used in determining the rock pressure for the field gave an average of 200 pounds to the square inch, but the variations between the wells in different portions of the field were so marked that it seems best to separate them into groups. The average pressure of 27 wells north of Navasota River was about 188 pounds to the square inch. The average of six wells just south of Navasota River was approximately 210 pounds, and the average of four wells just west of Groesbeck, belonging to the Robinson Oil & Gas Co., was about 270 pounds.

The original rock pressure of this field in July, 1913, after seven wells had been drilled, averaged about 276 pounds, and in October, 1915, one of the wells belonging to the Robinson Oil & Gas Co. showed a decline of only 2 pounds from this average, though some of the wells between the Robinson Oil & Gas Co.'s properties and Navasota River had declined in pressure below 200 pounds. On the north side of the Navasota very few wells showed pressures as high as 200 pounds at the time of gaging, and the maximum pressure determined was 213 pounds. The decline in rock pressure is shown in figure 8.

Rock pressures of wells in the Mexia-Groesbeck gas field.

[Pounds to the square inch.]

178	192	172	222	188	210
183	209	179	175	198	200
182	170	184	160	212	
276	197	206	170	188	
265	182	220	207	204	
272	173	200	187	213	
270	162	206	181	211	

In 37 wells the average rock pressure was 200 pounds to the square inch, though in the territory between the two developed areas the pressure should be nearly up to the initial 276 pounds per square inch, and if wells were drilled in this undeveloped territory they would doubtless raise the average. Three additional wells could be drilled in the undeveloped territory near Navasota River that would probably have an average pressure nearly equal to the wells west of Groesbeck. With these additional wells the average pressure of the field would be about 205 pounds per square inch.

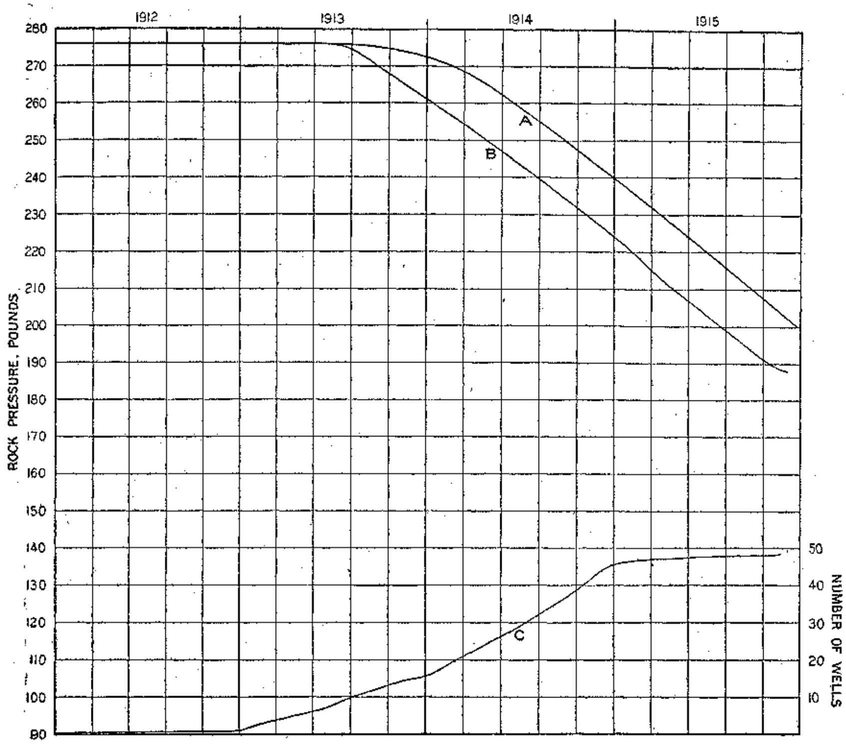

FIGURE 8.—Diagram showing the decline of rock pressure and the increase in the number of producing wells in the Mexia-Groesbeck gas field. A, Decline in whole field; B, decline in part of field north of Navasota River; C, increase in number of wells.

OPEN-FLOW VOLUMES OF THE WELLS.

In order to determine the capacity of the wells in the Mexia-Groesbeck field measurements were taken of the open-flow pressure of 36 representative wells, and the volumes were estimated by using tables issued for this purpose by the Oil Well Supply Co. These tables are copies of those published in volume 6 of the Ohio Geological Survey, pages 372 and 373, and represent careful determinations of the value of open-flow pressures in volume, stated in cubic feet daily. Nearly all the wells gaged to determine open-flow pressures were allowed to flow into the air for periods of 45 minutes or longer, and in many of them the pressure was gaged at intervals of 15 minutes from the time the wells were opened. One well, Webster

No. 2 of the Robinson Oil & Gas Co., was allowed to flow 23½ hours, and its pressure was determined at intervals for the purpose of constructing a curve showing the decline of pressure. This curve, together with the curve of another well in the south end of the field, is shown in the accompanying diagram (fig. 9). The list given below states the open-flow volumes of the wells at the expiration of 45 minutes after they were opened. Most of the figures represent actual

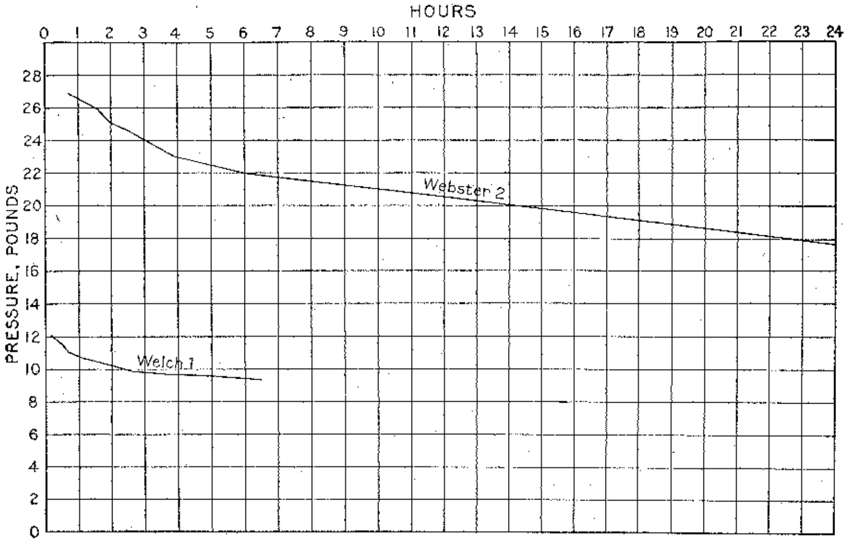

FIGURE 9.—Diagram showing the rate of decline in open-flow pressure of representative wells in the Mexia-Groesbeck gas field.

measurements, but the determinations for a few wells were made by interpolation or by prolongation of the curve obtained from readings for a shorter period. The determinations were based on a temperature of 50° F. for storage of the gas.

Open-flow volumes of wells in the Mexia-Groesbeck field, in cubic feet a day.

2,656,260	1,327,390	2,990,380	5,483,910
2,197,020	2,584,660	2,509,400	14,673,330
2,067,140	2,958,470	2,059,680	7,574,600
9,776,975	4,227,670	2,554,080	8,683,220
8,889,240	2,488,820	2,740,220	502,630
3,541,400	4,500,000	10,332,840	3,469,780
9,532,800	2,096,190	6,466,900	10,370,520
3,253,370	6,981,530	3,554,730	6,755,750
698,550	10,000,930	6,496,960	4,922,200

The total open flow for 36 wells at the expiration of 45 minutes was 181,919,545 cubic feet a day. To this total should be added about 40,000,000 cubic feet for wells not gaged. This volume could probably

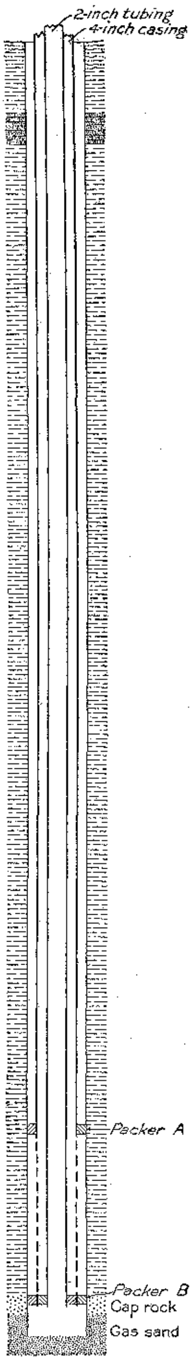

FIGURE 10.—Gas well in Mexia-Groesbeck field.

be increased 15,000,000 to 20,000,000 cubic feet by drilling enough wells to develop the territory between the producing areas, but the open flow of existing wells is about 220,000,000 cubic feet a day.

CONDITION OF THE WELLS.

The condition of the wells in the Mexia-Groesbeck gas field will seriously affect the amount of gas that can be obtained from them and the amount that can ultimately be obtained from the entire field. Most of the wells at the south end of the field have been cased to the cap rock, but the contact between the casing and the cap rock is not sufficiently tight to prevent the escape of gas around the outside of the casing. Cement has therefore been poured into the well around the casing to stop the escape of gas at the surface, but the efficacy of this method of cementing may be doubted, because not all the gas lost reaches the surface. In the northern part of the field the casings were set in the wells at some distance above the top of the gas sand. Many of the wells are finished with 4-inch casing set with the bottom some distance above the gas sand. (See fig. 10.) In some of these wells a packer is placed in position indicated by "Packer A." In order to prevent underground leakage of gas and caving of the sides of the hole the casings should be extended to the cap rock and the packer set at the point marked B. Some of these wells will probably need to be tubed with 2-inch pipe, with a packer (B) as shown in the diagram. The pressure of the gas in these wells declined rapidly before the construction of the principal pipe lines and the utilization of the gas in the cities that are now being supplied. This decline in pressure was due in part to the escape of gas into the strata above the cap rock, and the amount thus lost and the leakage from the gate valves and pipe lines amounted to about 24 per cent of all the gas originally in the field. This amount of gas was lost while the consumption was only about 4 per cent of the total supply of gas in the field; or, stated in a different way, the waste has been about six times as great as consumption.

The conservation of gas after it is drawn from the wells is an engineering problem, because it depends upon prevention of leaks from pipe lines, valves, and other fittings, but the question of preventing loss underground is geological, being controlled in part by the character of the strata. The gas lost underground was in part taken up by the shale adjoining the lower portions of the wells, below the bottom of the casing, but in some wells some of the gas appears to have found its way upward around the casing into porous strata that contained some fresh water. In addition to the loss of gas, the gas entering the fresh-water strata displaced some of the water, which descended into the well and now appears in the form of water vapor or as moisture in the shale that is blown from the well. There are some indications that the rate of decline of pressure resulting from the loss of gas in the strata above the cap rock, at first rapid, is now gradually diminishing, probably because the openings in the strata near the well are becoming filled with gas.

