UNITED STATES

DEPARTMENT OF THE INTERIOR

Harold L. Ickes, Secretary

GEOLOGICAL SURVEY

William E. Wrather, Director

A STUDY OF SECONDARY RECOVERY POSSIBILITIES

OF

THE HOGSHOOTER FIELD

Washington County, Oklahoma

By

I. W. Fox, C. H. Thigpen, R. L. Ginter, and G. P. Alden
(Conservation Branch - Oil & Gas Leasing Division)

CONTENTS

ILLUSTRATIONS

- - - - - - - - - -

A STUDY OF SECONDARY RECOVERY POSSIBILITIES OF THE HOGSHOOTER FIELD Washington County, Oklahoma

By

I. W. Fox, C. H. Thigpen, R. L. Ginter, and G. P. Alden

ABSTRACT

The Hogshooter field, located in east central Washington County, Oklahoma, was first developed during the period 1906 to 1913. The field was extended later during the period 1918 to 1922. The principal producing horizon is the Bartlesville sand, found at an average depth of 1,150 feet. To January 1, 1944, the Bartlesville sand has produced 7,566,000 barrels of oil from 5,610 productive acres and 871 oil wells. Peak production, averaging 2,025 barrels per day for the year, was attained in the year 1910. The accumulation of oil in the Bartlesville sand is not related to structure.

The total recovery from the Bartlesville sand in the Hogshooter field to January 1, 1944, is estimated to represent 10.3 per cent of the original oil in place, and the total residual oil is estimated to average 11,776 barrels per acre. Widespread application of vacuum, started in 1915, has had little beneficial effect on production. Some gas-repressuring in recent years has increased recovery to a small extent.

Conservatively estimated water-flood recovery possibilities are: 3,500 barrels per acre for an area consisting of 1,393 acres (4,875,000

barrels total) with a reasonable profit at the present price of crude oil, and 2,500 barrels per acre for an area of 2,248 acres (5,620,000 barrels total), with no profit indicated under existing conditions. The latter area would show a profit equal to the first-mentioned area only with an increase in price of crude oil of forty-five cents per barrel.

Subsurface waters at depths of 1,400 to 1,700 feet are indicated as a satisfactory source for use in water-flooding operations.

INTRODUCTION

Purpose of the Report

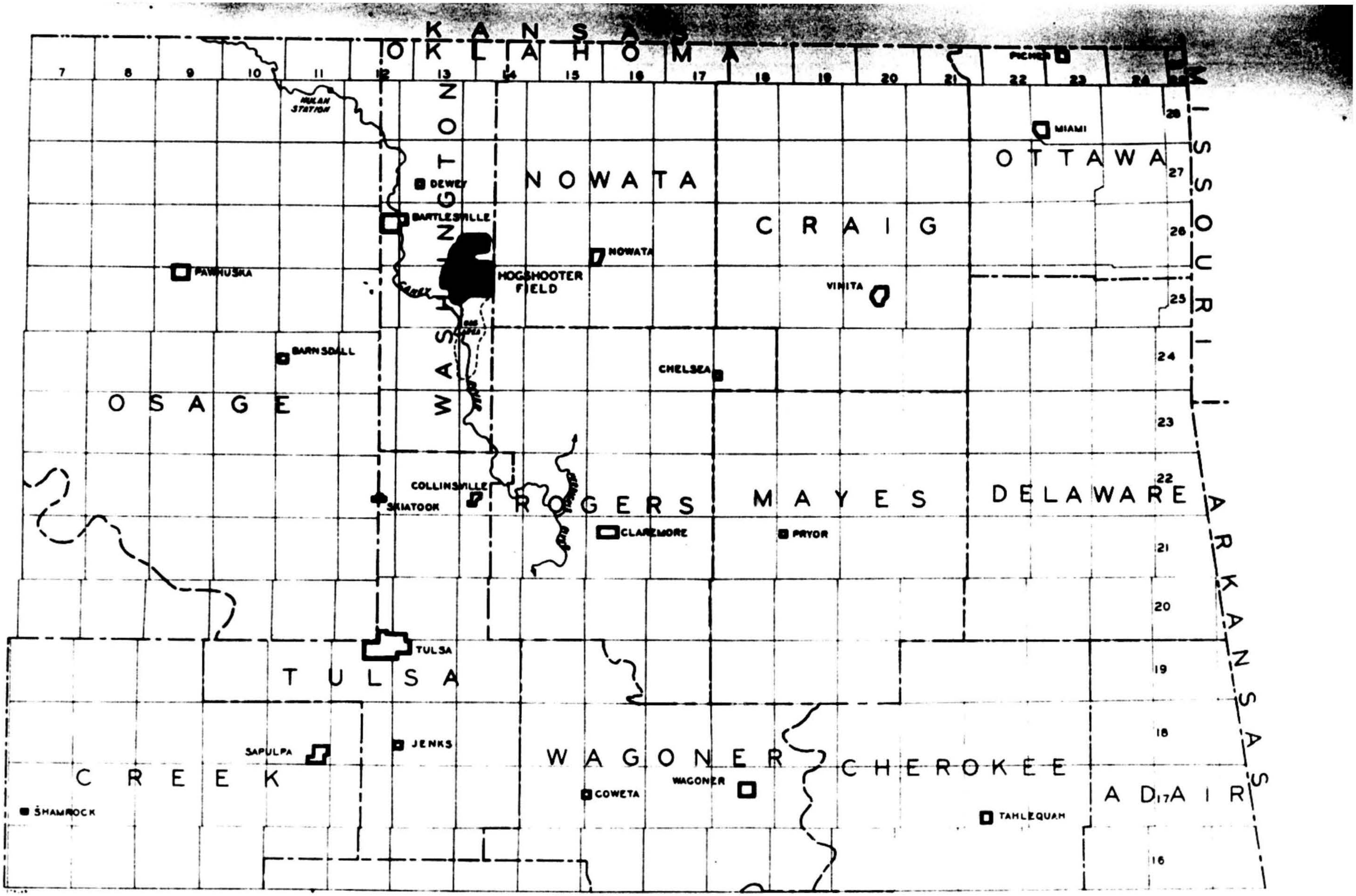
The present war and the resulting increased demand for petroleum and its by-products have brought an increasing appreciation of the problem of oil reserves and supply from the viewpoint of both the military service and industry. It is recognized that the rate of finding new oil reserves is so small that the productive capacity of the existing known reserves will be inadequate to meet the increased oil consumption. However, large volumes of oil remain in the majority of the so called depleted and semi-depleted producing fields as pptential reserves of millions of barrels of crude oil. These reserves, increasingly important for war use, can be recovered only by the application of secondary recovery methods such as repressuring with gas, air, or water. It is essential that any successful secondary recovery project be preceded by a petroleum engineering study in order that the oil producer will have some conception as to the quantity of oil he can expect to recover, the cost of recovery, and the rate at which it can be recovered. For this reason the Oil and Gas Leasing Division of the Geological Survey has commenced the investigation of secondary recovery projects and plans to compile into report form the findings therefrom. In addition it wishes to offer every possible aid to the oil producers with a view to obtaining increased oil recoveries.

The report consists of a study of the possibilities of applying secondary recovery to the Bartlesville sand of the Hogshooter field, Washington County, Oklahoma. Its principal purpose is to review the conditions under which early production was effected, to invite the attention of the oil industry to some of the areas deemed most favorable for secondary recovery projects, and thus act as a guide for the "core barrel", which in the final analysis will furnish data from which more definite conclusions may be drawn.

The undertaking of this project was made possible through a supplemental appropriation made available to the Oil and Gas Leasing Division of the Geological Survey. The initial studies for this report were started December 1, 1943.

Location and Extent of the Area

As shown by plate 1, the Hogshooter field is in the east-central part of Washington County in northeastern Oklahoma. The Standing Committee on Oil Field Nomenclature, Kansas-Oklahoma Division, Mid-Continent Oil and Gas Association, has designated the exact location and area of the Hogshooter field to be as follows:



MAP OF NORTHEASTERN OKLAHOMA SHOWING LOCATION OF THE HOGSHOOTER FIELD

PLATE I.

SCALE

0 5 10 15 20 MILES

SW¼ T. 26N., R. 14E.
Secs. 24, 25, and 36, T. 26N., R. 13E.
NW¼ T. 25N., R. 14E.
Secs. 1, 2, 11, 12, 13 and N½ sec. 24, T. 25N., R. 13E., Indian Meridian.

In accordance with this designation the field embraces an area of 16,960 acres of which the productive area of the Bartlesville sand is approximately 5,610 acres. The detailed location and extent of this area are shown by plate 2.

Data Examined

Lack of complete records prevented a comprehensive examination of all pertinent data. However, the data examined are sufficient to make possible this study and to draw reasonable conclusions on more than 90 percent of the productive area. Data obtained and studied were: drillers' well logs; plugging records; total oil production records by leases; gas and water production history; well clean-out samples; core analyses in nearby areas; development practice; and general field information such as present production status, present operating practice, and topography. Valuable data were also obtained by interviewing early and present operators.

Approximately 875 drillers' well logs were studied. Data obtained from these logs were: well locations; completion and abandonment dates; initial production data; depths to top and bottom of key-beds; total depths; casing records; and methods of well completion.

Data Assembled

It is believed that the data assembled and embodied in this report are within reasonable limits of accuracy; nevertheless, various estimates and assumptions were required. Of the 7,566,000 barrels of oil produced from the Bartlesville sand to January 1, 1944, the amount of 5,529,000 barrels was compiled from actual production records, whereas the difference of 2,037,000 barrels was estimated by means of production decline curves. Estimates of interstitial water, formation volume factor, and porosity were also used in the manner believed applicable to the original reservoir conditions.

Data assembled consist of a development and property map, a Bartlesville sand isopach map, a well initial oil production map, a total oil production map, a relative sand body condition map, a north-south subsurface cross-section, production decline curves, tables showing oil reserves, and economic data. Other pertinent data such as geology, reservoir characteristics and behavior, and water and gas resources were also included in the report.

Acknowledgments

This study was made under the general supervision of J. R. Reeve, Supervisor, Mid-Continent District, Oil and Gas Leasing Division, United States Geological Survey, Tulsa, Oklahoma.

Glenn R. V. Griffith, Bartlesville District Engineer, United States Geological Survey, acted as consultant and adviser in making the investigation and preparing this report. His general knowledge of northeastern Oklahoma was a real asset in conducting this project.

The authors are grateful for the assistance furnished by the following organizations, companies, and individuals who made this report possible by making available production data, well logs, and other information:

Sinclair Prairie Oil Company, Tulsa, Okla.; Cities Service Oil Company, and Lee Morrison, Bartlesville, Okla.; T. S. & C. R. Colpitt, Collinsville and Tulsa, Okla.; H. O. Helvie, Tulsa, Okla.; The Oklahoma Corporation Commission, Oklahoma City, Okla; the Five Civilized Tribes Indian Agency, Muskogee, Okla.; the U. S. Army District Engineer's Office, Tulsa, Okla.; and the U. S. Geological Survey Laboratory, Casper, Wyoming.

The completeness of this report, with respect to oil production data, is largely due to the cooperation rendered by the Sinclair Prairie Oil Company in making old production records available.

Special acknowledgment is made to H. O. Helvie for furnishing operating data on an active water-flood property located near the area covered by this report, and to the U. S. Geological Survey laboratory for its analyses of water and sand samples.

Pertinent information concerning the present oil and gas production status of the Hogshooter field was made available by T. S. & C. R. Colpitt.

TOPOGRAPHY, DRAINAGE, AND CULTURE

The northwest corner of the Hogshooter field (see pl. 1) is about six miles east of Bartlesville, Oklahoma.

The Hogshooter field lies on the Prairie Plains monocline, resulting from the Ozark uplift, with the formations dipping westward about 30 feet to the mile. The erosional topography is gentle and the rolling hills consist predominantly of sandstones. The altitudes of the field, estimated from the Nowata Quadrangle sheet, range from about 650 to 800 feet above sea-level.

The general drainage of the Hogshooter field region is in the direction of the Caney River to the south of the field. Hogshooter Creek, with its upper reaches in T. 26N., R. 14E., drains the major part of the field, and small lateral ravines in the east and west complete the Hogshooter drainage system. Hogshooter Creek enters the field in the northwest corner of sec. 21, T. 26N., R. 14E., and leaves the field in the northwest of the southwest quarter of sec. 19, T. 25N., R. 14E.

The paved Bartlesville-Nowata highway (U. S. Highway No. 60) borders the field on the north. The remaining network of section-line and half-section line roads are considered to be good country roads.

The Hogshooter field is served by four schools, and an additional school is located close to the field in the village of Oglesby in sec. 19, T. 25N., R. 14E.

Several lease operators reside on their properties, and one operator has a camp of considerable size in the field.

DEVELOPMENT HISTORY

The first oil well in Washington County was drilled by the Cudahy Oil Company in 1897 in what is now known as Johnstone Park, within the city limits of Bartlesville, Oklahoma1/. After the turn of the century, exploration became very active and resulted in the discovery of many additional oil fields in Washington County.

1/ Carpenter, Everett, Geology of Washington County: Oklahoma Geological Survey, Bulletin 40-V, p. 11, 1928.

In 1906 an outstanding oil and gas field, which was later to become well known as the Hogshooter field, was discovered about 6 miles southeast of Bartlesville along Hogshooter Creek.

The developed Hogshooter oil and gas area includes a narrow strip, about 14 miles long from north to south, and from a fraction of a mile to 5 miles wide. The oil-productive area, however, is confined to the northern part of the field and covers approximately 6 miles along the north-south axis. The gas field proper bounds the oil field on the east, and extends southward in a narrow belt beyond the limits of the oil-productive area.