It was at first believed that as the pressure of the field was lowered by consumption through pipe lines a portion of the gas that had entered the shales and sands above the cap rock might return to the well, but when the wells were gaged it was found that the lowering of the pressure resulting from the flow of gas into the air permitted the expansion of gas in the shales at so rapid a rate that fragments of shale were loosened from the wall of the well. Probably also some fresh water was forced down around the casing by gas in the upper water-bearing sands. It appears, therefore, that an attempt to recover the gas that has escaped into the formations above the cap rock is likely to be attended by clogging with shale and, in some wells, by flooding with fresh water. To avoid this danger it will be necessary to tube some of the wells with a pipe of smaller diameter, having a packer at the lower end, which should be firmly seated in the cap rock. This will necessarily result in diminishing the volume of gas that can be supplied from these wells, and most of the wells, being cased with 4-inch pipe, will need to be tubed with 2-inch pipe. This will decrease the volume of these wells to only about one-sixth of the volume supplied through the 4-inch casings, but it should prevent some of the wells from being clogged with shale or flooded with fresh water and in that way prolong their period of production.

AMOUNT OF GAS THAT CAN BE UTILIZED.

The total quantity of gas in the Mexia-Groesbeck field has been estimated at 2,331,057,000 cubic feet under a pressure of 200 pounds per square inch at the time the investigations for this report were made; but it is improbable that this gas can all be drawn from the sand for commercial use. In the Cherryvale field, Kansas, wells with a pressure of 8 pounds to the square inch still had an average volume of 28,810 feet a day, and it is therefore apparent that wells may be utilized under a comparatively low pressure. However, computations made by G. F. Becker, of the United States Geological Survey, show that nearly 95 per cent of the gas will have been utilized when the pressure is reduced to 15 pounds, provided the total bulk of the sand occupied by the gas were as much as at the present time. This estimate is too small by an amount that will depend on the rate of utilization of the gas and the rate of movement of the water into the sand as the pressure is lowered. As both of these factors are unknown, it is not possible to determine in advance just what quantity of sand will be occupied by gas when the pressure has been lowered to 15 pounds to the square inch, and in order to avoid overestimating the amount of gas that can be utilized, it is assumed that the quantity of gas sand continues uniform.

LIFE OF THE FIELD.

Few problems present as great difficulties as are met in attempting to estimate the life of a gas field, because it is difficult to determine the amount of gas in the sand and almost impossible to estimate in advance the percentage of the available supply that will be utilized. The amount of loss, both by leakage and by leaving gas in the sand, can not be estimated in advance, because they depend upon the conditions controlling exploitation. Under the most favorable conditions, where the field is controlled and exploited as a unit and where care is exercised in the construction and maintenance of pipe lines and in the utilization of wells, the amount of gas recovered and marketed should be much higher than if the field is exploited in the usual way. In attempting to make comparisons between the Mexia-Groesbeck field and those of other localities, it was found that the conditions governing exploitation and the amount of gas originally present were so variable that it was not possible to reach satisfactory conclusions based on experiences in other fields. It would of course be possible to determine the average life of a large number of gas fields, but it is very doubtful if this would furnish any guide in arriving at a safe conclusion concerning the probable life of the Mexia-Groesbeck field, because of the diversity in occurrence, in amount of gas, methods of exploitation, and many other factors. The marked variations of different gas fields from the average that has been obtained show the impracticability of attempting to estimate the life of a gas field by comparison with other fields. Some fields have been found to be productive for more than 10 years, and others have been exhausted in a short time. For example, the Hogshooter field, in Oklahoma, was productive on a large scale for only a little more than two years.

For the reasons enumerated, it seems best to summarize the information concerning the amount of gas remaining, the percentage of the original supply that has already been withdrawn from the field, and the proportion of this amount that has been utilized by consumers. These facts, together with a knowledge of the history and condition of the field, should make it possible for those engaged in the future exploitation of the field to obtain the maximum amount of gas by reducing to a minimum the loss during exploitation.

The consumption of 10 to 12 per cent of the open-flow volume of the wells in the Mexia-Groesbeck field should be possible, provided the wells are tubed to the cap rock and kept in good condition. The total amount of this open flow will be reduced if the tubing is done with 2-inch pipe, and the capacity of the wells tubed will be only about one-sixth of their present capacity. The life of the field will depend in considerable measure on careful and systematic exploitation. If wells near the margin of the field are allowed to yield as freely as those on the higher portions of the sand, they will soon begin to blow salt water and will ultimately become flooded. The effect of heavy draft on marginal wells will be to bring the salt water that occurs beneath the gas into the wells, thereby interfering with the flow of gas. At the same time the upper portion of the gas sand a short distance from the well may still contain gas that under careful management should have been recovered. This condition is shown graphically in figure 7 (p. 94), and it can be avoided by controlling the flow of the wells near the margin of the field. The entrance of salt water into a well might be partly remedied by lowering its head by pumping, as it was found in some of the Kansas fields that a flow of 100,000 cubic feet of gas a day could be obtained from a salt-water well by this method, but the cost of pumping would probably be greater than the value of the gas recovered from most of the wells, and it will be better practice to delay the incursion of salt water by checking the flow of the marginal wells.

The Mexia-Groesbeck field, when examined in October, 1915, contained 2,331,057,000 cubic feet of gas, under a pressure of 200 pounds per square inch. This volume may be regarded as comparatively unimportant, but when it is considered that gas is consumed under a much lower pressure and has a much greater volume, it will be found that there is enough gas remaining in this field to be important. The gas now in the field, if placed in a container under a pressure of 15 pounds per square inch, would have a volume of 31,080,766,666 cubic feet. If the prospective consumption from this field by the cities now being supplied be estimated at 1,500,000,000 cubic feet a year, this amount of gas could be expected to last for more than 20 years, or if the computations made are regarded as too great by as much as 50 per cent it would still last more than 10 years, provided there was no loss from leakage. If the amount of gas allowed to escape from wells and pipe lines continued to be as great as in the past, the field should supply the present demands for 5 to 7 years, and the percentage of the actual amount of gas from the sand that can be used will ultimately depend on the skill of the engineer in drawing it from the ground and transporting it to the market.

The present capacity of the wells, estimated at 10 per cent of the open-flow volume, would be about 22,000,000 cubic feet a day, but if the field is drawn upon at this rate without improving existing conditions of the wells many of them will continue to supply gas but a short time. If these wells should be improved and gas drawn from the wells at the rate of 22,000,000 cubic feet a day, the total volume in the field would last about 3¾ years, but again it is necessary to consider the ratio of consumption to waste, and the actual life of the field under such conditions will depend on this ratio.

ANALYSES.

The accompanying analyses of gas from the Mexia-Groesbeck field were made by G. A. Burrell in the laboratory of the Bureau of Mines at Pittsburgh, and an analysis of swamp gas collected near Natchez, Miss., is added for comparison. The samples were selected from different parts of the field and show the striking uniformity in the composition of the gas, which is nearly pure methane (CH_4), with small amounts of nitrogen (N) and carbon dioxide (CO_2).

Analysis No. 1 represents a sample taken from the Mexia Oil & Gas Co.'s Adamson well, near the north end of the gas field. Sample No. 2 was taken from the Central Texas Oil Co.'s Gamble well, between the Adamson well and Navasota River. The Posey well No. 1 of the Herring Oil & Gas Co., a short distance south of Navasota River, supplied sample No. 3. Sample No. 4 came from the Anglin well of the Robinson Oil & Gas Co., at the south end of the field. Sample No. 5 is the swamp gas from Natchez, Miss.

Analyses of gas.

[G. A. Burrell, analyst.]

	1	2	3	4	5
CO_2	0.6	0.2	0.7	Trace.	3.42
O_2	.0	.0	.0	0.0	.48
CH_4	98.4	98.3	98.1	98.5	81.12
N_2	1.0	1.5	1.2	1.5	14.98
	100.0	100.0	100.0	100.0	100.00
Specific gravity (air=1)	0.57	0.56	0.57	0.56	0.64
Heating value at 0° C. and 760 millimeters pressure, in British thermal units	1,047	1,047	1,045	1,052	884

A heating capacity of 1,047 British thermal units is much higher than that of the gas of the Petrolia field, described by Mr. Shaw on page 41, which has a heating value of 755 British thermal units. Interpreted in quantities, this means that 1,000 cubic feet of gas from the Mexia-Groesbeck field has a heating value equivalent to about 1,390 cubic feet of gas from the Petrolia field. As shown by the table, the swamp gas represented by sample No. 5 has a somewhat higher heating value than the gas from the Petrolia field and a much lower value than that of the Mexia-Groesbeck field.

POSSIBILITY OF EXTENDING THE FIELD.

The southern limit of the Mexia-Groesbeck field has been outlined in the recent drilling by the Robinson Oil & Gas Co., but this does not mean that additional anticlines, having the same general trend, may not be found farther south. In fact, there seems to be a very good possibility for the occurrence of gas south of this field. This inference is drawn from the fact that a number of wells drilled at random have encountered small volumes of gas in the Nacatoch sand and from the additional fact that the general disturbances which produced the Mexia-Groesbeck anticline have been distributed over a much larger area than is represented in that anticline. The attempts of the writer to ascertain the extent of possible producing territory in that direction were hampered by the fact that the surface exposures are poor and by the lack of well-defined rock layers that can be traced over a large enough area to determine structure. It should be noted, however, that if more time could have been devoted to the work, some results might have been attained.

Some wildcat wells have been located beyond the southern limits of the field, and it is possible that they may furnish information concerning the structure, even though they may not be successful in finding commercial quantities of gas.

The general trend of the structure near the north end of the Mexia-Groesbeck field, together with some observations on the dip of shale beds, has suggested the possibility of extending the producing area toward the north. The most promising locality for such an extension is indicated on the structure map (Pl. VI, in pocket), and one or two wells should be sufficient to test the possibilities of obtaining gas in the area north of the field.

POSSIBLE INCREASE IN NUMBER OF GAS SANDS.

At the present time the Mexia-Groesbeck gas field derives its supply from a single sand, and no question has aroused more general interest than that concerning the possibility of finding additional sands at greater depths that may prove productive of either gas or oil. Consideration of the general section of the Upper Cretaceous formations shown in the diagram of the refinery well at Corsicana (Pl. VII) warrants the conclusion that there is a probability of finding additional sands at greater depth. The question whether or not the sands will be productive is one that can not be answered except by drilling, though there seems to be an excellent chance that some of them will yield either gas or oil or both.

In discussing the geology it was noted that the characteristic fossils of the Nacatoch sand member of the Navarro formation are found at the surface at Corsicana and in the gas sand at Mexia. This leads to the conclusion that the surface formations at Corsicana are the substantial equivalents of those that would be found just below the gas-bearing sand at Mexia and Groesbeck. In the refinery well at Corsicana the gas sand was encountered at a depth of 1,075 to 1,095 feet and the oil sand between 1,205 and 1,215 feet. These sands may possibly be represented in the Mexia-Groesbeck field, and although their exact depth there can not be stated with accuracy, they should be expected between the gas sand of that field and the Austin chalk. If the beds at these horizons should prove to be barren, additional sands will be found at still greater depths. The Woodbine sand was encountered in the refinery well at Corsicana at a depth of 2,381 to 2,436 feet, and another porous sand at 2,444 to 2,484 feet. If a well drilled to test the lower sands should prove unsuccessful above the Austin chalk, it might be well to continue to these deeper sands in order to determine whether they are oil or gas bearing in the Mexia-Groesbeck field. In spite of the fact that these beds contain potable water at Corsicana, it is worth while to test them for oil and gas in the Mexia-Groesbeck field, where the structure is exceptionally favorable for the accumulation of oil and gas. The best place to locate a well to test the deep sands in the Mexia-Groesbeck field would be where the upper gas sand is high. Preference should therefore be given to the areas where this sand rises nearest to sea level, as shown by the contours on Plate VI (in pocket).