During the early period of field development, large oil and gas wells were not uncommon. Some of the larger wells had an initial production as high as 225 to 500 barrels of oil per day from the Bartlesville sand, and the Burgess sand gas wells showed initial open flow capacities of 5,000,000 to 30,000,000 cubic feet per day.

Gas Development

The Hogshooter gas field will be remembered as one of the most important gas fields of its time. The gas was produced from the Burgess sand found below the Bartlesville sand. Although the field has been relegated to lesser prominence by subsequent larger discoveries, the large gas production led to the construction of several sizeable gas lines from the field. Inasmuch as markets for the gas were lacking when the field was opened, large quantities of gas were wasted. During the early period of Hogshooter development, the Oklahoma law prohibited exportation of gas from the state. However, after 1909, when manufacturing enterprises entered the state and the laws governing gas transportation were revised, the market for gas was expanded and many of the former wasteful practices were curtailed. In some instances, natural gas in Oklahoma as late as 1910 sold for as low as 1½ to 2 cents per thousand cubic feet, although the average price at this time was from 6 to 8 cents per thousand cubic feet. Early development in the Hogshooter field affords a notable example of inefficient operation and unwise exploitation.

In 1910 a large operator entered the field and, after trunk lines were constructed, the gas was transported as far as Kansas City and Joplin, Missouri and for use locally in Oklahoma in the smelter industries of Bartlesville, Miami and Collinsville, and in the cement industry of Dewey.

The availability of a large gas supply drew the attention of many operators to the field, and the entrance of other companies later led to the construction of three gas compressor stations near the field. Gas was pumped out of the state in lines as large as 18 inches. The gas supply was drawn upon very heavily and the field was rapidly depleted because the gas wells were produced with no regard for their productive capacity or for reservoir pressure decline.

Reservoir pressure of the Burgess sand was reported to be 550 pounds per square inch in the winter of 1910, but was reduced to 355 pounds per square inch in July 1911, and to 80 pounds per square inch in December 1912. During July 1911, 158 wells produced an average of 8,000,000 cubic feet of gas per well per day, with a total daily output of 1,264,000,000 cubic feet.2/

2/ Blatchley, R.S., Waste of Oil and Gas in the Mid-Continent Fields: U. S. Bureau of Mines Tech. Paper 45, pp. 27-28, 1913.

Salt water was not evident when the gas field was first opened. However, when the reservoir pressure declined below 400 pounds per square inch, the salt water invaded the Burgess sand wells in large quantities. Continued heavy gas withdrawals and pressure decline accelerated the water influx to such an extent that many wells were drowned out by the year 1911. The water intrusion to other parts of the field eventually water-bound the whole area. Furthermore, the rapid decline of the gas wells and the invasion of the edge water so limited the gas supply that the field ceased to be a factor in the gas business. The gas supply eventually diminished to the point where it hardly met the fuel requirements of the leases.

During recent years new operators have entered the field by acquiring a number of old leases, and have attempted to stimulate oil production in the Bartlesville sand by gas repressuring. Gas has been made available for the recent operations through successful exploitation of gas reserves in the Tucker and "chat" formations. The quantities of gas from the newly developed sources meet the demands of the field operations and furnish approximately 10,000,000 cubic feet per month to outside markets. Nevertheless, the present-day gas reserve is considered to be very small.

Early Oklahoma oil fields were discovered and developed prior to the employment of geologists by companies engaged in oil exploration work. The discovery of Hogshooter was no exception, and as a result the field was developed without the intensive study and compilation of pertinent development data that modern-day practice considers essential.

Oil Development

The first oil wells in the Hogshooter field were drilled in 1906 to the Bartlesville sand, and three leases in secs 6 and 7, T. 25N., R. 14E., were partially developed during the year. A vigorous drilling campaign was carried on during the years 1907-10, with the peak oil production of over 2,025 barrels per day being reached in the year 1910. Production decline from the peak was extremely rapid, and the field quickly reached a settled production stage.

During the development stage and period of flush production, same wells in the Bartlesville sand were brought in with productivity rates ranging from 225 to 500 barrels per day, although the average initial production for the field was probably no greater than 50 to 60 barrels per well per day.

During the aforementioned period the price of oil reached a low of 36 cents per barrel in 1909; however, oil sold for less than 40 cents per barrel as late as the year 1915. This low market price was a factor in the classification of many low-initial wells as dry holes, and the early abandonment of some producing wells during the period of settled production. Moreover, during this period it was not unusual to classify wells that showed initial production of 5 barrels or less per day as dry holes, and the wells were plugged and abandoned immediately.[3/]

Many of the Bartlesville sand wells were shot heavily and in some cases the wells flowed naturally for a short time after completion. The wells of low initial production required immediate pump installation, and it is believed that the majority of the wells were produced by pumping at about the time of completion of initial

3/ Personal communication.

primary drilling early in 1913. During the period 1915-20, the crude oil market was under a more favorable price structure, with oil gradually increasing to a peak market price of $3.36 per barrel in 1920. As a result, the field went through a period of late primary development of field extension and drilling of inside locations on previously developed leases. Furthermore, because of the higher crude oil price, vacuum plants were installed by 1915, and gas was gathered for the gasoline plants under high vacuum. The period of greatest secondary development occurred during the years 1918-22. The rapid production decline of the field was retarded by the year 1917, but the major influencing factor was probably new drilling rather than applied vacuum on the field. Vacuum has had little effect at Hogshooter, and it is doubtful if the additional oil recovery in many operations has been sufficient to pay out the original investment in vacuum equipment.4/

In the early drilling of the Hogshooter field, little attention was paid to the shallower oil possibilities because of the greater yield from the deeper sands. Although the major portion of the production was taken from the lenticular Bartlesville sand in the Cherokee shale, early records indicated a small Peru sand area to be productive in the northern part of the field. The amount of oil produced from the Peru sand is considered to be of a minor quantity. In addition to the aforementioned productive horizons, a Burgess sand well in the northern part of the field produced a very viscous oil for a short time before abandonment.5/

4/ Lindsly, E. and Berwald, W. B., Effect of Vacuum on Oil Wells: United States Bureau of Mines, Bull. 322, pp. 64-68, 1930.

5/ Personal communication

During the early part of the 1930's, gas and air repressuring in conjunction with continued vacuum operation was attempted in the Hogshooter field in order to stimulate production. Little effect resulted from the early uncontrolled repressuring. However, the initial repressuring attracted the attention of other operators, and in 1935 a new operator in the field developed a more intensive repressuring program on an assembled block of leases. The results of the intensified repressuring were more satisfactory than those obtained previously. The oil recovery to January 1, 1944, which can be credited in the main to repressuring, approximates 420,000 barrels. The peak repressuring effect for the field was reached in 1938 with a total average production of 228 barrels per day for the year, from which time the production has been declining steadily. Early in 1944 the field was producing approximately 140 barrels per day from 140 oil wells. In addition to effective gas-repressuring, one lease in particular shows a marked stimulation of oil recovery over a period of years. This has been credited by the operator to the influence of a natural water-drive, caused by the infiltration of upper waters into the Bartlesville sand through faulty casing in adjacent standing wells.6/

Many of the oil wells in the field have been plugged and abandoned in a very haphazard manner, with little or no consideration given to the aspect of secondary recovery operations. Inadequate abandonment of wells after pulling the oil string was common in the early history of the field. Later, more efficient plugging technique favored filling the hole to the surface with mud-fluid.

6/ Personal communication.

present day plugging procedure in the field follows the conventional practice of sealing the producing zone with mud, covering with a cement plug, and filling the hole to the surface with mud fluid. The importance of proper plugging technique was recognized by the U. S. Geological Survey in early plugging operations. Since July 1925, the plugging of most wells on departmental leases has been witnessed, and on all wells abandoned on restricted Indian leases since December 5, 1941, the Geological Survey has required the use of mud opposite the producing horizon, capping with a cement plug, and filling the hole to the surface with mud.

As of January 1, 1944, the Bartlesville sand in the Hogshooter field has been credited with a total production of 7,566,000 barrels of oil from 871 oil wells. Of this total oil production, 84 percent, or 6,430,000 barrels, is attributable to primary production. A small amount of oil, in addition to that produced from the Bartlesville, has been recovered from the Peru sand; however, the total oil production from this sand is not a matter of record. The Bartlesville sand productive area in the field comprises 5,610 acres out of the 16,960 acres allotted to the field proper. Recovery from the Bartlesville sand reservoir to date amounts to approximately 1,350 barrels per acre.

The life of Bartlesville sand wells during primary production was exceedingly varied. Wells with low initial production and with low oil recovery per acre show a primary productive life history of 6 to 12 years. Wells of much higher recovery show an 18-year productive life, and the best producing wells in the field show a productive history of 20 years or more.

GEOLOGY

Bulletin 62 of the Oklahoma Geological Survey[7] was drawn upon heavily for this brief geological resume. Part of the statement pertaining to the subsurface is a result of well log study. In addition, one set of cable tool samples from a well in sec. 33, T. 25N., R. 13E., was fonnd to be sufficient confirmation as to the coarseness of the Burgess sand grains and the cherty nature of the top of the "Mississippi lime". Several of the logs for wells in the Hogshooter field, drilled after 1920, described the top of the Mississippian as the "Mississippi chat," and this appears to be accurate. The character of the Burgess sand in the well mentioned above is typical for the Burgess of northeast Oklahoma.

Surface Stratigraphy

The surface rocks consist of the Nellie Bly sandstones and shales, the Hogshooter limestone, and the Coffeyville sandstones and shales, all of which are in the Skiatook group of the Missouri subseries of the Pennsylvanian series. There are also a few samll outliers of the Dewey limestone (Skiatook group) west of Hogshooter Creek. In the southern part of the oil field the Pennsylvanian rocks are concealed by the alluvium of the Caney River flood-plain.

No mapping data were collected in the field except the well elevations, which were used for the north-south cross-section (see pl. 4).

7/ Oakes, M. C., Geology and Mineral Resources of Washington County, Oklahoma; Oklahoma Geological Survey, Bull. 62, 1940.

Subsurface Stratigraphy

Pre-Cambrian System

Oakes[8] lists four wells in Washington County, Oklahoma, that were drilled to the Spavinaw granite of pre-Cambrian age.

None of the Hogshooter wells were deep enough to reach the pre-Cambrian. The top of the granite was logged at a depth of 2,335 feet in a well 3 miles west of the field, in sec. 10, T. 25N., R. 13E. Another granite well is on the Bartlesville anticline in sec. 17, T. 26N., R. 13E., The granite, found in this well at a depth of 1,805 feet, is considered to be equivalent to the pre-Cambrian granite that is exposed at Spavinaw, Oklahoma.

Ordovician System
Arbuckle Limestone

In this region the Arbuckle lime is reported to range in thickness from 100 to 700 feet. These beds are not mentioned in the Hogshooter logs that were examined. The cherty lime (dolomite), in the two wells mentioned above, was reported at depths of 1,620 and 1,760 feet, respectively, with water reported in the latter well in sec. 17, T. 26N., R. 13E.

A well in sec. 36, T. 26N., R. 14E., a few miles east of the Hogshooter field, reached the Arbuckle at a depth of 1,760 feet. The well produces 2,200 barrels of water per day from the Arbuckle limestone.

The Arbuckle limestone is overlain, unconformably, by the Chattanooga shale, or by the Mississippi limestone.

8/ Op. cit., p. 93.

Carboniferous System
Mississippian Series
Chattanooga Shale

The Chattanooga shale, locally reported absent, ranges in thickness from 80 feet to the vanishing point. This black carbonaceous shale was penetrated by a few wells in this region. In sec. 17, T. 25N., R. 14E., a thickness of 61 feet was reported at a depth of 1,583 feet. In the Arbuckle well in sec. 36, T. 26N., R. 14E., a thickness of 70 feet was logged at a depth of 1,537 feet.

"Mississippi Lime"

In many localities, the "Mississippi lime" is referred to as the "Mississippi chat" owing to the pronounced cherty nature commonly found in the upper beds. These beds, with local unconformity, overlie the Chattanooga shale, and they unconformably overlie the Arbuckle limestone where the Chattanooga shale is absent. In this district the "Mississippi lime" ranges in thickness from 225 to 300 feet.

A few wells in the Hogshooter field are now producing gas from the "chat" zone, and appreciable amounts of water are often found in this formation.

The well to the east of the field in sec. 36, T. 26N., R. 14E., reported the top of the "chat" at 1,260 feet; in sec. 17, T. 25N., R. 14E., 1,300 feet; in sec. 31, T. 26N., R. 14E., 1,395 feet; in sec. 1, T. 25N., R. 13E., 1,390 feet; in sec. 2, T. 25N., R. 13E., 1,363 feet, and in sec. 21, T. 25N., R. 14E., the top of the "chat" was found at 1,255 feet. The last well showed 275 feet of "Mississippi lime," and 63 feet of Chattanooga shale.

Pennsylvanian Series

The Cherokee, essentially a dark and light shale, 400 to 600 feet in thickness, unconformably overlies the "Mississippi lime." The Cherokee contains a few thin limestone members (mappable) and several lenticular sandstones.

A coarse-grained permeable gas-bearing sand called the Burgess is found locally, and usually in direct contact with the "Mississippi lime." Wells drilled to the Burgess sand have frequently filled with water, and this water may prove to be of real value for water-flooding use.

The Tucker sand, found above the Burgess and below the Bartlesville, is now producing a small quantity of gas in the Hogshooter field; however, it has never been an important gas-producing zone in the field.

The Bartlesville sand body is continuous over the field. The major part of the oil was produced from this sand, which, in northeast Oklahoma usually carries oil. The Bartlesville sand, however, does not always make a producing oil well, because of unfavorable sand conditions.

The Prue sand is a lenticular sand above the Bartlesville sand and a short distance below the Ft. Scott limestone. The records of wells in the Hogshooter field do not show oil production from the Prue.

Many logs show a thin limestone, the Verdigris member of the Cherokee, just below the Prue sand.

Ft. Scott Limestone (Oswego)

The "Oswego lime" conformably overlies the Cherokee shale, and its thickness in the Hogshooter field ranges from 75 to 125 feet, with about a 10-foot shale break near the middle of the formation. This white, crystalline, and fossiliferous limestone is one of the main markers over large areas in Oklahoma. A small amount of water and gas is reported at many places in this formation.

Labette Shale

Above and conformable with the Ft. Scott limestone is found 150 to 180 feet of clay shales and dark siliceous shales, known as the Labette shale. The Peru sand, which has produced some oil in the Hogshooter field, often occurs in this shale, usually in the lower part.

Pawnee Limestone

The Pawnee limestone, 30 to 55 feet in thickness, conformably overlies the Labette shale. Many logs show a small shale break in the lower part of the Pawnee. Fossils are common in this formation.

Bandera Shale

The Bandera is a dark gray shale that conformably overlies the Pawnee limestone.

Altamont Limestone

Conformably overlying the Bandera shale is found the light gray Altamont limestone with a thickness ranging from 30 to 50 feet. Fossils are common in this limestone. The last three members, the Pawnee, the Bandera, and the Altamont, together are called the "Big Lime" by the drillers.

Nowata Shale

The Nowata shale consists of a dark gray dense siliceous shale conformably overlying the Altamont limestone. This shale, locally 100 to 200 feet in thickness, carries a lenticular sand body called the Wayside sand. The records of wells in the Hogshooter field do not show oil production from the Wayside sand.

Lenapah Limestone

The Lenapah limestone rests conformably upon the Nowata shale. Its thickness does not exceed 20 feet and some logs fail to record it.

The Lenapah is usually overlain, unconformably, by the Seminole formation of the Missouri subseries.

Structural Features

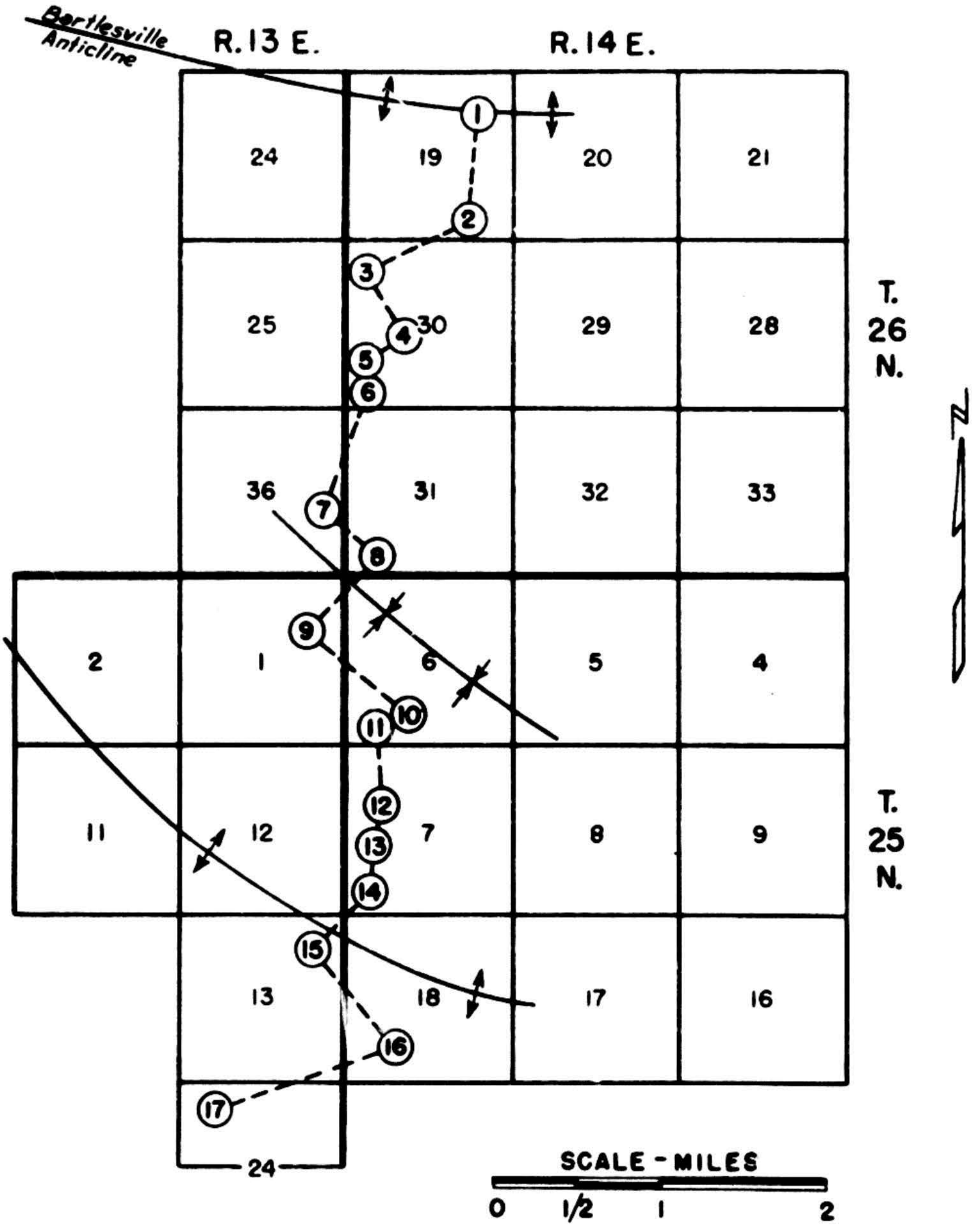
Certain structural features of the Hogshooter field, as shown by Oakes[9], are presented on plate 3, which also shows the line of the north-south cross-section.

A north to south cross-section, based on drillers' logs, is presented on plate 4.

The Hogshooter field, as mentioned previously in this report, is a small part of a monocline with beds dipping westward about 30 feet per mile. This monocline is broken by mild structural features which are discussed by Oakes[10]. The Oil production of the Hogshooter field apparently bears no relation to these structural features.

9/ Op. cit., p. 99.

10/ Idem., pp. 98-103.



① CROSS-SECTION WELL NO.

MAP SHOWING LOCATION OF CROSS-SECTION AND STRUCTURAL FEATURES OF HOGSHOOTER FIELD WASHINGTON COUNTY, OKLAHOMA

(Structural features from M. C. Oaks, Okla. Geological Survey, Bulletin No. 62, 1940)

PLATE 3.

As shown by the Bartlesville sand isopach map (pl. 5), the producing sand is more or less lenticular, and production is found that is not associated with structural control. Attention is called to the axis of the small syncline (pl. 3) that trends southeast from the center of sec. 36, T. 26N., R. 13E., through sec. 6 and the SW¼ sec. 5, T. 25N., R. 14E. The syncline passes through one of the better productive sections of the field.

The line of the field cross-section, plate 4, closely parallels the strike of the surface beds and the cross-section reflects the attitude of the formations. The anticlinal folding in the southern part of the field is well represented by the peak position of the "Oswego lime" in well No. 16, which is located one-half mile south of the axis of the fold.

In the central part of the field the elevations of the formations suggest the presence of a syncline between wells Nos. 5 to 10, inclusive.

Well No. 17 is about halfway between the axis of the anticline that trends southeast from the SW¼ sec. 2, T. 25N., R. 13E., through sec. 18, T. 25N., R. 14E., and the axis of the Caney River syncline to the south. The top of the "Oswego lime" in this well appears consistent with these structural features.

The relationship of the wells at the north end of the section to the Bartlesville anticline to the north is not apparent.

The following two drillers' logs represent the deeper wells of the Hogshooter field.

Well No. 1

NE¼ sec. 17, T. 25N., R. 14E.; completed 1-7-21; dry hole

	Top	Bottom	
Soil	0	3	
Shale	3	43	
Sand, water	43	63	
Shale, dark	63	73	
Sand, water	73	83	
Shale, light	83	390	
Lime (Big lime)	390	420	
Shale, dark	420	436	
Lime, (Big lime)	436	485	
Shale, sandy	485	505	
Shale, light	505	625	
Lime (Oswego)	625	713	
Shale	713	745	
Sand (Squirrel)	745	770	
Lime	770	778	
Shale, dark	778	900	
Sand, white	900	918	
Shale, white	918	930	
Sand	930	950	
Shale, white	950	1,044	
Sand (Bartlesville)	1,044	1,069	
Shale, dark	1,069	1,110	
Lime	1,110	1,115	
Shale, dark	1,115	1,200	
Lime	1,200	1,210	
Lime	1,210	1,220	
Sand (Burgess)	1,220	1,285	Hole full of water
Shale	1,285	1,290	
Sand	1,290	1,295	
Chat (Mississippi)	1,295	1,505	
Lime	1,505	1,583	
Shell, hard	1,583	1,590	
Shale, black (Chattanooga)	1,590	1,644	
Shell, hard	1,644	1,646	
Sand, water	1,646	1,651	TD

Well No. 2

SW¼ sec. 1, T. 25N., R. 13E., completed 8-19-37; gas 1500 M.;
Rock pressure 550 lb.

	Top	Bottom	
Clay	0	6	
Sand	6	10	
Shale	10	65	
Lime	65	75	
Shale	75	320	
Lime, broken	320	330	
Shale	330	340	
Shale, sandy	340	355	show gas
Shale, white	355	361	
Shale, dark	361	375	
Shale, light	375	415	
Shale	415	438	
Lime, sandy	438	458	
Shale	458	475	
Shale, light	475	533	
Lime (Big lime)	533	606	
Shale, black	606	609	
Lime (Big lime)	609	616	
Shale, white	616	758	
Lime (Oswego)	758	779	
Shale, black	779	786	
Lime (Oswego)	786	831	
Shale, sandy	831	870	
Sand (Squirrel)	870	915	
Shale	951	1,008	
Shale, light	1,008	1,046	
Sand, white	1,046	1,050	
Shale	1,050	1,092	
Shale, dark	1,092	1,107	
Shale, white	1,107	1,136	
Shale, dark	1,136	1,144	
Shale	1,144	1,180	
Sand (B'ville)	1,180	1,203	(Shot with 30 qts., Production 3/4 bbl. oil)
Shale	1,203	1,383	
Sand (Burgess)	1,383	1,390	dry
Chat (Miss.)	1,390	1,400	TD

OIL PRODUCTION DATA

Since the date of discovery in 1906, to January 1, 1944, the Bartlesville sand of the Hogshooter field has produced an estimated volume of 7,566,000 barrels of oil. Of the 871 productive oil wells, there were available approximately 250 initial production figures with completion dates which are shown on the initial production map (pl. 6). Table 1 shows the average initial oil production per well per day by years for the field as a whole. The three best productive areas, in terms of total oil recovery per acre, are shown by plate 7. The average well initials in barrels per well per day for the first 6 years were: 45 for the field as a whole, 54 for area 1, 32 for area 2, and 41 for area 3.

The available initial production data indicate that between 1914 and 1920 the average initial production declined to approximately 15 barrels per well per day. From the beginning of 1920 through 1922 the average initial production for the field increased to approximately 41 barrels per well per day, probably as a result of field extension in areas showing good reservoir conditions. In connection with this it is interesting to note that the price of oil began to increase gradually in 1915, and during 1920 reached a peak of $3.36 per barrel. During the period of 1918 through 1922, there was considerable drilling and development, opening new extensions to the field in the northeast, west, and south.

As mentioned in the introduction, complete production records were not available. In compiling production data for this report, it was estimated that 7,566,000 barrels of Bartlesville sand oil has been produced to January 1, 1944. Of this amount, 73.1 percent,

Table 1.

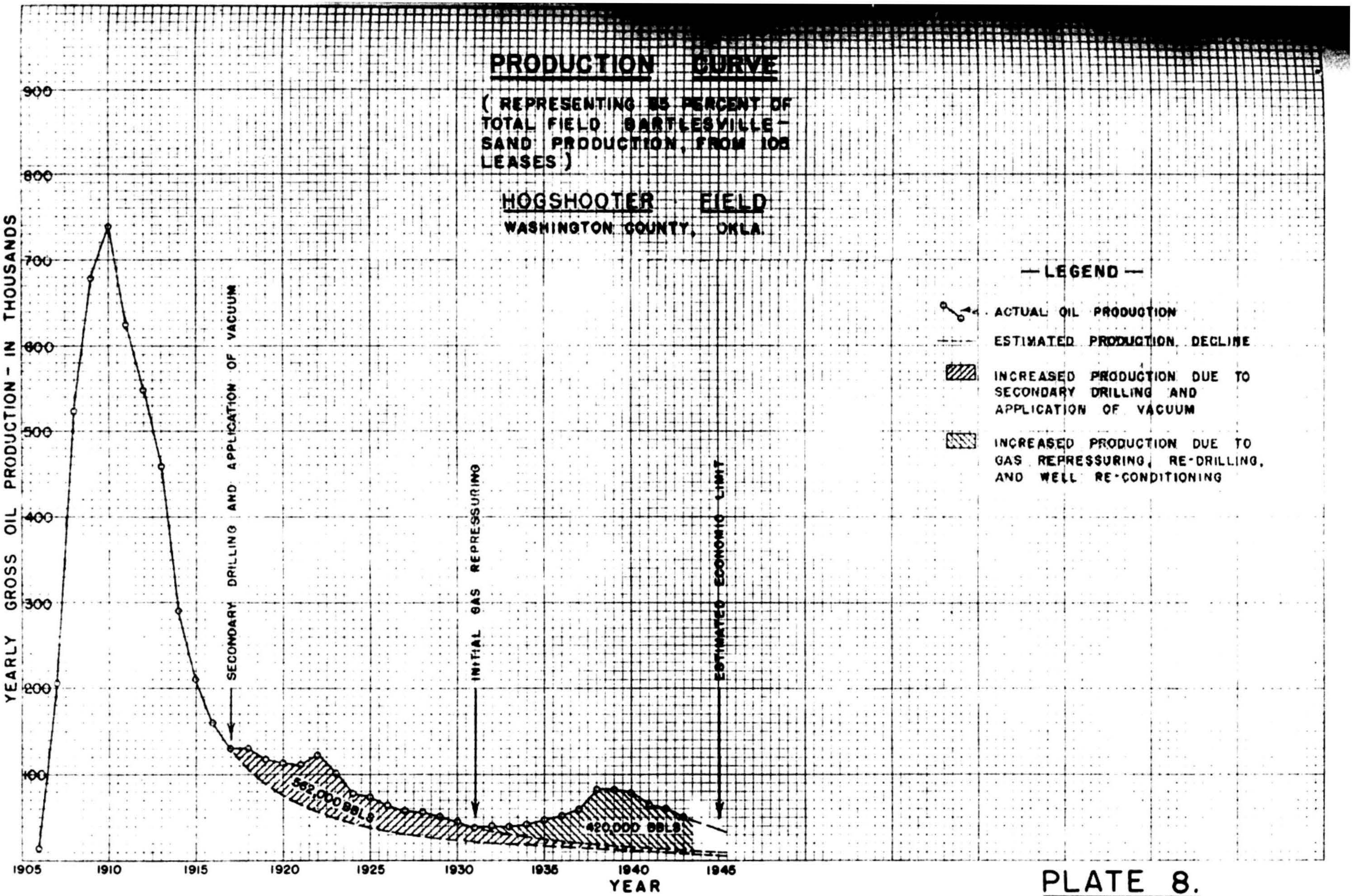
Initial Oil Production Data
Average per well per day in barrels