SUMMARY.

Of the area examined east and southeast of Dallas only the Mexia-Groesbeck field can be regarded as capable of producing enough gas to be of importance to a large city, and the value of this field depends very largely upon the elimination of waste in the production and marketing of the gas. The total volume of gas in October, 1915, has been estimated at 31,080,766,666 cubic feet, under a pressure of 15 pounds per square inch, the approximate pressure of consumption. If marketed at a rate of 1,500,000,000 cubic feet per year, the probable average consumption from existing pipe lines, the estimated life of that field, provided there is no waste, would be a minimum of 10 years and a maximum of 20 years; if marketed at the rate of 22,000,000 cubic feet per day, the capacity of the existing wells, the amount of gas in the field should be great enough to last about three and three-fourths years, though before the expiration of the period the existing wells would need to be supplemented by others in the undeveloped territory, and in order to transport the gas to greater distances than the length of the present pipe lines it would be necessary to install compressors. It is possible that the Mexia-Groesbeck field may be extended toward the north and that new fields of similar character may be found both to the north and south of the existing field. An area 10 to 20 miles wide extending from Baileyville northeastward to the vicinity of Greenville and Cooper is regarded as worthy of more detailed geologic examination and prospecting with the drill, with the expectation of finding other fields similar to the Mexia-Groesbeck field. It is probable that new producing sands will be found in this pool, and some of them may have a greater capacity than the sand that has already been developed.

WELL LOGS.

Logs of wells furnished by the Mexia Oil & Gas Co.

Pittman well No. 26.

[Driller, S. T. Sturdevant. 581 feet of 6-inch casing, with 4-inch liner and tubing; concrete between casing and liner and outside of casing.]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface soil and clay	55	55
Water sand	7	62
Soft water rock	4	66
Blue water sand with white shells	102	168
Black shale with streaks of gas sand	32	200
Gumbo; some 4 to 6 foot streaks of sand; some gas	50	250
Gumbo with layers of sand and bowlders, streaked	65	315
Tough gumbo	63	378
Shale	22	400
Gumbo	20	420
White "gippy" gumbo, very hard	10	430
Hard black slate	20	450
Tough gumbo	30	480
Slate	50	530
Gumbo	20	550
Loose blue shale; petroleum odor	15	565
Tough gumbo	35	600
Blue shale	47	647
Gumbo	8	655
Gray shale	8	663
White gumbo and gray shale	12	675
Hard cap	4	679
Sand and gumbo, streaked	13	692

Kimble well No. 24.

[Driller, S. T. Sturdevant. 33 feet 9 inches of 6-inch casing; 612 feet of 4-inch casing.]

Sand	32	32
Rock and bowlders	8	40
Blue sand	20	60
Shale and gravel	25	85
Black shale	50	135
Hard black slate	15	150
Gray or blue sandy shale	105	255
Black shale	345	600
Gumbo	15	615
Gray shale	25	640
White shale	10	650
Cap rock (porous sand)	6	656
Sand	11	667
Porous rock, second cap	8	675

Logs of wells furnished by R. L. Underwood.

Bates well No. 1.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface	8	8
Lime rock	165	173
Black shale	50	223
Gumbo	40	263
Gray shale	70	333
Gumbo	20	353
Gray shale	100	453
Gumbo	80	533
Gray shale and sand	150	683
Gumbo	40	723
Gray shale and some sand	100	823
Gumbo	20	843
Light shale and sand	52	895
Cap rock	3	898
Gas sand (gas at 900 feet)	5	903
Salt water at	....	912

B. B. Barron well No. 1.

Rock	235	295
Shale	540	835
Rock and sand (show of gas at 930 feet)	95	930
Shale	90	1,020
Rock	2	1,022
Shale	228	1,250
Rock	3	1,253
Shale	167	1,420
Rock	1	1,421
Shale	279	1,700
Sand (show of gas)	220	1,920
Shale and gumbo	80	2,000

Logs of wells furnished by T. F. Smith.

Louise Gamble well No. 1.

[Drilled in 1914. Wall, packer. 658 feet of 6-inch casing; 657 feet of 4-inch casing.]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface sand	4	4
Yellow clay	4	8
Blue rock	8	16
Blue shale	280	296
Shale rock	7	303
Blue shale	114	417
Shale and gumbo	34	451
Gumbo	47	498
Blue shale	95	593
Gray shale	60	653
White shale	4	657
Cap rock	8	665
Gas sand	22	687

Joe Kennedy well No. 2.

[Drilled in 1914.]

Soil sand	4	4
Joint clay	47	51
Blue shale	348	399
Gumbo	44	443
Blue shale	160	603
Gray shale	33	636
White shale	4	640
Cap rock	7	647
Gas sand	23	670

Logs of wells furnished by T. F. Smith—Continued.

A. G. Manning well No. 1.

[Drilled in 1914. 20 feet of 6-inch casing; 735 feet of 6-inch casing.]

	Thickness.	Depth
	Feet.	*Feet.*
Soil sand	3	3
Yellow clay	17	20
Lime rock	27	47
Water sand	3	50
Lime rock	84	134
Packed sand	30	164
Lime rock	11	175
Packed sand	11	186
Lime rock	12	198
Packed sand	54	252
Blue shale	340	592
Gumbo	45	637
Blue shale	10	647
Gray shale	80	727
White shale	11	738
Cap rock	3	741
Gas sand	11	752

Mackey well No. 2.

Surface soil	4	4
Yellow clay	33	37
Black shale	600	637
White shale	41	678
Cap rock	4	682
Gas sand	8	690

William Stevens well No. 2.

[Drilled in 1914.]

Surface sand	3	3
Lime rock	16	19
Packed sand	8	27
Lime rock	14	41
Packed sand	42	83
Black shale	180	263
Gumbo	37	300
Black shale	95	395
Gumbo	185	580
Blue shale	60	640
Light shale	48	688
Cap rock	1	689
Sand	11	700
Salt water.		

W. H. Hill well No. 1.

[Drilled in 1914.]

Surface sand	4	4
Joint clay	42	46
Blue shale	280	326
Lime rock	38	364
Packed sand	40	404
Lime rock	3	407
Packed sand	12	419
Blue shale	95	514
Gumbo	85	599
Blue shale	90	689
White shale	13	702
Cap rock	8	710
Gas sand	12	722

Logs of wells furnished by T. F. Smith—Continued.

W. H. Hill well No. 2.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface sand	3	3
Joint clay	16	19
Rock and sand	184	203
Blue shale	74	277
Lime rock	30	307
Blue shale	27	334
Gumbo	195	529
Blue shale	104	633
Light shale	85	718
Cap rock	2	720
Sand	12	732
Salt water.		

J. B. Best well No. 1.

Surface	4	4
Joint clay	24	28
Lime rock	174	202
Packed sand	30	232
Black shale	190	422
Gumbo	85	507
Black shale	118	625
White shale	80	705
Cap rock	1	706
Sand	4	710
Salt water.		

Joe Kennedy well No. 3.

Surface sand	1	1
Joint clay	65	66
Blue shale	288	354
Gumbo and shale	27	381
Gumbo	85	466
Blue shale	127	593
Gray shale	67	660
White shale	5	665
Cap rock	8	673
Gas sand	20	693

A. E. Bertherson well No. 2.

[Drilled in 1914.]

Surface sand	3	3
Yellow clay	24	27
Lime rock	124	151
Packed sand and rocks	90	241
Blue shale	240	481
Gumbo	40	521
Blue shale	153	674
Light shale	48	722
Cap rock	7	729
Gas sand	21	750

A. E. Bertherson well No. 3.

[Drilled in 1914.]

Surface sand	4	4
Yellow clay	19	23
Lime rock	131	154
Lime rock and packed sand	94	248
Blue shale	245	493
Gumbo	120	613
Gray shale	45	658
White shale	41	699
Cap rock	24	723
Gas sand	24	747

Logs of wells furnished by T. F. Smith—Continued.

A. E. Bertherson well No. 4.

[Drilled in 1914.]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface soil	4	4
Yellow clay	32	36
Lime rock	90	126
Lime rock and packed sand	127	253
Blue shale	160	413
Lime rock	8	421
Blue shale	84	505
Gumbo	70	575
Gray shale	92	667
White shale	37	704
Cap rock	12	716
Gas sand	22	738

Stewart well No. 1.

Brown surface sand	3	3
Yellow clay	28	31
Lime rock	8	39
Water sand	12	51
Lime rock	4	55
Sand rock	12	67
Blue shale	92	159
Gumbo	74	233
Gumbo and shale	278	511
Gray shale	124	635
Light shale	34	669
Cap rock	1	670
Gas sand	6	676
Salt water.		

Joe Kennedy well No. 1.

Brown surface sand	3	3
Joint clay	45	48
Blue shale	184	232
Shell rock	3	235
Blue shale	10	245
Shale rock	7	252
Blue shale	227	479
Gumbo and shale	30	509
Gumbo	60	569
Light shale	64	633
White shale	28	661
Cap rock	12	673
Gas sand	18	691

William Stevens well No. 1.

[Drilled in 1914.]

Surface sand	1	1
Joint clay	18	19
Sand rock	3	22
Blue shale	15	37
Sand rock	8	45
Blue shale	170	215
Gumbo and shale	140	355
Gumbo	200	555
Blue shale	35	590
Light gray shale	87	677
White shale	21	698
Cap rock	2	700
Gas sand	20	720

Logs of wells furnished by T. F. Smith—Continued.

R. H. Lyle well No. 1.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface sand	8	8
Joint clay	32	40
Sand rock	8	48
Water sand	16	64
Lime rock	12	6
Packed sand	56	132
Blue shale	345	477
Gumbo	60	537
Blue shale	35	572
Gumbo	10	582
Blue shale	20	602
Light shale	85	687
White shale	28	715
Cap rock	3	718
Gas sand	8	726

R. H. Lyle well.

[Drilled in 1914.]

Surface sand	6	6
Joint clay	45	51
Blue shale	375	426
Gumbo	40	466
Blue shale	165	631
Light shale	64	695
White shale	3	698
Cap rock	3	701
Gas sand	10	711

Mackey well No. 1.

Surface soil	3	3
Yellow clay	44	47
Black shale	173	220
Lime rock	38	258
Black shale	120	378
Gumbo	170	548
Gray shale	40	588
Black shale	212	800
No sand.		

AREA COVERED BY A GENERAL RECONNAISSANCE.

PRINCIPAL FEATURES.

A general reconnaissance was extended from the vicinity of Thornton northward a distance of 120 miles to Cash, and covered a strip of territory from 10 to 20 miles in width. At many places in this area small quantities of gas have been found associated with salt water, and gas has been developed in commercial quantities at Mexia, Groesbeck, Corsicana, and Chatfield. In addition, a large quantity of oil has been obtained in the vicinity of Corsicana. The presence of the gas indicates that the areas are underlain by formations that may supply gas or oil wherever the structure is favorable for the accumulation of these substances. The surface exposures are so poor that search for such structure must be confined very largely to the collection of data from wells. Information obtained at Wortham, Currie, Corsicana, Mabank, and Cash shows that there has been more or less deformation of the strata throughout a large part of the area examined. The evidence indicates that the former southeasterly dip of the formations in this territory is in many places lessened and at some places even reversed, the dip being toward the northwest. The presence of this area of deformation leads to the conclusion that it probably contains other undiscovered structures similar to those at Mexia, Groesbeck, Corsicana, and Chatfield. It is inferred that these structures probably have small areas, and their discovery will depend very largely on drilling wildcat wells, with such assistance as can be rendered by a geologic study of the scattered surface exposures and the logs of wildcat wells that have already been drilled.

WORTHAM.

One of the first discoveries of gas south of Corsicana was made at Wortham, about 7 or 8 miles north of Mexia. The discovery well was owned by the city and was within the corporate limits. It had a very large flow of gas and sprayed enough oil to stain the buildings in the vicinity. The log of this well, furnished by Mr. C. L. Witherspoon, shows the character of the formations penetrated.

Log of the city well at Wortham.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale and gumbo		1,120
Hard gumbo and shale	80	1,200
Hard sand	30	1,230
Gumbo	20	1,250
Rock	4	1,254
White sand	5	1,259
Rock	½	1,259½
Oil and gas sand	21	1,280

Another well drilled near Wortham, on the Speed lease, furnishes a section to a greater depth than the city well.

Log of Speed well, near Wortham.

	Thickness.	Depth.
	Feet.	*Feet.*
No record		800
Shale and gumbo, with some sand	665	1,255
Hard sand, with some shale	55	1,510
Soft shale	150	1,660
Hard sand rock	80	1,740
Soft shale	490	2,230
Lime rock	18	2,248

The hard sand rock at 660 to 740 feet contained enough gas to blaze above the floor of the derrick when ignited. The lime rock encountered at the bottom of the well is apparently the Austin chalk, and this log, together with that of the city well, shows that there are at least two sands in the shales and clays overlying the Austin chalk.

The city well at Wortham was completed May 12, 1912, and while the casing was being withdrawn it blew out with so large a volume of gas that it could not be controlled. It continued to blow gas with a spray of oil for a week, when it finally became choked with sand. The driller asserts that it was the largest gas well that was ever drilled in Texas. The unusual volume of gas obtained from this well caused considerable excitement and led to the drilling of a number of others. One well about 50 feet from the city well was drilled to a greater depth without encountering either gas or oil. Another well about 50 yards east of the discovery well encountered enough oil at a depth of about 1,180 feet to permit the pumping of about one barrel a day. A well about 50 yards south of the discovery well, with a depth of about 1,220 feet, had a flow of gas estimated at 4,000,000 cubic feet a day, but this flow continued only a short time until the well was flooded with salt water.

According to the reports of some of the citizens, more than 30 wells were drilled in the vicinity of the town, but none of the others encountered enough gas or oil to be of any value. Apparently, the structure conditions in this vicinity are unfavorable for the accumulation of any large quantity of either gas or oil, though they may be found in small areas, such as those around the city well and the other productive wells near by.

CURRIE.

The accompanying diagram (fig. 11) shows the distribution of a few wells in the vicinity of Currie. These wells are of considerable interest because some of them had large volumes of gas when they were first drilled, and at least one of them was capable of producing a small amount of oil. The Henry Swink well (No. 1) is still bubbling considerable gas four years after it was drilled and makes a better showing than any of the other wells in the vicinity of Currie. The depth of the gas sand in this well could not be learned.

Well No. 2 is now being drilled to test the capacity of the shallow oil sand.

Well No. 3, on the Quinby farm, encountered gas sand at a depth of 419 feet below sea level. This well now shows a small amount of gas bubbling through salt water. A thin bed of sand was encountered at a depth of 300 feet, below a thick layer of limestone.

Another well (No. 4) that was drilled three-fourths of a mile north of Currie, on the Hillburn farm, encountered oil in sand 5 feet thick at a depth of 360 feet. Beneath the oil sand was 33 feet of lime rock, and the gas sand was encountered at 882 feet and extended to a depth of 904 feet. The log of this well from 904 feet down is as follows:

Log of lower part of Hillburn well near Currie.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale and gumbo	33	937
Salt-water sand	20	957
Sand rock	4	961
Pack sand with some shale	159	1,120
Shale and gumbo	380	1,500

A little high-gravity oil is now flowing from this well and is accompanied by a few bubbles of gas and a large amount of alkaline water. The gas comes from the sand at a depth of 542 feet below sea level, and the oil is reported to be from the sand immediately overlying the limestone.

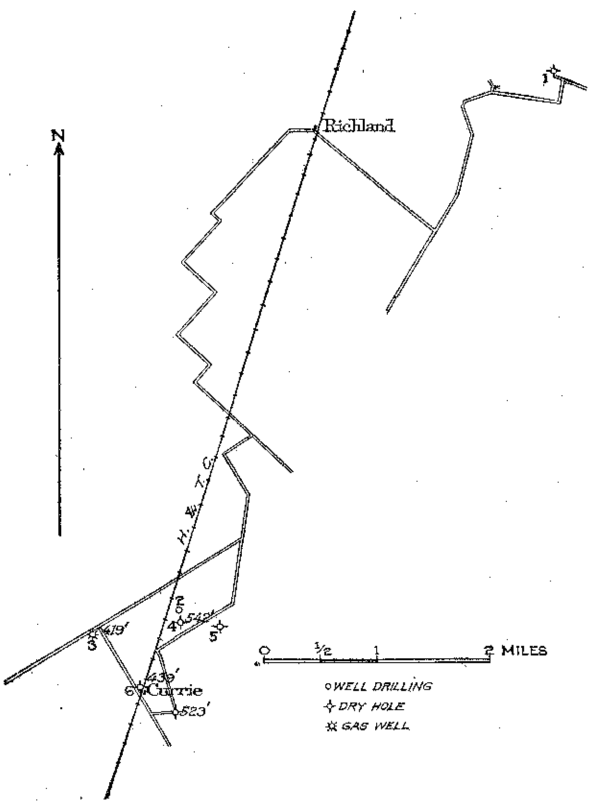

FIGURE 11.—Diagram showing the relations of wells drilled at Currie.

About half a mile east of the Hillburn well gas was encountered in a well drilled on the Brinson farm (No. 5). The exact depth to the gas-bearing sand at that point could not be learned, and according to the most reliable information the flow of gas lasted only a few hours.

The well on the Frank Wright farm (No. 6), near the Houston & Texas Central Railroad at Currie, is said to have yielded sufficient gas to be utilized, but within a few days the flow of salt water became so large that the well had to be abandoned. The log of this well is as follows:

Log of Frank Wright well, Currie.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand and clay	70	70
Shale	290	360
Hard lime rock	40	400
Shale with a few bowlders	450	850
Gas sand	15	865
Gumbo	20	885
Salt water sand	20	905

The varying depths to the gas sand in the vicinity of Currie suggest that the sand, if it is continuous, must have undergone a marked deformation, probably accompanied by faulting on a large enough scale to destroy its continuity. As an alternative explanation, it may be suggested that the gas sand in this area is really in the form of discontinuous lenses, but in either case the conditions do not appear favorable for the development of commercial quantities of gas, though it might be worth while to prospect some of the adjoining territory.

CORSICANA.

Corsicana has been the center of both oil and gas production, but the value of oil has been much greater than that of gas. Petroleum was discovered in this region more than 15 years ago, and although the field has never been a large producer, its aggregate output has been large. It is remarkable for the great number of wells that have continued to produce for several years. One well near the city of Corsicana has yielded oil since September, 1898.

Two distinct kinds of petroleum are produced, one being a light oil suitable for refining and the other being much heavier and better suited for fuel oil. The light or high-gravity oil is found near Corsicana, and the heavier oil farther east toward Powell.

Gas has been found at various places in the oil field, but most of the wells have had a small production and have lasted only a short time. The only commercially important gas fields near the town of Corsicana are about 2¾ miles a little west of south of Powell and 1 mile south of Chatfield. These two fields have supplied gas to the city of Corsicana. The Powell field has an approximate length of 1¼ miles and a width of a quarter to half a mile. Several wells have been drilled in this field, the most productive being Stone No. 2, which was about 890 feet deep and had a pressure of 375 pounds to the square inch. This well supplied gas to the city of Corsicana for about three years. There was so much salt water with the gas that it was necessary to install a large separator at the well, and all the wells subsequently drilled found more or less salt water associated with the gas. Additional wells were drilled in this pool to supplement the supply from the first well, and some of the earlier wells are now dead. Two or three of the wells would still supply some gas, but the pressure is so low that it could not be utilized without compressors, and it is doubtful if the amount of gas that could be obtained from the wells would warrant the expenditure of much money for installing compressors.

The gas pool near Chatfield occupies an area of about the same extent as the one near Powell, and four or five producing wells were drilled in it. The gas from this field was piped to the city of Corsicana and furnished about one-third of the total amount used before the pipe line was constructed from the Mexia-Groesbeck field. At present this field is entirely dead and the casings have been pulled from the wells.

Logs of wells near Corsicana, Powell, and Chatfield.

Corsicana Petroleum Co., waterworks well No. 30.

[Contractor, R. Walling. Drilled Apr. 30–May 1, 1903.]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil		3
Clay	14	17
Shale	223	240
Rock	1	241
Shale	40	281
Rock	2	283
Shell	17	300
Do	900	1,200
Rock and shell	23	1,223
Sand	20	1,243
Rock	1	1,244
Salt-water sand	10	1,254

No show of oil or gas.

Corsicana Petroleum Co., Kerr well No. 1.

[Drilled Nov. 25 to Dec. 14, 1901. Dry hole. Filled up 175 feet with salt water from sand at 1,191-1,199 feet.]

Joint clay		40
Shale	90	130
Water sand	5	135
Shale	5	140
Lime bowlder	2	142
Blue marl	98	240
Hard lime bowlder	3	243
Blue marl	737	980
Blue shells	205	1,185
Shale	6	1,191
Salt-water sand	8	1,199
Blue marl	204	1,603
White lime	6	1,609

Logs of wells near Corsicana, Powell, and Chatfield—Continued.

Corsicana Petroleum Co., I. B. Roberts well No. 3.

[Drilled by Houston Oil Co. of Texas, Jan. 6, 1905.]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	1	1
Yellow clay	34	35
Hard bluish sand	48	83
Gravel and white sand	5	88
Brownish shale	293.5	381.5
Black quartz	58.8	440.3
Brownish shale	405.8	846.1
Top of first gas sand	......	846.1
Through sand into shale, good gas pressure	40.8	886.9
Shale	118.1	1,005
More gas sand and better pressure	18.7	1,023.7
Shale	8.3	1,032
Salt-water sand	13	1,045
Shale and bluish mud; abandoned at this depth	139.2	1,184.2

Corsicana Petroleum Co., Whiteselle well.

[Drilled Feb. 15–Mar. 5, 1904.]