Year	Field	Area 1	Area 2	Area 3
1907	48	70	33	50
08	80	96	20	75
09	42	46	55	15
10	28	40	31	26
11	32	29	25	33
12	38	40	28	47
13	17	15	23	18
14	30		10	5
15	10			
16	2			
17	15			10
18	15		14	26
19	14		2	20
20	25		2	58
21	49			49
22	50		53	
23	8		5	
24	10			10
25	9	8		
26	3	5		1
27				
28	2		3	2
29				
30				
31				
32				
33				
34				
35				
36	15	8		22
37	4	5	5	3
38	12		12	
39	3	2	15	
40	2			2

or 5,529,000 barrels, was actual production data obtained from records, whereas 2,036,000 barrels was estimated by the use of production decline curves.

Table 2 and plate 8 show the Bartlesville sand production history of 105 leases in the Hogshooter field comprising approximately 4700 acres, or 84 per cent of the productive area of the field from the date of field discovery through 1943. The oil data shown totalling 6,455,000 barrels represent 85 per cent of the total estimated field production to January 1, 1944. Certain of these leases have had good oil recovery; others relatively poor recovery, and the remaining leases cover the range between the two extremes.

An examination of these data shows three distinct periods in the production history of the field. The first 12 years represent the period of development and normal decline. These yearly production figures plotted on logarithmic paper conform very definitely to a straight line, which is characteristic of normal decline in a gas-expansion type reservoir, producing at maximum capacity at all times with no effort toward controlled withdrawal. This straight line has been extrapolated to determine the estimated yearly production if the normal decline had been allowed to continue. However, as the production data show, the normal decline was interrupted, and the second period (1917-1931) of 14 years' duration represents for the most part secondary and late primary development. It is thought that the application of vacuum has not noticeably affected the total oil recovery. The third period, or last 12 years (1931-1943), shows a gradual increase in production, which reached a peak in 1938, and thereafter began to decline. This increase may be attributed to several factors. In some



PRODUCTION CURVE
(REPRESENTING PERCENT OF TOTAL FIELD BARTLESVILLE - SAND PRODUCTION, FROM LEASES)
HOGSHOOTER FIELD
WASHINGTON COUNTY, OKLA.
— LEGEND —
ACTUAL OIL PRODUCTION
ESTIMATED PRODUCTION DECLINE
INCREASED PRODUCTION DUE TO SECONDARY DRILLING AND APPLICATION OF VACUUM
INCREASED PRODUCTION DUE TO GAS REPRESSURING, RE-DRILLING, AND WELL RE-CONDITIONING
YEARLY GROSS OIL PRODUCTION - IN THOUSANDS
900
800
700
600
500
400
300
200
100
SECONDARY DRILLING AND APPLICATION OF VACUUM
INITIAL GAS REPRESSURING
ESTIMATED ECONOMIC LIMIT
562,000 BBLS
420,000 BBLS
1905
1910
1915
1920
1925
1930
1935
1940
1945
YEAR

PLATE 8.

Table 2.
Bartlesville sand oil production of the Hogshooter field
(85% of total Bartlesville sand production from 105 leases only)

Year	Actual Oil prod. M. bbl.	Actual cumulative Oil prod. M. bbl.	Yearly % recovery of total	Cumulative % recovery of total	Estimated normal decline M. bbl.	Net gain actual prod. over estimated normal prod. M. bbl.
1906	15	15	0.2	0.2		
07	206	221	3.2	3.4		
08	524	745	8.1	11.5		
09	679	1,424	10.5	22.0		
10	739	2,163	11.4	33.0		
11	625	2,788	9.7	43.1		
12	549	3,337	8.5	51.6		
13	459	3,796	7.1	58.7		
14	290	4,086	4.5	63.2		
15	211	4,297	3.3	66.5		
16	161	4,458	2.5	69.0		
17	131	4,589	2.0	71.0		
18	130	4,719	2.0	73.0	110	20
19	119	4,838	1.8	74.8	88	31
20	115	4,953	1.8	76.6	74	41
21	112	5,065	1.7	78.3	65	47
22	123	5,188	1.9	80.2	57	66
23	102	5,290	1.6	81.8	50	52
24	79	5,369	1.2	83.0	45	34
25	75	5,444	1.2	84.2	40	35
26	66	5,510	1.0	85.2	36	30
27	59	5,569	0.9	86.1	33	26
28	57	5,626	0.9	87.0	30	27
29	51	5,677	0.8	87.8	28	23
30	46	5,723	0.7	88.5	25	21
31	39	5,762	0.6	89.1	23	16
32	40	5,802	0.6	89.7	22	18
33	40	5,842	0.6	90.4	20	20
34	41	5,883	0.6	91.0	19	22
35	48	5,931	0.7	91.7	18	30
36	52	5,983	0.8	92.5	17	35
37	60	6,043	0.9	93.5	16	44
38	83	6,126	1.3	94.8	15	68
39	82	6,208	1.3	96.0	14	68
40	79	6,287	1.2	97.2	13	66
41	66	6,353	1.0	98.3	13	53
42	61	6,414	0.9	99.2	12	49
43	51	6,465	0.8	100.0	11	40
TOTAL	6,465					982

M. represents thousands of barrels.

instances new inside locations have been drilled, old plugged-out areas have been redrilled, remedial work has been done on old wells, and some gas repressuring has been undertaken on a few properties.

A quantitative analysis of the net increase during the last 26 years from the varying methods for stimulating production is shown in the accompanying tabulation, and may be summarized as follows:

Total production (actual)	6,465,000 bbl.
Less: Total production (estimated, if normal decline had continued)	5,483,000 bbl.
Net increase	982,000 bbl.
Percent increase (982,000/5,483,000)	18

Of this net increase of 982,000 barrels, it is estimated that 562,000 barrels was due principally to late primary development, and application of vacuum, and 420,000 barrels to minor secondary development, reworking of old wells, and gas repressuring.

Two interesting facts are shown by these data. The first, that more than two-thirds of the total production of these properties was produced in less than one-third of the total life of the field. The second, that during the last 68 percent of the life of the field, the net increase by all applied methods, for stimulating and increasing production, and by development of new properties, resulted in a total increase in recovery of only 18 percent over and above that which would have been obtained if the normal decline of the older leases had been allowed to take its course.

Table 3 shows oil production, acreage, and well data by quarter sections. Table 4 shows a recapitulation of data from table 3 for the

OIL PRODUCTION AND OIL RESERVE DATA

Sec.-Twp.-Rge.	Total Productive Acres	Total Producing Wells	Well Density-Acres per Well	Total Oil Recovery to 1-1-44: Total Barrels	Bbl. per Acre	Bbl. per Ac.-Ft.	Bbl. per Well	Sand Thickness (Feet)	Porosity (Percent)	Reservoir Void Space: Bbl. per Acre	Total Bbl. (in thousands)	Original Reservoir Oil @ Standard Conditions: Bbl. per Acre	Bbl. per Acre-Foot	Total Bbl. (in thousands)	Oil Recovery: Percent of Reservoir Voids	Percent of Original Reservoir Oil @ Std. Conditions	Residual Reservoir Oil as of 1-1-44, @ Std. Conditions: Total Bbl. (in thousands)	Bbl. per Acre	Percent Saturation of Total Reservoir Voids
									← ESTIMATED →										
1 - 25N - 13E																			
NE¼	90	19	4.7	111,566	1,240	47	5,872	26	9.8	19,767	1,779.0	11,762	452.4	1,058.6	6.3	10.5	947.0	10,522	53.2
SE¼	130	16	8.8	78,425	605	30	4,902	20	9.6	14,895	1,936.4	8,862	443.1	1,152.1	4.1	6.8	1,073.7	8,257	55.4
SW¼	110	17	6.5	56,504	514	21	3,324	24	8.8	16,385	1,802.4	9,749	406.2	1,072.4	3.1	5.3	1,015.9	9,235	56.4
NW¼	75	10	7.5	42,970	573	22	4,297	26	6.3	12,708	953.1	7,561	290.8	567.1	4.5	7.6	524.1	6,988	55.0
2 - 25N - 13E																			
NE¼	140	19	7.4	59,725	426	19	3,145	23	7.6	13,561	1,898.5	8,068	350.8	1,129.5	3.1	5.3	1,069.8	7,642	56.3
SE¼	115	20	5.8	81,594	709	29	4,080	23	8.3	14,810	1,703.2	8,811	383.1	1,013.3	4.8	8.0	931.7	8,102	54.7
SW¼	20	3	6.7	8,298	415	17	2,766	25	7.3	14,158	283.2	8,425	337.0	168.5	2.9	4.9	160.2	8,010	56.6
NW¼	10	1	10.0	1,642	164	10	1,642	17	6.0	7,913	79.1	4,709	277.0	47.1	2.1	3.5	45.5	4,545	57.5
11 - 25N - 13E																			
NE¼				0															
SE¼	20	2	10.0	11,773	589	24	5,887	25	8.6	16,680	333.6	9,925	397.0	198.5	3.5	5.9	186.7	9,336	56.0
SW¼	30	4	7.5	6,505	217	9	1,626	25	6.3	12,219	366.6	7,250	290.0	217.5	1.8	3.0	211.0	7,033	57.6
NW¼	10	1	10.0	500	50	3	500	20	6.0	9,310	93.1	5,540	277.0	55.4	0.5	0.9	54.9	5,490	59.0
12 - 25N - 13E																			
NE¼	35	6	5.8	28,680	819	37	4,780	22	9.1	15,532	543.6	9,241	420.1	323.4	5.3	8.9	294.7	8,422	54.2
SE¼	135	29	4.7	346,233	2,565	95	11,939	27	15.7	32,886	4,439.6	19,567	742.7	2,641.5	7.8	13.1	2,295.3	17,004	51.7
SW¼				0															
NW¼	30	4	7.5	16,783	559	23	4,196	24	7.8	14,523	435.7	8,640	360.0	259.2	3.8	6.5	242.4	8,081	55.6
13 - 25N - 13E																			
NE¼	140	29	4.8	241,444	1,725	75	8,326	23	12.4	22,126	3,097.6	13,165	572.4	1,843.1	7.8	13.1	1,601.7	11,440	51.7
SE¼	145	34	4.3	228,400	1,575	69	6,718	23	13.0	23,196	3,363.4	13,802	600.1	2,001.0	6.8	11.4	1,772.6	12,227	52.7
SW¼	35	8	4.4	17,500	500	20	2,188	25	7.0	13,577	475.2	8,078	323.1	282.7	3.7	6.2	265.2	7,578	55.8
NW¼	30	4	7.5	4,115	137	5	1,029	28	6.3	13,685	410.6	8,120	290.0	243.6	1.0	1.7	239.5	7,983	58.3
24 - 25N - 13E																			
NE¼	10	1	10.0	274	27	1	274	18	6.3	8,798	88.0	5,220	290.0	52.2	0.3	0.5	51.9	5,193	59.0
SE¼				0															
SW¼				0															
NW¼	10	1	10.0	797	80	4	797	18	6.3	8,798	88.0	5,220	290.0	52.2	0.9	1.5	51.4	5,140	58.4
24 - 26N - 13E																			
NE¼	30	4	7.5	10,720	357	14	2,680	26	6.3	12,708	381.2	7,540	290.0	226.2	2.8	4.7	215.5	7,183	56.5
SE¼	25	5	5.0	7,500	300	12	1,500	25	6.5	12,607	315.2	7,500	300.0	[illegible]	2.5	4.0	180.0	7,200	57.1
SW¼	10	1	10.0	1,960	196	8	1,960	25	5.5	10,667	106.7	6,325	253.0	63.2	1.8	3.1	61.2	6,129	57.4
NW¼				0															
25 - 26N - 13E																			
NE¼	90	10	9.0	52,790	587	27	5,279	22	9.5	16,214	1,459.3	9,647	438.5	868.2	3.6	6.1	815.4	9,060	55.9
SE¼	130	14	9.3	129,692	998	43	9,264	23	11.0	19,628	2,551.6	11,679	507.8	1,518.3	5.1	8.5	1,388.7	10,681	54.4
SW¼	50	7	7.1	34,260	685	30	4,894	23	6.8	12,134	606.7	7,220	313.9	361.0	5.6	9.5	326.7	6,535	53.8
NW¼	50	6	8.3	13,440	269	13	2,240	20	6.9	10,706	535.3	6,370	318.5	318.5	2.5	4.2	305.1	6,101	57.0
36 - 26N - 13E																			
NE¼	45	5	9.0	48,034	1,067	46	9,607	23	11.7	20,877	939.5	12,422	540.1	559.0	5.1	8.6	511.0	11,355	54.4
SE¼	105	14	7.5	150,185	1,430	60	10,728	24	12.9	24,019	2,522.0	14,292	595.5	1,500.7	6.0	10.0	1,350.5	12,862	53.5
SW¼	20	2	10.0	13,455	673	27	6,728	25	10.0	19,395	387.9	11,540	461.6	230.8	3.5	5.8	217.3	10,867	56.0
NW¼	10	1	10.0	2,207	221	11	2,207	20	6.5	10,085	100.9	6,000	300.0	60.0	2.2	3.7	57.8	5,779	57.3