Soil	5	5
Clay	16	21
Shale	45	66
Rock	1	67
Shale	195	262
Rock, very hard; case barrel	3	265
Shale	9	274
Rock, very hard	3	277
Shale	24	301
Rock	1	302
Shale	18	320
Rock	1	321
Shale	139	460
Gumbo	14	474
Shale	367	841
Gumbo	5	846
Shale	220	1,066
Rock, hard in places	4	1,070
Sand; no gas, some water	25	1,095
Shale	55	1,150

Slight traces of oil at 1,085 feet.

Anderson well No. 7, Chatfield.

[Drilled Nov. 11, 1908.]

Clay	......	10
Rock	2	12
Clay	33	45
Sand	60	105
Shale and gumbo	734½	839½
Gas sand	8	847½

Roberts well No. 1.

[Drilled Sept. 20, 1907.]

Clay	......	57
Rock	3	60
Sand	114	174
Shale and gumbo	686¾	860¾
Gas sand	16	876¾

Logs of wells near Corsicana, Powell, and Chatfield—Continued.

Stone well No. 5.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and gravel	....	60
Shale	784	844
Rock	$\frac{5}{6}$	$844\frac{5}{6}$
Sand; showed both oil and gas	$3\frac{1}{6}$	848
Sand and shale	26	874
Hard sand and shale	32	906
Cap rock and sand	12	918
Sand rock	15	933
Cap rock	2	935
Sand	1	936

The oil and gas found near Corsicana and Chatfield are obtained from two or more sand beds in the upper portion of the Upper Cretaceous series, probably the Navarro formation. The well logs have a particular interest because the surface formation near Corsicana is of about the same geologic age as the gas sand at Mexia and Groesbeck, and the wells at Corsicana show the presence of sands in either the Navarro or the Taylor formation below the horizon of the sand that supplies gas in the Mexia-Groesbeck field. Sands have been found at still greater depth near Corsicana in the water wells of the city and in a deep well at the Magnolia Petroleum Co.'s refinery. The relation of these deep sands to the producing sands is shown in the diagram of the refinery well (Pl. VII, p. 78). The water obtained from these deep sands is relatively pure, though it contains enough salt to give it a brackish taste. These sands can not be expected to be productive in the vicinity of Corsicana, but they might supply oil or gas in the gas field south of Powell and possibly also at Chatfield.

CASH.

The accompanying diagram (fig. 12) shows the relations of three wells that have been drilled in the vicinity of Cash. Both Nos. 1 and 2 are shallow wells. No. 1 has a little showing of gas and a small volume of salt water. No. 2 contains enough gas to cause a heavy flow of salt water, and it is necessary to keep the well capped to avoid flooding the surrounding land. This well might possibly be utilized to supply a house, as the amount of gas would apparently be ample for that purpose. Both of these wells penetrate a shallow sand that is probably an approximate equivalent to the oil or gas sands of Corsicana. Well No. 3 has been drilled to a greater depth and found showings of oil and gas in the Woodbine sand. It did not encounter an appreciable amount of gas in the shallow sands that supplied the showings in wells Nos. 1 and 2.

The amount of information available concerning the area near Cash is not sufficient to warrant suggestions as to further prospecting, but the fact that the sands are much higher than the sands that are correlated with them at Quinlan and Terrell and are reported to be higher than the sands of the same age at Greenville suggests that there may be an anticline near Cash and makes it seem advisable to continue prospecting.

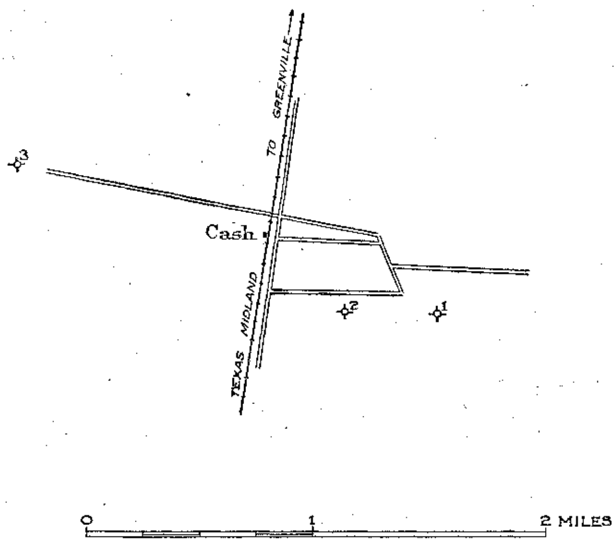

FIGURE 12.—Diagram showing the relations of wells drilled at Cash.

A few miles south of Cash in the vicinity of Quinlan some shallow wells encountered small showings of gas in a sand that is probably the equivalent of the shallow gas sand at Cash.

MABANK.

The accompanying diagram (fig. 13) shows the distribution of wells that were drilled in the vicinity of Mabank, and the figures given show the depths of the gas-bearing sand below sea level. All these wells, except the one northeast of Mabank, supplied small amounts of gas with salt water, but the structure suggested by the elevations of the gas sand is too flat to warrant the drilling of additional wells with the expectation of finding commercial quantities of gas within the area shown by the diagram.

In the region near Mabank the Midway formation is at the surface and the wells penetrate the Cretaceous rocks for a considerable distance. It is therefore inferred that the gas sand in this region belongs to the Navarro formation and that it may be tentatively correlated with the gas sand of the Mexia-Groesbeck field. Deeper sands may be struck in the Cretaceous rocks at Mabank, but they are probably of little economic importance, because the folding there is not sufficiently pronounced to permit the accumulation of much gas or oil.

SUMMARY.

Gas has been found at Baileyville, Koose, Thornton, Groesbeck, Mexia, Wortham, Currie, Richland, Corsicana, Powell, Chatfield, Mabank, Cash, and Cooper. At only three of these places have wells furnished gas in commercial quantities and at only two have wells furnished oil; but the significance of the presence of gas in the area between Baileyville and Cooper is not affected by the commercial value of the discoveries that have been made. These discoveries show the presence of gas-bearing sands through this belt, and inves-

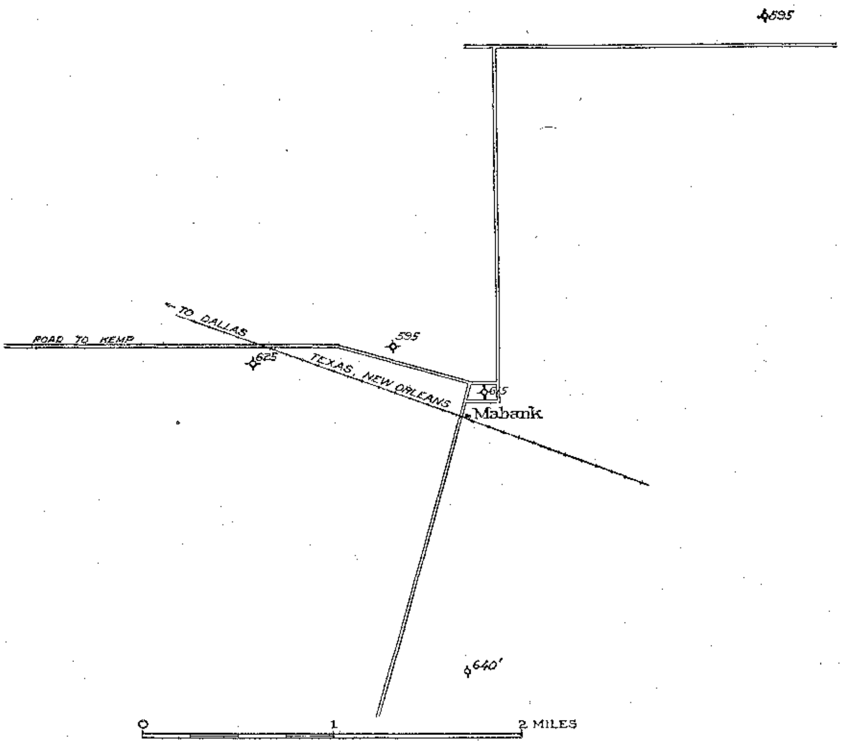

FIGURE 13.—Diagram showing the relations of wells drilled at Mabank.

tigations indicate that the dip of the beds here is not uniformly toward the southeast but is interrupted by terraces and minor reversals of dip. Sructure favorable to the accumulation of oil or gas, similar to that at Mexia, Groesbeck, Powell, and Corsicana, will no doubt ultimately be discovered in this region, which is therefore regarded as a possible oil and gas field.

NOTES ON THE GAS FIELDS OF CENTRAL AND SOUTHERN OKLAHOMA.

By Carroll H. Wegemann.

THE GENERAL SITUATION.

Scattered through Muskogee, Okmulgee, and northern McIntosh counties, along the southern edge of the great Oklahoma oil and gas fields, are numerous areas that have produced natural gas in great quantities. Fields near Henryetta, Schulter, Okmulgee, Boynton, Haskell, and Muskogee contain wells whose initial flows are reported to have ranged from a few million to 40,000,000 cubic feet a day. Over much of the area the gas is directly associated with oil pools and has been developed and, it must be admitted, wasted in connection with the production of oil. The gas is found in the oil sands and in sands overlying them and has proved more or less of a hindrance in the immediate production of oil. The far-reaching effects of the presence of the gas in increasing the amount of oil recoverable from the sands has been appreciated by few of the oil operators. The various methods of wasting the gas above ground or beneath the surface have been discussed too often to require description here, but the fact remains that vast stores of valuable gas have been dissipated, and that even now it is difficult for companies interested in the preservation of the gas to avoid the bad effects of too heavy drains on the gas reservoirs in neighboring properties over which they have no control. The Bureau of Mines and the State authorities have already taken steps to conserve the remaining gas supplies, and it is believed that their action will eventually lead to greatly improved conditions in the gas fields.

Active drilling is still in progress in the Muskogee-Okmulgee field, and new areas of productive oil and gas territory are being brought in. Undrained areas of gas probably remain in the vicinity of some of the old oil fields. It is doubtful if other gas pools as great in extent as those already developed will be found in this old area, but it seems safe to say that careful drilling throughout this area may open many large gas wells whose product could be utilized if pipe lines were available. It is evident, however, from the amount of drilling already done in the region and the quantities of gas already taken out that the productive gas wells yet to be drilled must be scattered over a considerable area, and the expense involved in building lines to them will be proportionately great—so great, perhaps, as to reduce considerably the distance to which the product can be transported with commercial success.

The life of gas wells in this region varies greatly, being governed by the thickness and porosity of the various sands, but most of all by the methods used to prevent waste and the management of adjacent wells. A few wells that show large volumes when brought in decline quickly in production, probably because the gas sands that supply them are of small extent. The rapid decline of other wells and their "drowning" with salt water are undoubtedly the result of drawing too heavily on them or on wells adjacent to them. However, it is not unusual to find wells which under careful management have yielded gas for two or three years with but little diminution in volume.

South of the main area of the oil and gas fields above described and separated from it by broad stretches of unproductive territory are several gas fields, recently developed, in which the gas does not appear to be associated with oil in any great quantity. Two of these fields have been examined by the writer, and brief descriptions of them are given below. Additional details will be given later in a report with maps covering portions of the region discussed in these notes.

CHECOTAH GAS FIELD.

The Checotah gas field lies about 5 miles south of the town of Checotah, in McIntosh County. The first productive well was completed on February 10, 1914, and up to the time of the writer's examination (November, 1915) seven gas wells had been drilled, having initial volumes ranging from 1,500,000 to 15,000,000 cubic feet a day. The principal yield of gas is obtained at depths ranging from 1,970 to 2,100 feet, although gas in paying quantities (1,000,000 to 2,000,000 cubic feet a day) is found in most of the wells at 600 to 700 feet below the surface, and in some parts of the field a third gas sand at depths of 1,500 to 1,600 feet is reported. A list of the wells follows:

Green River No. 1, SW. ¼ SW. ¼ sec. 29, T. 11 N., R. 17 E.; completed Feb. 10, 1914.

Green River No. 2, NE. ¼ NW. ¼ sec. 32, T. 11 N., R. 17 E.; completed June 7, 1914.

Green River No. 3, SW. ¼ SE. ¼ sec. 30, T. 11 N., R. 17 E.; completed Oct. 22, 1915.

Gladys Bell No. 1, SW. ¼ SE. ¼ sec. 29, T. 11 N., R. 17 E.; completed Oct. 26, 1915.

Gladys Bell (Bunker Hill Oil Co. No. 1), SW. ¼ SE. ¼ sec. 36, T. 11 N., R. 16 E.; completed July, 1914.

Markowitz & Kell, C. D. Cook No. 1, SE. ¼ SW. ¼ sec. 25, T. 11 N., R. 16 E.

A shallow well, 645 feet in depth, in the SW. ¼ NE. ¼ sec. 32, T 11 N., R. 17 E.

Four dry holes have been put down in the vicinity of the field, in the NE. ¼ NE. ¼ sec. 35, T. 11 N., R. 17 E., and the SE. ¼ SW. ¼ sec. 4, NW. ¼ NW. ¼ sec. 16, and NW. ¼ NW. ¼ sec. 20, T. 11 N., R. 16 E.

The structural feature on which the gas is found appears to be a dome slightly longer than broad, its longer axis trending in a northeasterly direction. Wells Nos. 1 and 2 of the Green River Oil Co., in the SW. ¼ SW. ¼ sec. 29 and the NE. ¼ NW. ¼ sec. 32, T. 11 N., R. 17 E., appear to be on the crest of the dome. From these wells the gas pool probably extends for about 2 miles to the southwest and possibly farther, its limits not having yet been fully defined. If the structure is fairly regular, as it appears to be from the rather meager data at hand, the gas pool may be expected to extend for about 1½ miles northwest and southeast of Green River wells Nos. 1 and 2, or, in other words, the gas pool probably has a width of about 3 miles. Its extent toward the northeast is uncertain, but it seems reasonable to assume that the pool may extend in this direction for a mile or a mile and a half from its highest point. The area of the gas pool as a whole is probably about 10 square miles. It seems unlikely that oil will be found in large amount associated with the gas of this field, although it must be admitted that the borders of the gas territory have not yet been tested.

The rocks in the Checotah field belong to the Pennsylvanian series of the Carboniferous system, as shown by the presence of a coal bed about 3 feet thick, reported in the logs of some of the wells at about 800 feet. The strata recorded in the several well logs appear to be comparatively uniform in thickness, and exact correlations can therefore be made between the wells. The sand from which the principal supply of gas is derived is about 50 feet thick, but the gas is not distributed evenly through the sand, lying rather in pay streaks, each of which is from 5 to 20 feet in thickness.

A gas field 10 square miles in area, with wells yielding, according to reports, from 1,500,000 to 15,000,000 cubic feet of gas as initial daily production, is capable of producing, if properly drilled, an enormous quantity of gas. The life of the wells and the life of the field as a whole will of course depend on the care with which the gas supplies are protected from leakage and from invasion by water.

Some evidence noted in the field, which was not, however, amplified by a detailed examination, seems to show that the dome on which the gas wells are located lies on a general axis of uplift extending in a northeasterly direction, and it is possible that other small domes may be discovered on this axis to the northeast of the present field.

ADA GAS FIELD.

The Ada gas field is in Pontotoc County, one mile west of the town of Ada. The field has been developed within the last 15 months, and up to the time of the writer's examination (November, 1915) 10 gas wells had been put down, all in T. 4 N., R. 6 E., as follows:

MacThwaite Oil & Gas Co.:
- Allen No. 1, SW. ¼ NE. ¼ SE. ¼ sec. 31.
- Allen No. 2, NE. ¼ NE. ¼ SE. ¼ sec. 31.
- Carney No. 1, SW. ¼ SE. ¼ NW. ¼ sec. 31.
- Harden No. 1, SE. ¼ SE. ¼ NE. ¼ sec. 31.
- Charlton No. 1, SE. ¼ SW. ¼ sec. 31.
- Erwin No. 1, NE. ¼ SE. ¼ SE. ¼ sec. 31.

Skelly & Sankey:
- Bruner No. 1, NW. ¼ SW. ¼ SE. ¼ sec. 31.
- City of Ada No. 1, NW. ¼ NE. ¼ SE. ¼ sec. 31.
- Ford Harris No. 1, NW. ¼ SW. ¼ NW. ¼ sec. 32.

Skelly Cantwell No. 1, NW. ¼ SW. ¼ SW. ¼ sec. 32.

Rex Oil & Gas Co.: Cassie Leader No. 1, SW. ¼ SE. ¼ sec. 30.

Both the surface rocks and those encountered in the wells belong to the upper part of the Carboniferous system and consist of sandstones, limestones, and shales that vary considerably in thickness and character from one well to the next, so that it is somewhat difficult to make accurate correlations from the well logs. The gas pool appears, however, to be situated on a small dome the longer axis of which trends N. 72° E. The dome appears to be somewhat irregular, and it is probable that the lower limit of the gas pool is by no means a horizontal plane. On the southwest and northwest the gas-producing area is limited by dry holes, but on the northeast prospecting is still in progress, and the extent of the pool in that direction is as yet unknown. It is probable, however, from the shape of the fold as already apparent, that the gas-producing area is not more than 1½ square miles.

The principal supply of gas is found at depths ranging from 1,000 to 1,200 feet and is derived in most of the wells from two beds of sandstone which range from 10 to 40 feet in thickness and are separated by 25 to 50 feet of shale. The initial flows of the wells range from 2,500,000 to 16,000,000 cubic feet of gas a day, and the initial rock pressure runs as high as 440 pounds. Single wells appear to be capable of producing without injury between 400,000 and 500,000 cubic feet of gas daily. One of the wells shows a little oil when the gas is drawn on heavily, but oil in notable quantity has not yet been found in this field.

POOLS IN CARTER AND STEPHENS COUNTIES.

No report on the gas fields of central and southern Oklahoma would be complete without reference to the gas pools in Carter and Stephens counties. In Carter County the largest gas wells are found at the southeast extremity of the Healdton oil pool,[1] in sec. 15, T. 4 S., R. 3 W. The initial volume of one of these wells, drilled in February, 1915, was reported as 40,000,000 cubic feet a day. Gas sands above the principal oil sands are found in most of the oil wells on the Healdton dome, and large supplies of gas, to which little attention is paid, have already been developed in the search for oil in this field. In October, 1915, a gas well with an initial volume of 18,000,000 cubic feet a day was drilled southwest of the village of Fox, about 8 miles north of the Healdton field.

In the Loco field,[2] which lies in secs. 9, 10, and 15, T. 2 S., R. 5 W., 3 miles southwest of the town of Loco, 9 productive wells have been drilled which have tested a territory about 1½ square miles in extent. The gas wells range in initial volume from about 6,000,000 to 20,000,000 cubic feet a day. The gas has not yet been utilized, but it is understood that a pipe line to the field is contemplated.

The Duncan gas field[3] lies in sec. 12, T. 1 N., R. 6 W., about 10 miles northeast of the town of Duncan, or 15 miles north of the Loco field. Six gas wells have been drilled, all in one section, and the producing territory is probably of comparatively small extent. The wells, however, show initial volumes of 3,000,000 to 18,000,000 cubic feet a day, and the town of Duncan obtains its gas supply from them.

GAS FROM DEEPER SANDS.

In these notes no consideration has been given to the possibilities of striking deeper sands in the pools. There should, in fact, be a number of underlying sands in the Pennsylvanian series in most of the pools, though it can not be certainly predicted whether they will be found to contain gas, oil, or water. The pools farther south, such as the Checotah pool, are more likely to contain gas than oil in large amounts in the deeper sands. If gas is present in lower sands it should be under greater pressure and therefore more productive area for area. It will be noted that the drilling in these pools has generally gone but little below 2,000 feet, some of the wells being less than 1,200 feet deep. In the course of time these pools will undoubtedly be drilled until the lowest sands that can be reached by modern methods have been tapped.

[1] Wegemann, C. H., and Heald, K. C., The Healdton oil field, Carter County, Okla.: U. S. Geol. Survey Bull. 621, pp. 13–30, 1915 (Bull. 621–B).

[2] Wegemann, C. H., The Loco gas field, Stephens and Jefferson counties, Okla.: U. S. Geol. Survey Bull. 621, pp. 31–42, 1915 (Bull. 621–C).

[3] Wegemann, C. H., The Duncan gas field, Stephens County, Okla.: U. S. Geol. Survey Bull. 621, pp. 43–50, 1915 (Bull. 621–D).

CONCLUSIONS REGARDING OKLAHOMA.

In conclusion it may be stated that the gas resources of central and southern Oklahoma are sufficient, if protected from waste and properly handled, to furnish supplies to such cities as Dallas and Fort Worth for years to come. The gas is, however, for the most part distributed over large areas in many pools of comparatively small size, and it may prove unprofitable under present conditions to build pipe lines of sufficient extent to collect it. Among the larger gas pools may be mentioned the field south of Checotah, in McIntosh County, which is at present being drilled. The large supplies of gas in the immediate vicinity of the Healdton oil field are worthy of careful consideration, especially since the bringing in of the new gas well near Fox, north of the field, which suggests the possibility of the presence of other gas pools in this vicinity.

INDEX.