TABLE 3

OIL PRODUCTION AND OIL RESERVE DATA

Sec.-Twp.-Rge.	Total Productive Acres	Total Producing Wells	Well Density-Acres per Well	Total Oil Recovery to 1-1-44: Total Barrels	Bbl. per Acre	Bbl. per Ac.-Ft.	Bbl. per Well	Sand Thickness (Feet)	Porosity (Percent)	Reservoir Void Space: Bbl. per Acre	Total Bbl. (in thousands)	Original Reservoir Oil @ Standard Conditions: Bbl. per Acre	Bbl. per Acre-Foot	Total Bbl. (in thousands)	Oil Recovery: Percent of Reservoir Voids	Percent of Original Reservoir Oil @ Std. Conditions	Residual Reservoir Oil as of 1-1-44, @ Std. Conditions: Total Bbl. (in thousands)	Bbl. per Acre	Percent Saturation of Total Reservoir Voids
									← Estimated →										
19 - 26N - 14E																			
NE¼	70	10	7.0	35,395	506	25	3,540	20	8.2	12,723	890.6	7,570	378.5	529.9	4.0	6.7	494.5	7,064	55.5
SE¼	120	14	8.6	192,762	1,606	60	13,769	27	12.1	25,345	3,041.4	15,080	558.5	1,809.6	6.3	10.6	1,616.8	13,474	53.2
SW¼	110	16	6.9	133,000	1,209	55	8,313	22	12.0	20,481	2,252.9	12,166	553.9	1,340.5	5.9	9.9	1,207.5	10,977	53.6
NW¼	95	12	7.9	127,869	1,346	54	10,656	25	11.9	23,080	2,192.6	13,733	549.3	1,304.6	5.8	9.8	1,176.7	12,387	53.7
20 - 26N - 14E																			
NE¼	10	1	10.0	700	70	3	700	22	6.0	10,241	102.4	6,094	277.0	60.9	0.7	1.1	60.2	6,024	58.8
SE¼	25	3	8.3	553	22	1	184	19	6.0	8,844	221.1	5,263	277.0	131.6	0.3	0.4	131.0	5,241	59.2
SW¼	10	1	10.0	2,500	250	15	2,500	17	7.4	9,760	97.6	5,807	341.6	58.1	2.6	4.3	55.6	5,557	57.0
NW¼				0															
21 - 26N - 14E																			
NE¼				0															
SE¼				0															
SW¼	30	2	15.0	2,900	97	5	1,450	20	5.7	8,844	265.3	5,262	263.1	157.9	1.1	1.8	155.0	5,165	58.4
NW¼	40	5	8.0	3,430	86	4	686	22	5.7	9,729	389.2	5,788	263.1	231.5	0.9	1.5	228.1	5,702	58.5
28 - 26N - 14E																			
NE¼				0															
SE¼				0															
SW¼				0															
NW¼	65	9	7.2	98,357	1,513	72	10,929	21	15.1	24,601	1,599.1	14,637	697.0	951.4	6.2	10.3	853.0	13,124	53.3
29 - 26N - 14E																			
NE¼	105	21	5.7	93,194	887	44	4,438	20	10.2	15,826	1,661.7	9,416	470.8	986.7	5.6	9.4	895.5	8,529	53.9
SE¼	10	2	5.0	3,559	356	16	1,780	22	6.7	11,435	114.4	6,805	309.3	68.1	3.1	5.2	64.5	6,449	56.4
SW¼	30	4	7.5	13,950	465	24	3,488	19	9.0	13,265	398.0	7,893	415.4	236.8	3.5	5.9	222.9	7,428	56.0
NW¼	70	12	5.8	31,210	446	19	2,601	23	7.9	14,096	986.7	8,388	364.7	587.2	3.2	5.3	555.0	7,942	56.3
30 - 26N - 14E																			
NE¼	70	5	14.0	74,957	1,070	38	14,991	28	11.8	25,632	1,794.2	15,252	544.7	1,067.6	4.2	7.0	992.6	14,182	55.3
SE¼	125	18	6.9	284,497	2,276	95	15,805	24	17.0	31,653	3,956.6	18,833	784.7	2,354.1	7.2	12.1	2,069.6	16,557	52.3
SW¼	155	25	6.2	183,475	1,184	46	7,339	26	10.5	21,179	3,282.7	12,602	484.7	1,953.3	5.6	9.4	1,769.8	11,418	53.9
NW¼	150	17	8.8	89,030	594	22	5,237	27	8.3	17,386	2,607.9	10,344	383.1	1,551.6	3.4	5.7	1,462.6	9,750	56.1
31 - 26N - 14E																			
NE¼	115	15	7.7	198,404	1,725	75	13,227	23	16.5	29,442	3,385.8	17,517	761.6	2,014.5	5.9	9.8	1,816.1	15,792	53.6
SE¼	125	16	7.8	288,167	2,305	92	18,010	25	17.2	33,359	4,169.9	19,850	794.0	2,481.3	6.9	11.6	2,193.1	17,545	52.5
SW¼	135	22	6.1	333,392	2,470	107	15,154	23	16.6	29,620	3,998.7	17,624	766.3	2,379.4	8.3	14.0	2,046.0	15,155	51.2
NW¼	125	13	9.6	114,344	915	38	8,796	24	11.5	21,412	2,676.5	12,739	530.8	1,592.4	4.3	7.2	1,478.1	11,824	55.2
32 - 26N - 14E																			
NE¼				0															
SE¼	30	5	6.0	42,930	1,431	62	8,586	23	12.5	22,304	669.1	13,271	577.0	398.1	6.4	10.8	355.2	11,840	53.1
SW¼				0															
NW¼	10	1	10.0	3,650	365	18	3,650	20	8.2	12,723	127.2	7,570	378.5	75.7	2.9	4.8	72.1	7,205	56.7
33 - 26N - 14E																			
NE¼				0															
SE¼	60	9	6.7	37,379	623	31	4,153	20	10.0	15,516	931.0	9,232	461.6	553.9	4.0	6.7	516.5	8,609	55.5
SW¼	130	20	6.5	191,030	1,469	64	9,552	23	13.4	23,910	3,108.3	14,226	618.5	1,849.4	6.1	10.3	1,658.4	12,757	53.4
NW¼				0															

TABLE 3 - CONTINUED

OIL PRODUCTION AND OIL RESERVE DATA

Sec.-Twp.-Rge.	Total Productive Acres	Total Producing Wells	Well Density – Acres per Well	Total Oil Recovery to 1-1-44				Sand Thickness (Feet)	Porosity (Percent)	Reservoir Void Space		Original Reservoir Oil @ Standard Conditions			Oil Recovery		Residual Reservoir Oil as of 1-1-44 @ Std. Conditions		
				Total Barrels	Bbl. per Acre	Bbl. per Ac.-Ft.	Bbl. per Well			Bbl. per Acre	Total Bbl. (in thousands)	Bbl. per Acre	Bbl. per Acre-Foot	Total Bbl. (in thousands)	Percent of Reservoir Voids	Percent of Original Reservoir Oil @ Std. Conditions	Total Bbl. (in thousands)	Bbl. per Acre	Percent Saturation of Total Reservoir Voids
									← ESTIMATED										→
4 - 25N - 14E																			
NE¼	25	5	5.0	13,000	520	29	2,600	18	9.0	12,568	314.2	7,478	415.4	187.0	4.1	7.0	174.0	6,957	55.4
SE¼				0															
SW¼	10	2	5.0	2,000	200	10	2,000	20	5.2	8,068	80.7	4,800	240.0	48.0	2.5	4.2	46.0	4,600	57.0
NW¼	85	15	5.7	122,064	1,436	60	8,138	24	11.4	21,226	1,804.2	12,629	526.2	1,073.5	6.8	11.4	951.4	11,193	52.7
5 - 25N - 14E																			
NE¼	25	3	8.3	21,593	864	43	7,198	20	12.2	18,930	473.3	11,264	563.2	281.6	4.6	7.7	260.0	10,400	54.9
SE¼				0															
SW¼	150	26	5.8	258,091	1,721	72	9,927	24	14.1	26,253	3,938.0	15,622	650.9	2,343.3	6.6	11.0	2,085.2	13,901	53.0
NW¼	50	9	5.6	76,555	1,531	67	8,506	23	12.4	22,126	1,106.3	13,165	572.4	658.3	6.9	11.6	581.7	11,634	52.6
6 - 25N - 14E																			
NE¼	130	20	6.5	261,065	2,008	84	13,053	24	15.5	28,860	3,751.8	17,172	715.5	2,232.4	7.0	11.7	1,971.3	15,164	52.5
SE¼	135	24	5.6	269,212	1,994	83	11,217	24	15.0	27,929	3,770.4	16,618	692.4	2,243.4	7.1	12.0	1,974.2	14,624	52.4
SW¼	135	21	6.4	189,100	1,401	56	9,005	25	11.9	23,080	3,115.8	13,733	549.3	1,854.0	6.1	10.2	1,664.9	12,332	53.4
NW¼	150	24	6.3	522,676	3,485	125	21,778	28	19.0	41,273	6,191.0	24,556	877.0	3,683.4	8.4	14.2	3,160.7	21,071	51.1
7 - 25N - 14E																			
NE¼	105	19	5.5	130,470	1,243	50	6,867	25	13.4	25,989	2,728.8	15,463	618.5	1,623.6	4.8	8.0	1,493.1	14,220	54.7
SE¼	20	2	10.0	45,160	2,258	87	22,580	26	20.0	40,342	806.8	24,003	923.2	480.1	5.6	9.4	434.9	21,745	53.9
SW¼	160	29	5.5	524,485	3,278	131	18,086	25	18.4	35,687	5,709.9	21,233	849.3	3,397.3	9.2	15.4	2,872.8	17,955	50.3
NW¼	110	17	6.5	251,077	2,283	100	14,769	23	16.0	28,549	3,140.4	16,988	738.6	1,868.7	8.0	13.4	1,617.6	14,705	51.5
8 - 25N - 14E				0															
9 - 25N - 14E																			
NE¼	20	3	6.7	4,000	200	10	1,333	20	6.2	9,620	192.4	5,724	286.2	114.5	2.1	3.5	110.5	5,524	57.4
SE¼	40	6	6.7	11,214	280	13	1,869	21	7.1	11,557	462.7	6,882	327.7	275.3	2.4	4.1	264.1	6,602	57.1
SW¼				0															
NW¼	30	3	10.0	8,000	267	19	2,667	14	8.5	9,232	277.0	5,494	392.4	164.8	2.9	4.9	156.8	5,227	56.6
16 - 25N - 14E																			
NE¼	50	5	10.0	10,000	200	13	2,000	15	7.1	8,262	413.1	4,916	327.7	245.8	2.4	4.1	235.8	4,716	57.1
SE¼	10	1	10.0	200	20	1	200	15	6.3	7,331	73.3	4,362	290.8	43.6	0.3	0.5	43.4	4,342	59.2
SW¼				0															
NW¼				0															
17 - 25N - 14E																			
NE¼	20	2	10.0	500	25	1	250	15	6.3	7,331	146.6	4,362	290.8	87.2	0.3	0.6	86.7	4,337	59.2
SE¼	10	1	10.0	250	25	1	250	15	6.3	7,331	73.3	4,362	290.8	43.6	0.3	0.6	43.4	4,337	59.2
SW¼	10	1	10.0	250	25	1	250	15	6.3	7,331	73.3	4,362	290.8	43.6	0.3	0.6	43.4	4,337	59.2
NW¼				0															
18 - 25N - 14E																			
NE¼	25	6	4.2	64,697	2,588	113	10,783	23	16.8	29,977	749.4	17,836	775.5	445.9	8.6	14.9	381.2	15,248	50.9
SE¼				0															
SW¼	60	15	4.0	98,528	1,642	78	6,569	21	18.2	29,651	1,779.1	17,642	840.1	1,058.5	5.5	9.3	960.0	16,000	54.0
NW¼	140	37	3.8	340,923	2,435	116	9,214	21	16.0	26,068	3,649.5	15,511	738.6	2,171.5	9.3	15.7	1,830.6	13,076	50.2
FIELD TOTAL	5,610	871	6.44	7,565,720	1,349	56.8	8,686	23.4	12.2	22,148	123,818.4	13,132	560.5	73,669.2	6.1	10.3	66,065.5	11,776	53.4

TABLE 3 - CONTINUED

Table 4.