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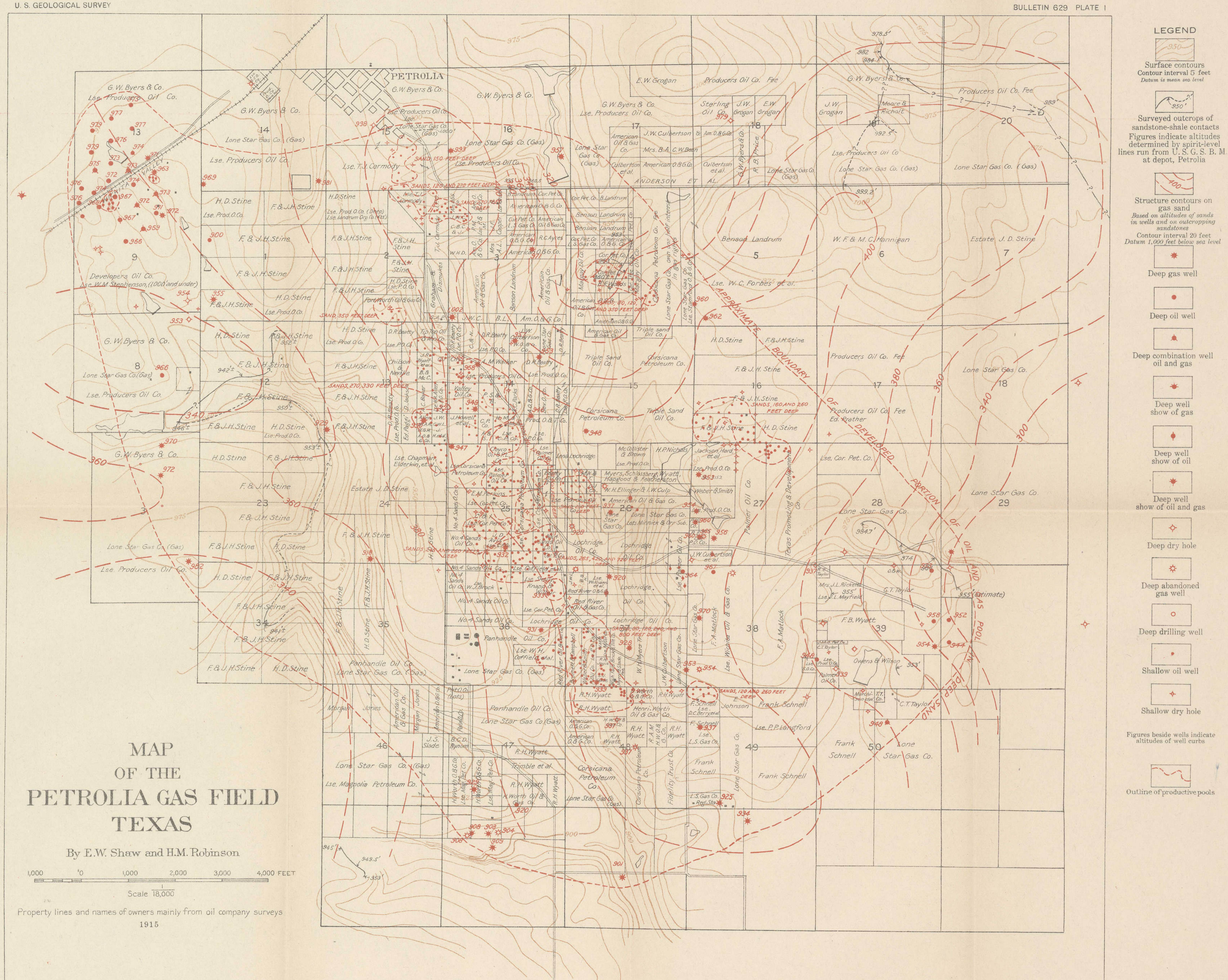
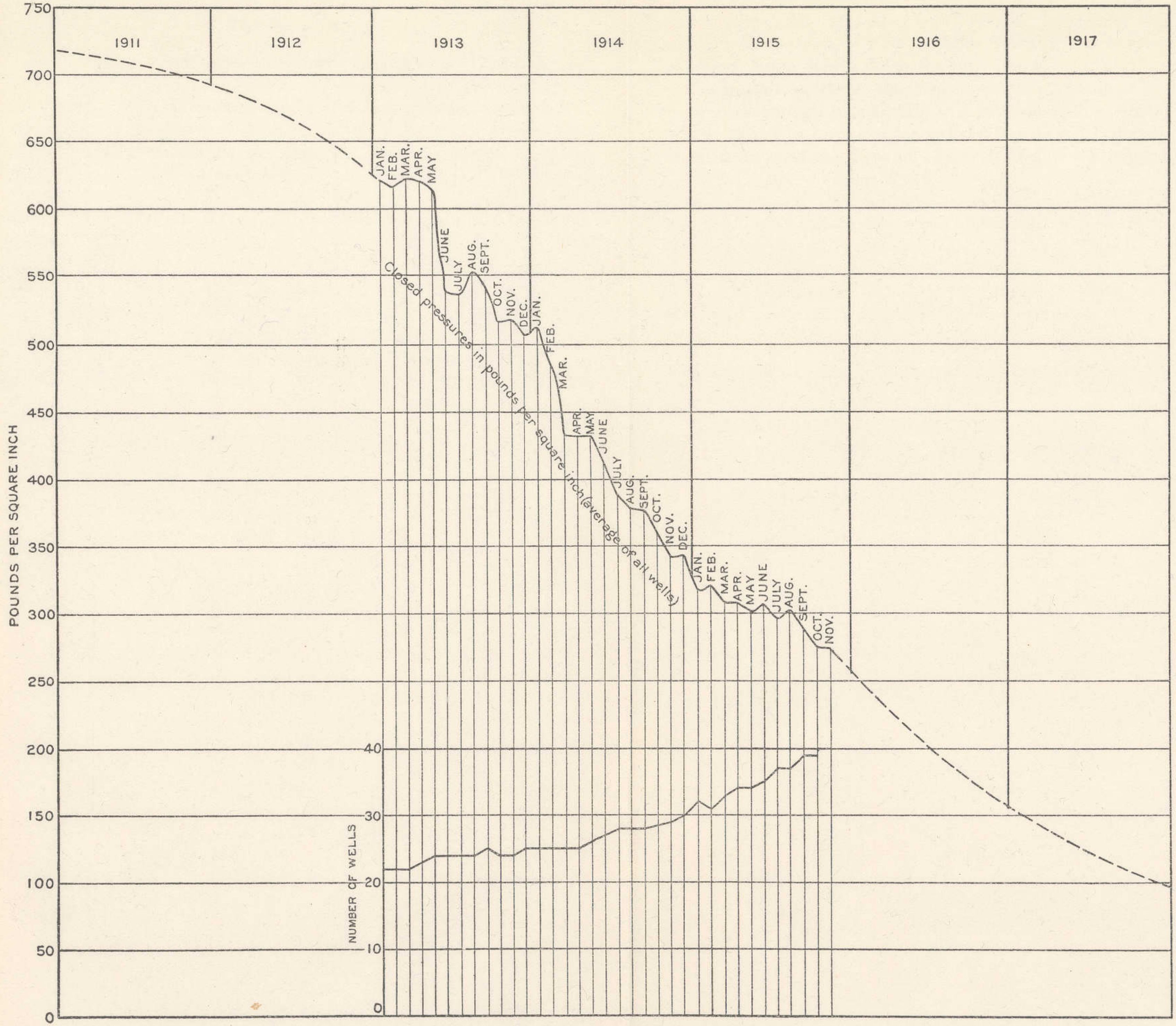
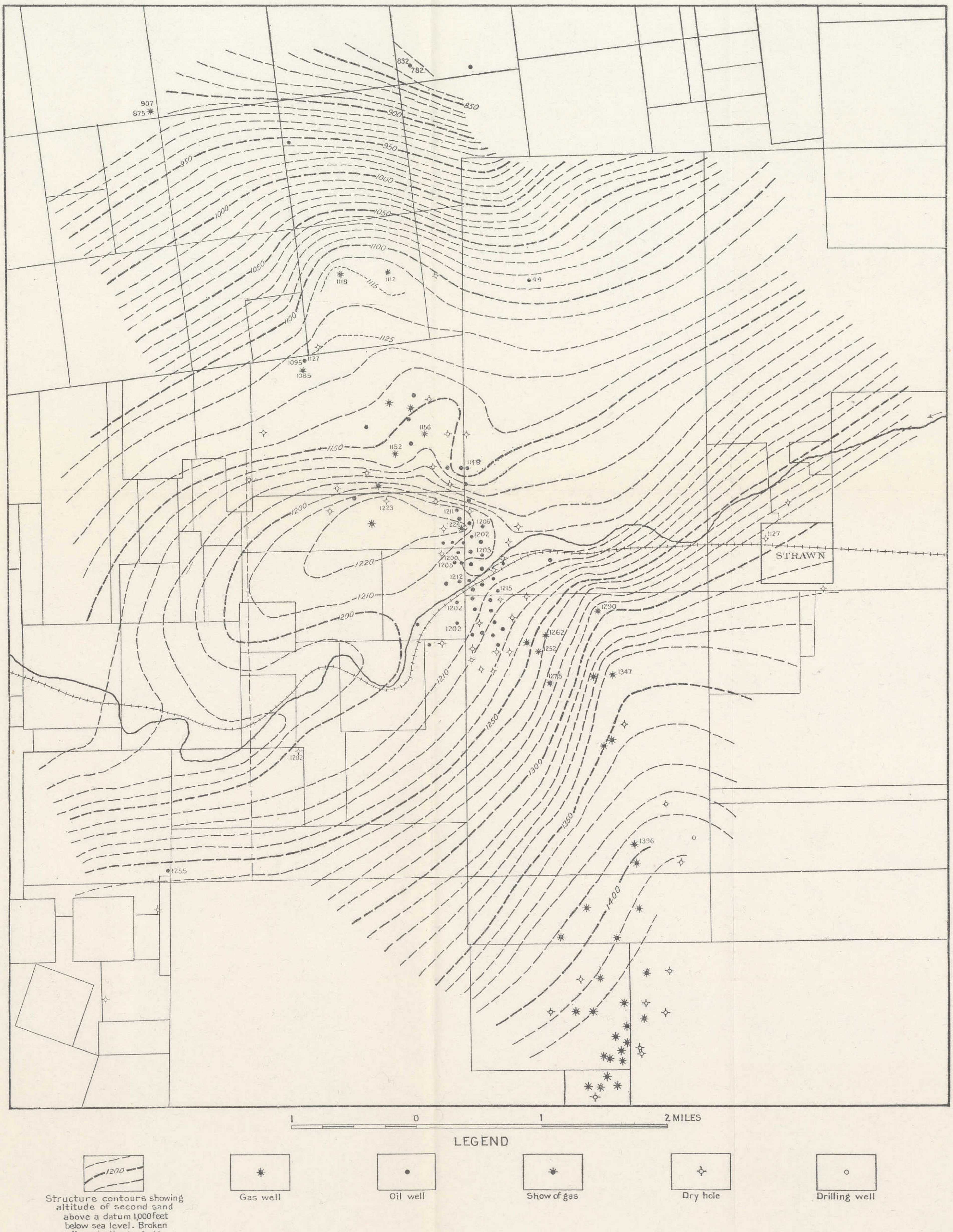

MAP
OF THE
PETROLIA GAS FIELD
TEXAS
By E.W. Shaw and H.M. Robinson
1,000 0 1,000 2,000 3,000 4,000 FEET
Scale 1/18,000
Property lines and names of owners mainly from oil company surveys
1915
LEGEND
Surface contours
Contour interval 5 feet
Datum is mean sea level
Surveyed outcrops of sandstone-shale contacts
Figures indicate altitudes determined by spirit-level lines run from U. S. G. S. B. M at depot, Petrolia
Structure contours on gas sand
Based on altitudes of sands in wells and on outcropping sandstones
Contour interval 20 feet
Datum 1,000 feet below sea level
Deep gas well
Deep oil well
Deep combination well oil and gas
Deep well show of gas
Deep well show of oil
Deep well show of oil and gas
Deep dry hole
Deep abandoned gas well
Deep drilling well
Shallow oil well
Shallow dry hole
Figures beside wells indicate altitudes of well curbs
Outline of productive pools
PETROLIA
APPROXIMATE BOUNDARY OF DEVELOPED PORTION OF OIL AND GAS POOL IN DEEP SAND
ENGRAVED AND PRINTED BY THE U.S.GEOLOGICAL SURVEY



CURVES SHOWING AVERAGE CLOSED PRESSURE OF GAS WELLS OF LONE STAR GAS CO. IN PETROLIA FIELD, TEXAS, BY MONTHS, FROM JANUARY, 1913, TO NOVEMBER, 1915, INCLUSIVE.