Oil Production and Oil Reserve Data

(Recapitulation of table 3)

Field total	
Actual gross oil production, bbl....................	5,529,329
Estimated gross oil production, bbl....................	2,036,391
Total gross oil production, bbl....................	7,565,720
Percent actual production obtained on basis of total.	73.1
Total productive acres....................	5,610
Total productive wells....................	871
Oil recovery per acre, bbl....................	1,349
Oil recovery per acre foot, bbl....................	56.8
Oil recovery per well, bbl....................	8,686
Well density, acres per well....................	6.44
Average porosity, percent....................	12.2
Sand thickness, feet....................	23.4
Total reservoir void space, bbl....................	123,818,400
Reservoir void space per acre, bbl....................	22,148
Total original oil in place, bbl....................	73,669,200
Original oil in place, bbl. per acre....................	13,132
Original oil in place, bbl. per acre foot............	560.5
Oil recovery, percent of reservoir voids.............	6.1
Oil recovery, percent of original oil in place.......	10.3
Total residual oil in reservoir, bbl....................	66,065,500
Total residual oil in reservoir, bbl. per acre.......	11,776
Total residual oil, percent saturation of reservoir voids....................	53.4

NOTE: Estimated original and residual oil reserves were corrected to standard conditions by using an estimated connate water content of 30 percent and an estimated formation volume factor of 1.18.

field as a whole. Table 4 indicates that 871 Bartlesville sand wells have produced, to January 1, 1944, a total of 7,566,000 barrels of oil from approximately 5,610 productive acres. This amount represents a total oil recovery of 1,350 barrels per acre, 57 barrels per acre foot, and 8,700 barrels per well, with an average well density of 6½ acres per well.

Plate 7 is an oil production map of the Bartlesville sand showing total oil recovery per acre from five areas to January 1, 1944. The recovery from area 1 has been 3,000 or more barrels of oil per acre; area 2, 2,000 to 3,000 barrels per acre; area 3, 1,000 to 2,000 barrels per acre; area 4, 500 to 1,000 barrels per acre, and area 5, less than 500 barrels per acre. Area 6 may have possibilities of being productive, whereas area 7 is dry or unknown.

Table 5 shows that a total of 1,414,000 barrels of oil has been produced from 76 wells on 400 acres comprising area 1. This amounts to a total average oil recovery of 3,534 barrels per acre, 136 barrels per acre foot and 18,601 barrels per well, with an average well density of 5.3 acres per well. The recovery from area 2 has been 2,402,000 barrels of oil from 1,000 acres and 140 wells. This amounts to an average oil recovery of 2,402 barrels per acre, 98 barrels per acre foot, and 17,157 barrels per well, with an average well density of 7.1 acres per well.

The recovery from area 3 has been 2,579,400 barrels of oil from 1,775 acres and 283 wells. This amounts to an average recovery of 1,453 barrels per acre, 62 barrels per acre foot, and 9,114 barrels per well, with an average well density of 6.3 acres per well.

Table 5.

Oil Production - Oil Reserve Data (Areas refer to pl. 7)

	Area 1	Area 2	Area 3
Gross oil production, bbl.	1,413,671	2,402,035	2,579,377
Total productive acres	400	1,000	1,775
Total productive wells	76	140	283
Oil recovery, bbl. per acre	3,534	2,402	1,453
Oil recovery, bbl. per acre foot	135.9	98.4	61.6
Oil recovery, bbl. per well	18,601	17,157	9,114
Well density, acres per well	5.3	7.1	6.3
Average porosity, percent (Estimated)	18	17	13.1
Sand thickness, feet	26	24.4	23.6
Total reservoir void space, bbl.	14,522,800	32,180,000	42,573,375
Reservoir void space, bbl. per acre	36,307	32,180	23,985
Total original oil in place, bbl.	8,641,200	19,147,000	25,331,025
Original oil in place, bbl. per acre	21,603	19,147	14,271
Original oil in place, bbl. per acre foot	830.9	784.7	604.7
Oil recovery, percent of reservoir voids	9.7	7.5	6.1
Oil recovery, percent of original oil in place	16.4	12.5	10.2
Residual reservoir oil, bbl.	7,227,600	16,745,000	22,751,950
Residual reservoir oil, bbl. per acre	18,069	16,745	12,818
Residual oil saturation, percent of reservoir voids	50	52	53.4

At the beginning of 1944, 140 wells were producing approximately 140 barrels of oil per day. Bartlesville sand water production was negligible and water produced from other zones owing to casing leaks amounted to about 20 percent of the total oil and water produced.

RESERVOIR CHARACTERISTICS AND BEHAVIOR

Pressure-Volume Relations

The Hogshooter field, discovered in 1906, reached its peak production of approximately 740,000 barrels per year in 1910, and by the year 1915 had declined 73 percent from the peak. Although there are no bottom hole pressure records for this field, it is estimated that the original Bartlesville sand reservoir pressure was approximately 500 pounds per square inch, which is normal for the average depth of the producing formation. An examination of the average production rate of decline curves (pl. 9), discloses that the bottom hole pressure declined rapidly, owing to unrestricted withdrawals. Decline characteristics as shown by plate 9 are typical of open flow operations in a gas-expansion type reservoir.

Gas-oil ratio records are unavailable. In order to give some general idea as to the early Bartlesville sand gas production, several operators of early developed oil properties and gasoline plants were interviewed. On the basis of the information obtained, it is believed that gas-oil ratios, during the early or flush production life of the field, were about 1,000 cubic feet per barrel of oil produced. However, it is estimated that the original gas in solution was 300 to 400 cubic feet per barrel, with the remaining produced gas coming from a free gas cap, the volume of which is unknown. In the past five years, a few new oil wells drilled on inside locations have produced small volumes of gas from the Bartlesville sand.

Production Rate of Decline

The following curves, plate 9, figures 1 and 2, represent the average rate of decline of the field. Data for the curves were obtained by selecting twenty-four leases considered to be representative of the field. Total recoveries range from the best to the poorest, and include leases whose date of first production was anywhere between 1907 and 1918. The points were obtained by taking the arithmetical sum of the first year's production of each lease, and similarly with the second year's production and each subsequent year. This type of curve does not show the actual production for any particular calendar year, but it does show the average rate of production decline for the mumber of years after the date of development.

These curves show quite clearly the net effect of the application of vacuum, of gas-repressuring, of comparatively recent re-drilling of old plugged-out areas, and of remedial work done on old wells. The shaded area was found to represent 8.9 percent of the total recovery of the leases to date. Owing to the nature of the data used, it is not possible to allocate the net gain over the normal decline to the different methods utilized for stimulating production. It is quite evident that this gain in production is small considering the magnitude of the operations and the expense involved.

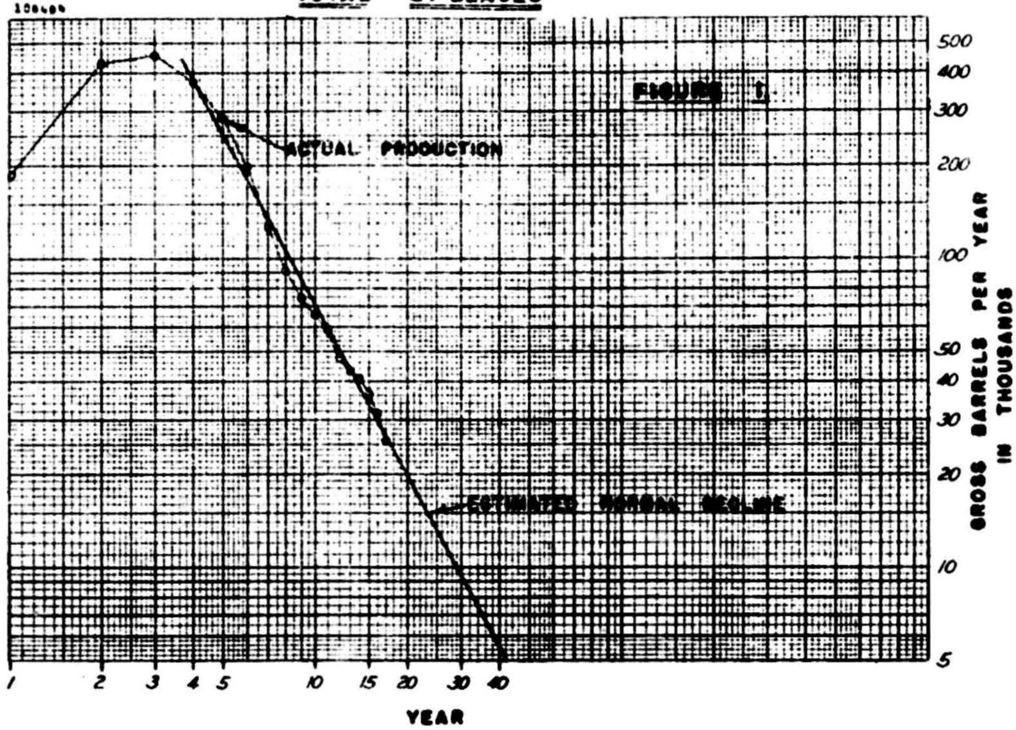
The individual lease production decline curves, which were prepared for essentially all leases in the field, show no great divergence from the average curve as to the rate of decline experienced during the

PRODUCTION RATE OF DECLINE CURVES

HOGSHOOTER FIELD

WASHINGTON COUNTY, OKLAHOMA

TOTAL — 24 LEASES



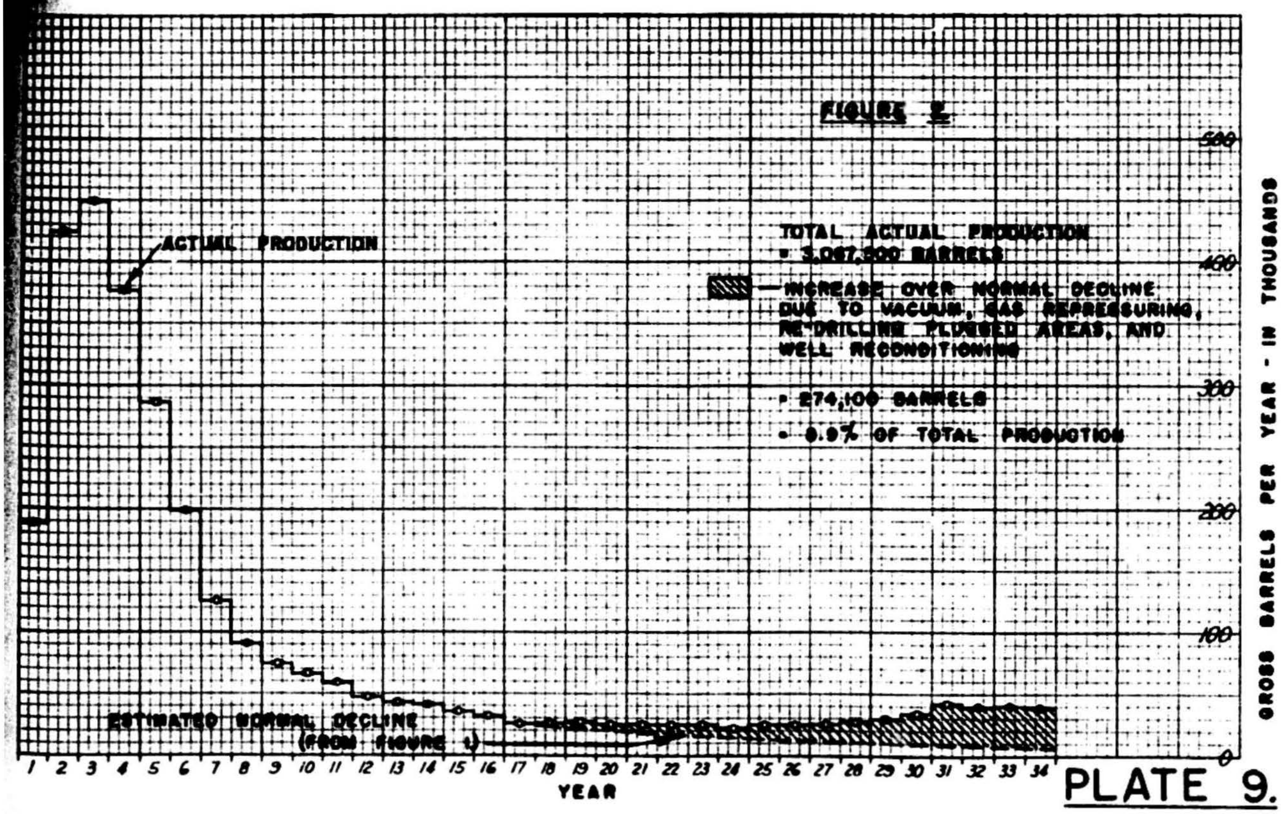


PLATE 9.

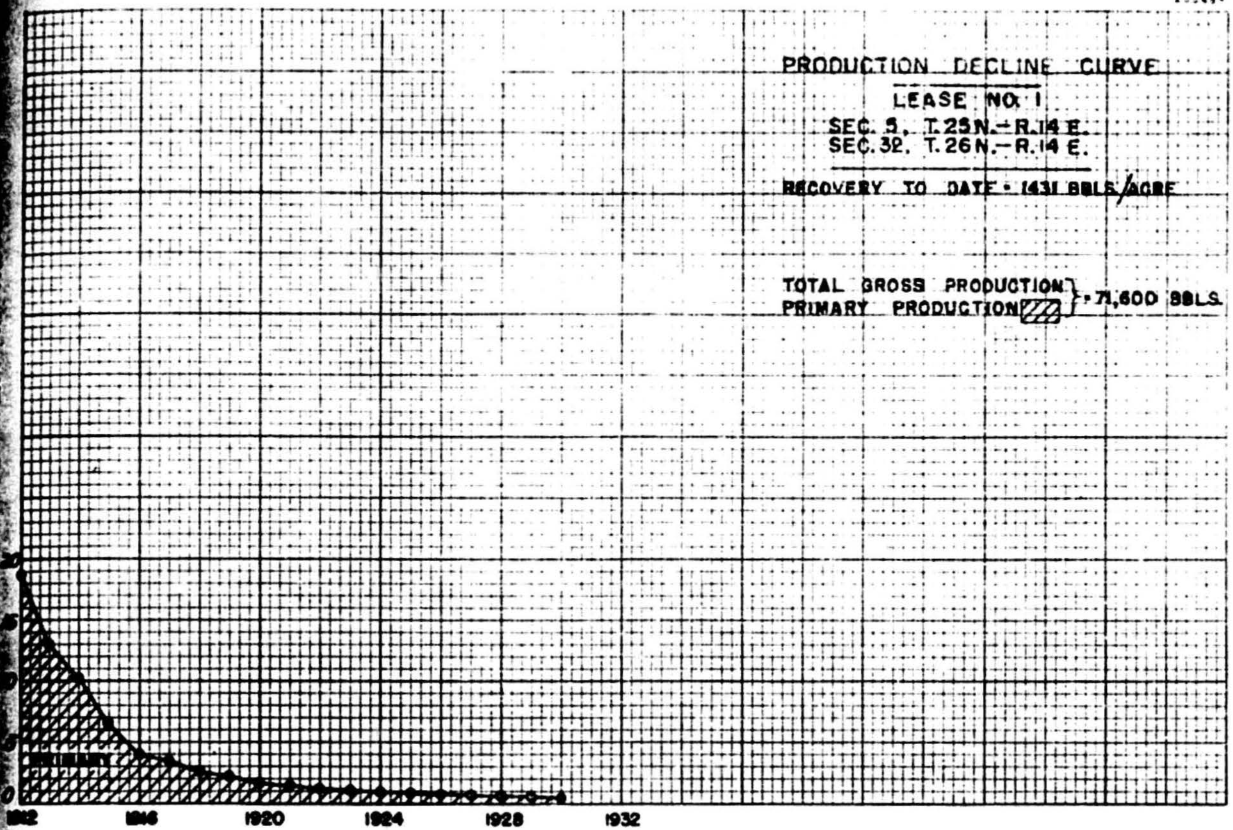
early life of the properties. Individual curves for eight leases are included herewith (pls. 10, 11, 12, and 13) as representative of the different production procedures followed in the field and the production obtained.

Leases 1 and 2 (pl. 10) illustrate the result of unrestricted production and normal decline, with no attempt to increase production through secondary methods. The well densities were comparable, and the difference in recovery-per-acre may be attributed only to variations in sand conditions and thickness.

Leases 3 (pl. 11), 5 (pl. 12), and 8 (pl. 13) show the effect of vacuum application, and of subsequent gas-repressuring and well remedial work. Although the net gain has not been exceptionally high on these leases, the extrapolated normal decline indicates that the leases would have been plugged and abandoned eight to ten years ago had it not been for the application of such methods.

Leases 4 (pl. 11) and 7 (pl. 13) are presented as examples of leases that have been completely plugged and later re-drilled. The resulting production is not what might have been anticipated, as the new wells on lease 7 are better located with respect to the old wells than are those on lease 4, and gas is being injected into the Bartlesville sand on lease 7. The great difference in production may again be attributed only to the particular sand conditions under each property.

Lease 6 (pl. 12) shows an increase in production of 61 percent over that from the estimated normal decline. All evidence indicates that this lease had been subjected to an accidental water-drive by water infiltration into the Bartlesville sand through faulty


PRODUCTION DECLINE CURVE
LEASE NO. 1
SEC. 5, T.25N.–R.14 E.
SEC. 32, T.26N.–R.14 E.
RECOVERY TO DATE = 1431 BBLS./ACRE
TOTAL GROSS PRODUCTION
PRIMARY PRODUCTION
= 71,600 BBLS.
PRIMARY
0
5
10
15
20
1912
1916
1920
1924
1928
1932

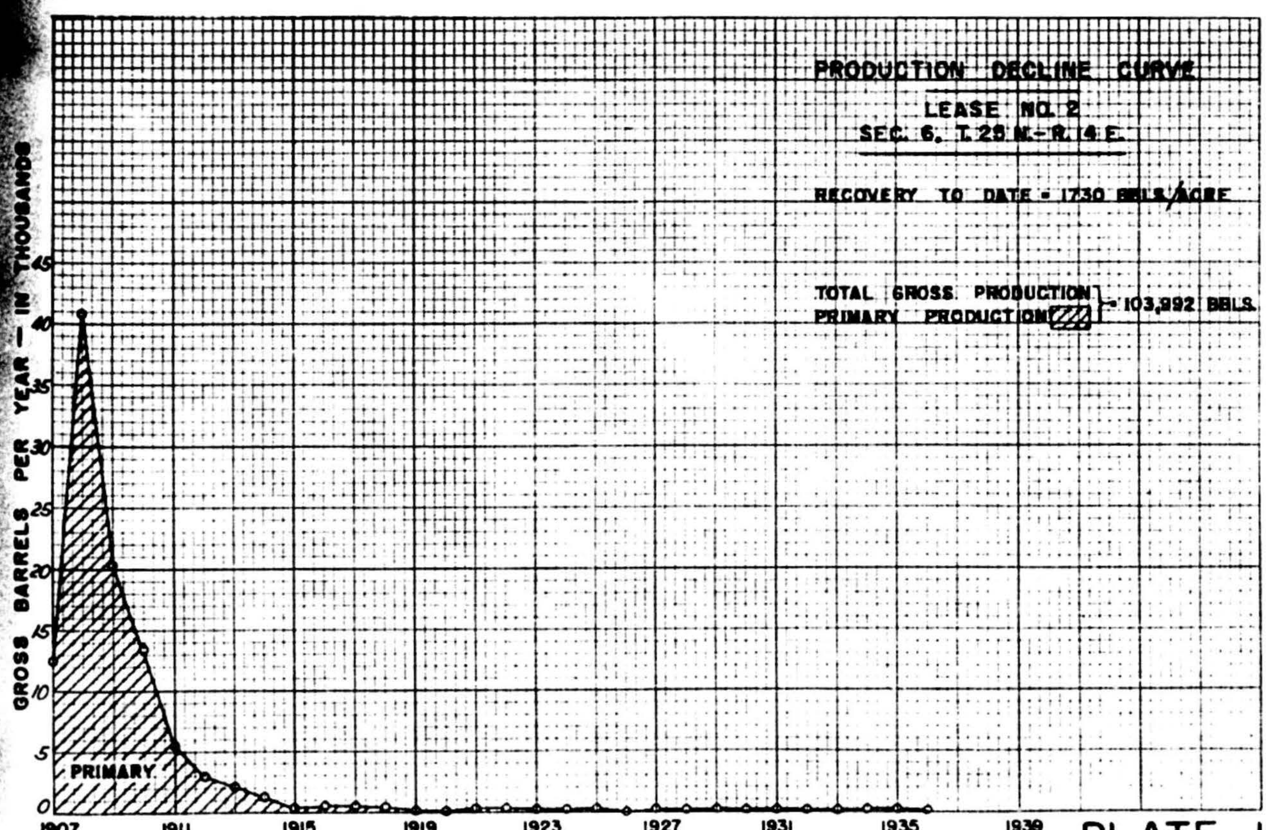
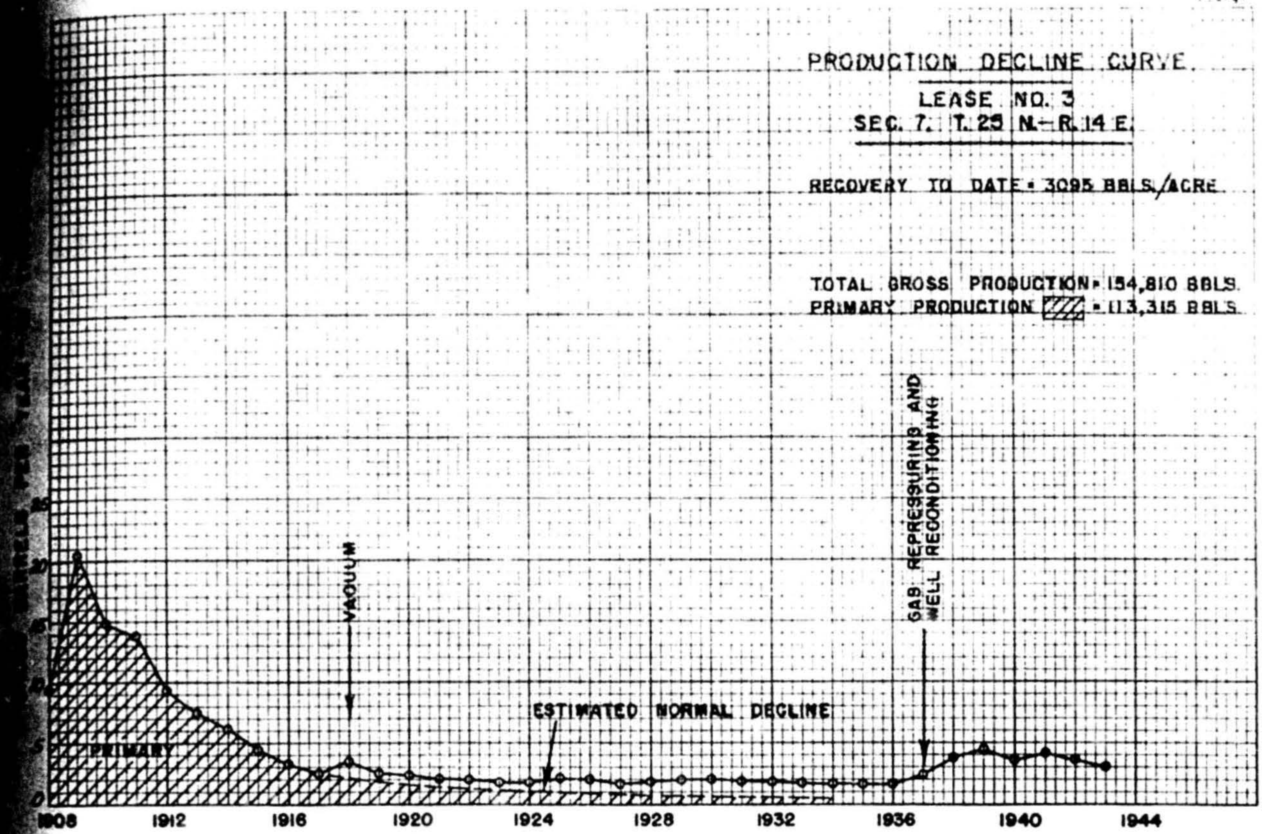

PRODUCTION DECLINE CURVE
LEASE NO. 2
SEC. 6, T.25 N.–R. 14 E.
RECOVERY TO DATE = 1730 BBLS./ACRE
TOTAL GROSS PRODUCTION
PRIMARY PRODUCTION
= 103,992 BBLS.
GROSS BARRELS PER YEAR — IN THOUSANDS
PRIMARY
0
5
10
15
20
25
30
35
40
45
1907
1911
1915
1919
1923
1927
1931
1935
1939

PLATE 10.


PRODUCTION DECLINE CURVE.
LEASE NO. 3
SEC. 7. T. 25 N.—R. 14 E.
RECOVERY TO DATE = 3095 BBLS./ACRE
TOTAL GROSS PRODUCTION = 154,810 BBLS.
PRIMARY PRODUCTION = 113,315 BBLS.
VACUUM
GAS REPRESSURING AND WELL RECONDITIONING
ESTIMATED NORMAL DECLINE
PRIMARY
1908
1912
1916
1920
1924
1928
1932
1936
1940
1944