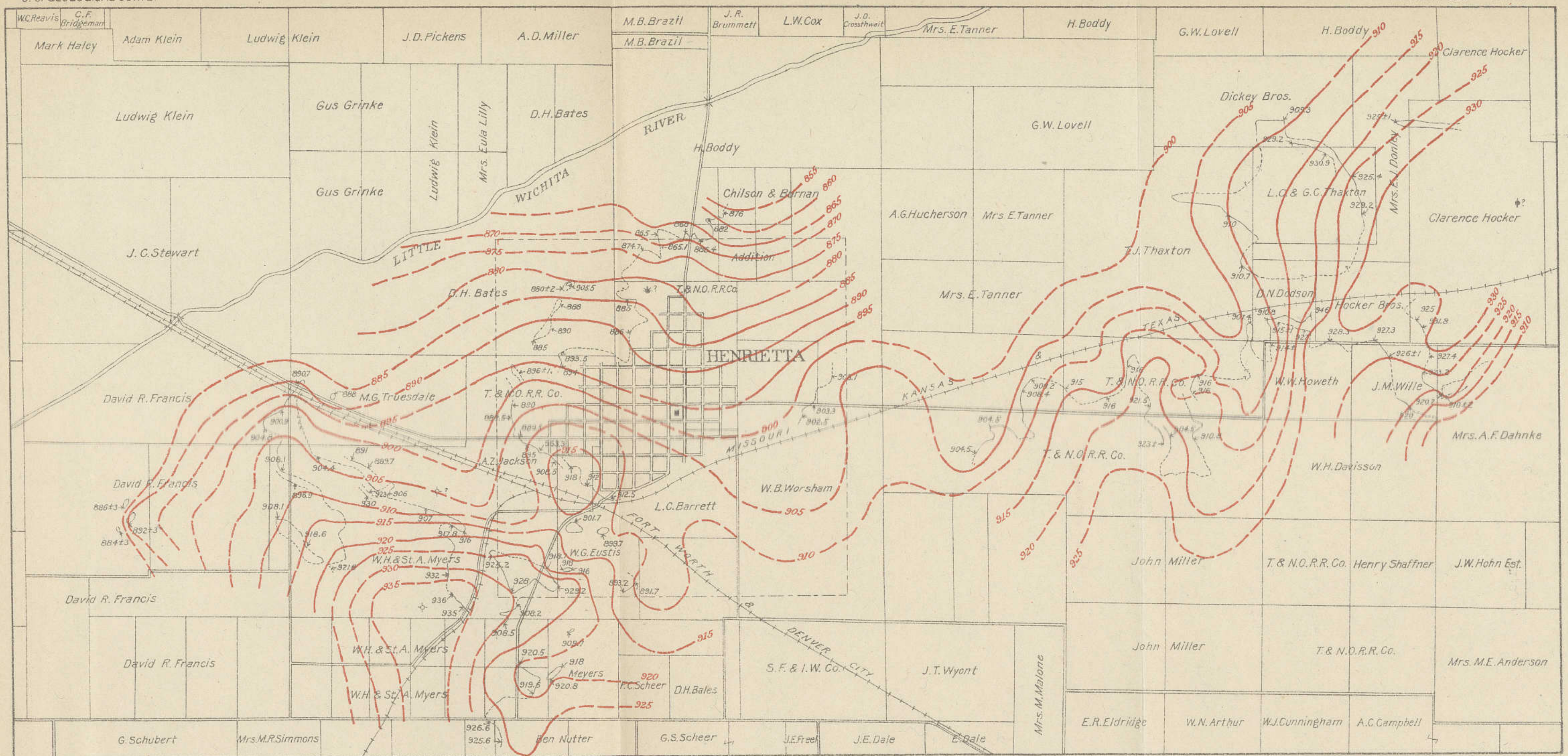
MAP SHOWING GEOLOGIC STRUCTURE IN THE VICINITY OF STRAWN, TEX.

Land lines from maps made by oil companies and the county surveyor

MAP SHOWING STRUCTURE OF PARTS OF THE AREA BETWEEN WICHITA VALLEY RAILWAY AND WICHITA RIVER, IN CLAY COUNTY, TEXAS

By E. W. Shaw and H. M. Robinson

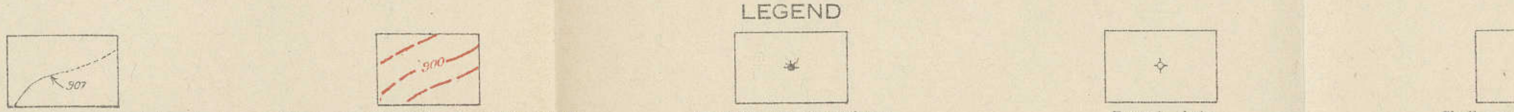
1915



Land lines from maps made by oil companies and the county surveyor

Scale $\frac{1}{48,000}$ — 1 0 1 2 Miles

LEGEND



Surveyed outcrops of sandstone-shale contacts in the Wichita formation of the Permian series, which comprises all the hard rocks exposed in the area. Figures indicate relative altitudes along contacts, but not precise altitudes above sea level

Structure contours based on altitudes of sandstone-shale contacts determined by planetable and telescopic alidade, and on dip slopes and sandstone benches. Contour interval 5 feet

Shallow well, show of gas

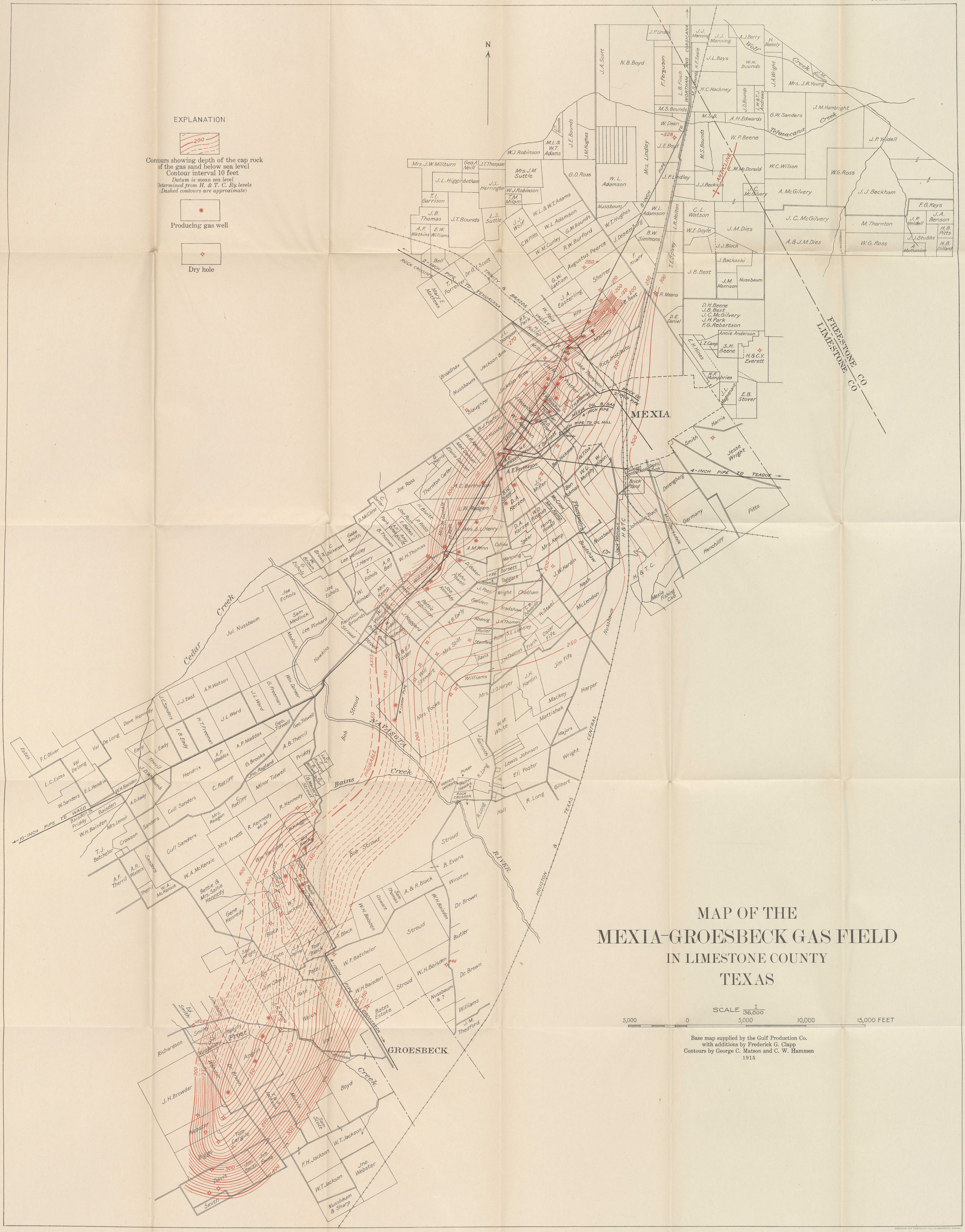
Deep dry hole

Shallow well, show of oil

MAP SHOWING GEOLOGIC STRUCTURE NEAR HENRIETTA, CLAY COUNTY, TEXAS

By H. M. Robinson and E. W. Shaw

1915


MAP OF THE
MEXIA-GROESBECK GAS FIELD
IN LIMESTONE COUNTY
TEXAS
SCALE 1/36,000
5,000 0 5,000 10,000 15,000 FEET
Base map supplied by the Gulf Production Co.
with additions by Frederick G. Clapp
Contours by George C. Matson and C. W. Hammen
1915
EXPLANATION
Contours showing depth of the cap rock of the gas sand below sea level
Contour interval 10 feet
Datum is mean sea level
Determined from H. & T. C. Ry. levels
(Dashed contours are approximate)
Producing gas well
Dry hole
N
MEXIA
GROESBECK
FREESTONE CO
LIMESTONE CO
Cedar Creek
Navasota River
Bains Creek
Tehuacana Creek
Wolf Creek
10-INCH PIPE TO WACO
4-INCH PIPE TO TEAGUE
4-INCH PIPE TO GROESBECK
2-INCH PIPE TO TEHUACANA
TRINITY & BRAZOS VALLEY
HOUSTON & TEXAS CENTRAL
WORTHAM AND CORSICANA
ANTICLINE
AXIS PROBABLE
MEXIA OIL & GAS CO
BRICK CO
4-INCH PIPE
2-INCH PIPE TO OIL MILL
PUMP
ROCK CRUSHER
Mexia Fishing Club
Rice Institute
Brick Yard

DIAGRAMS OF MATERIALS PENETRATED IN WELLS

ENGRAVED AND PRINTED BY THE U.S.GEOLOGICAL SURVEY