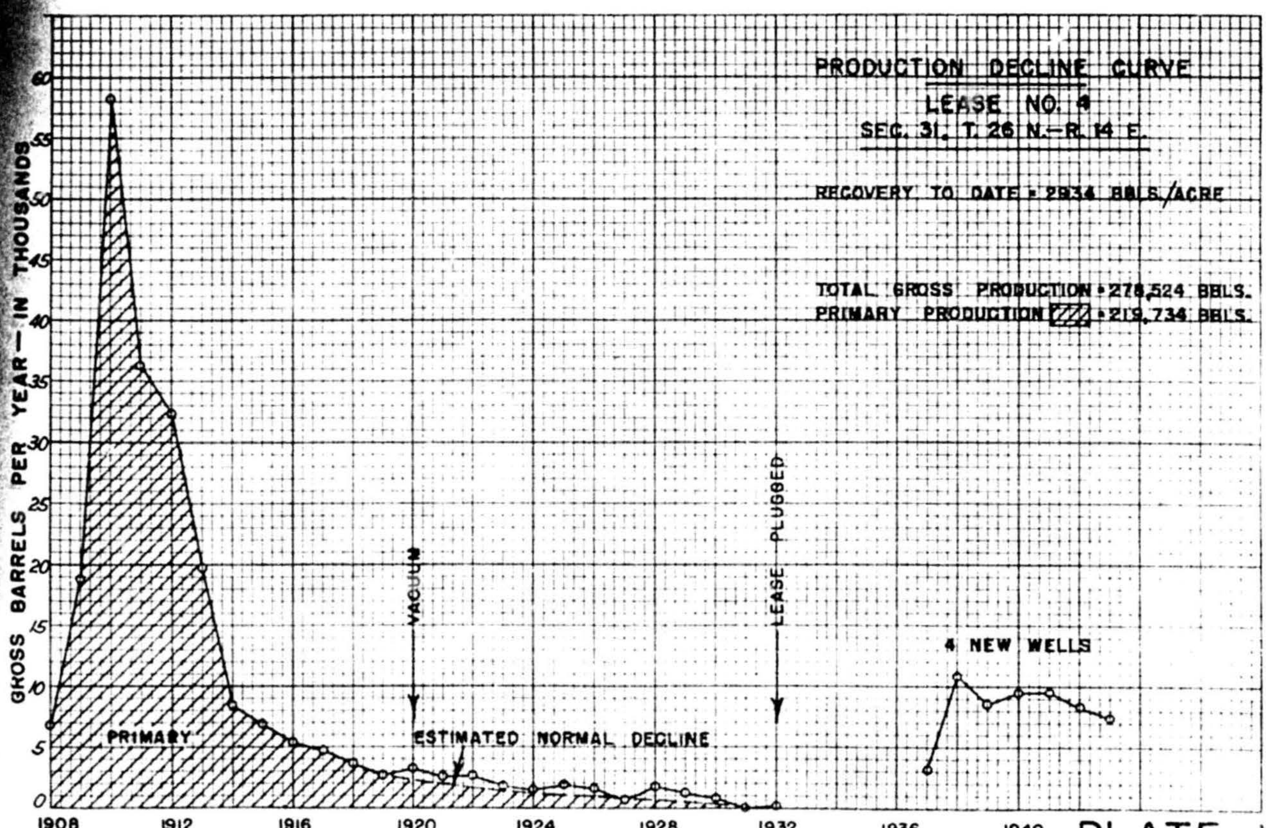
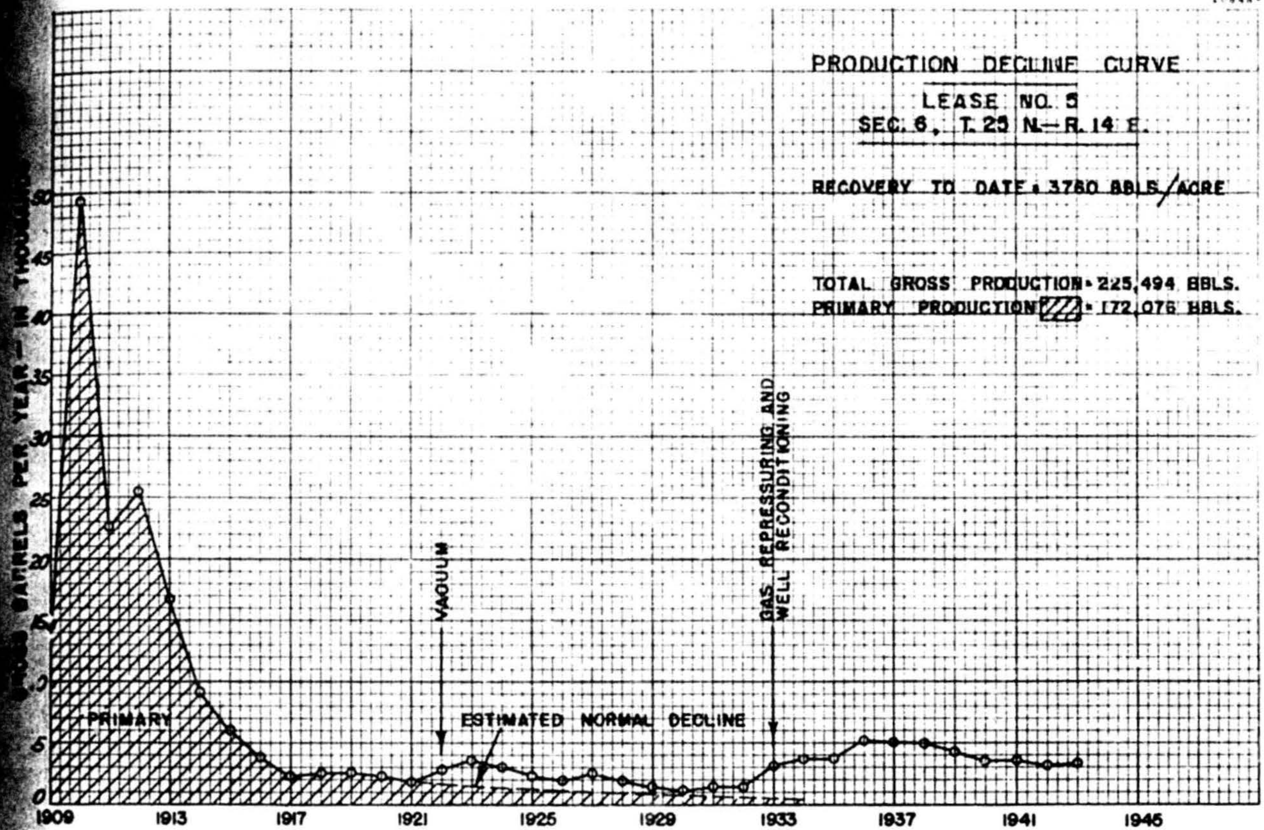

PRODUCTION DECLINE CURVE
LEASE NO. 4
SEC. 31. T. 26 N.—R. 14 E.
RECOVERY TO DATE = 2934 BBLS./ACRE
TOTAL GROSS PRODUCTION = 278,524 BBLS.
PRIMARY PRODUCTION = 219,734 BBLS.
GROSS BARRELS PER YEAR — IN THOUSANDS
VACUUM
LEASE PLUGGED
4 NEW WELLS
ESTIMATED NORMAL DECLINE
PRIMARY
0
5
10
15
20
25
30
35
40
45
50
55
60
1908
1912
1916
1920
1924
1928
1932
1936
1940

PLATE II.


PRODUCTION DECLINE CURVE
LEASE NO. 5
SEC. 6, T. 25 N.—R. 14 E.
RECOVERY TO DATE = 3760 BBLS./ACRE
TOTAL GROSS PRODUCTION = 225,494 BBLS.
PRIMARY PRODUCTION = 172,076 BBLS.
GROSS BARRELS PER YEAR — IN THOUSANDS
PRIMARY
VACUUM
ESTIMATED NORMAL DECLINE
GAS REPRESSURING AND WELL RECONDITIONING
1909
1913
1917
1921
1925
1929
1933
1937
1941
1945

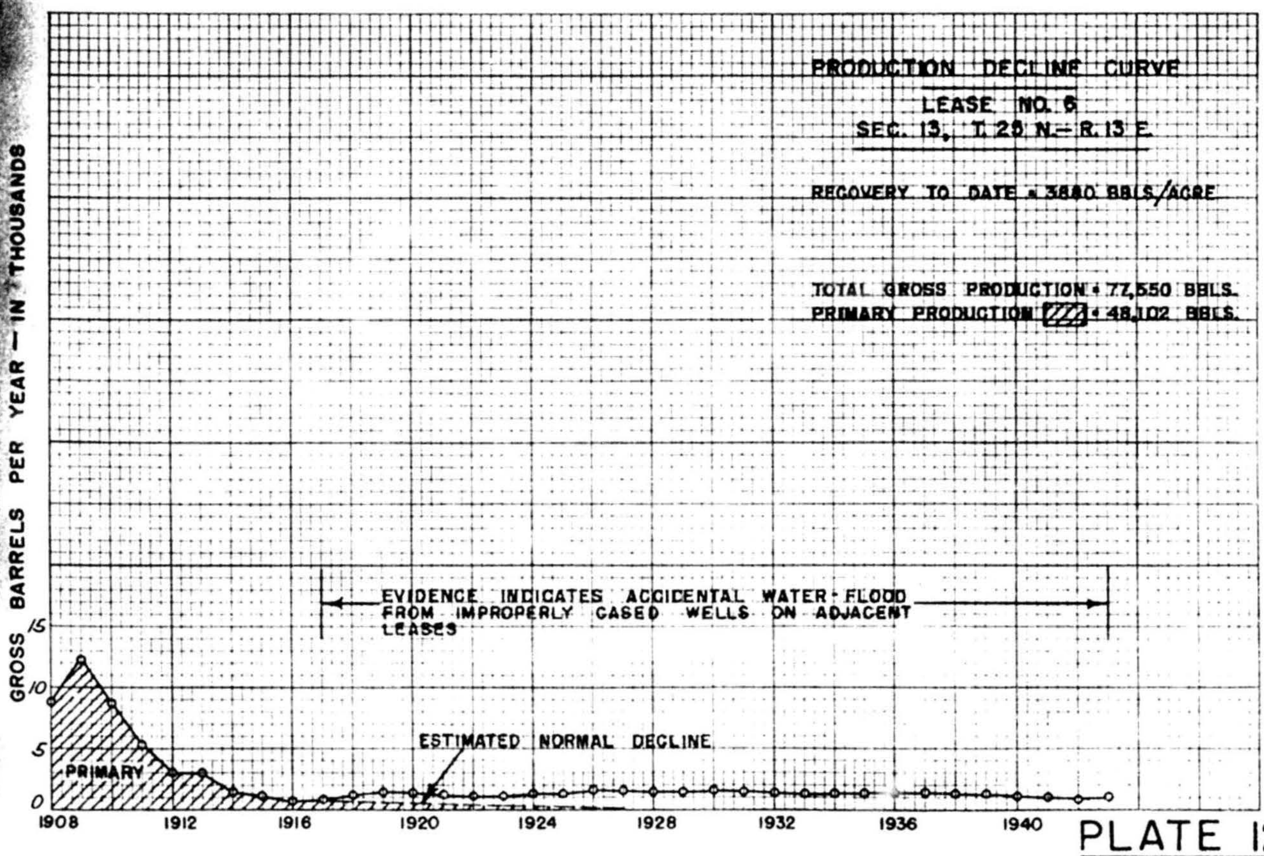
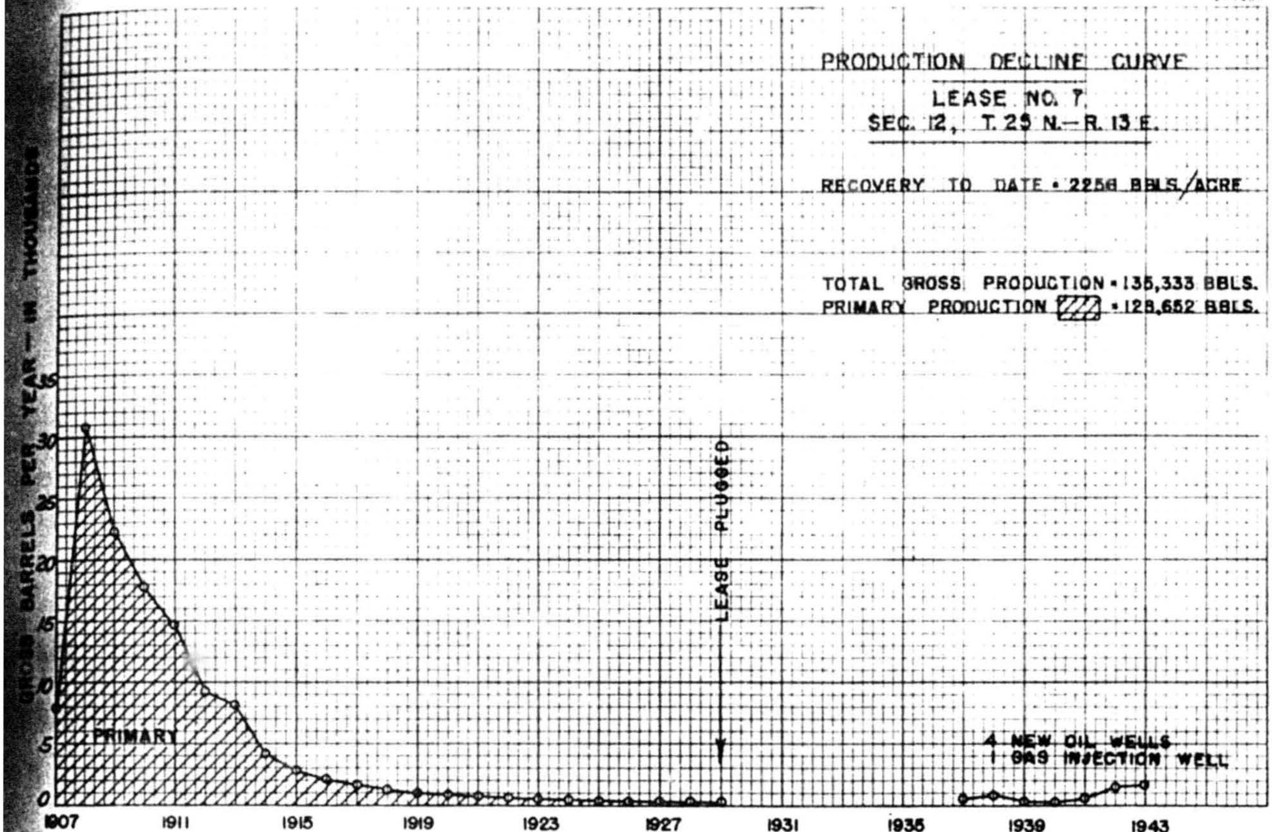

PRODUCTION DECLINE CURVE
LEASE NO. 6
SEC. 13, T. 25 N.—R. 13 E.
RECOVERY TO DATE = 3880 BBLS./ACRE
TOTAL GROSS PRODUCTION = 77,550 BBLS.
PRIMARY PRODUCTION = 48,102 BBLS.
GROSS BARRELS PER YEAR — IN THOUSANDS
EVIDENCE INDICATES ACCIDENTAL WATER-FLOOD FROM IMPROPERLY CASED WELLS ON ADJACENT LEASES
ESTIMATED NORMAL DECLINE
PRIMARY
1908
1912
1916
1920
1924
1928
1932
1936
1940

PLATE 12.


PRODUCTION DECLINE CURVE
LEASE NO. 7
SEC. 12, T. 25 N.– R. 13 E.
RECOVERY TO DATE = 2256 BBLS./ACRE
TOTAL GROSS PRODUCTION = 135,333 BBLS.
PRIMARY PRODUCTION = 128,652 BBLS.
GROSS BARRELS PER YEAR – IN THOUSANDS
LEASE PLUGGED
4 NEW OIL WELLS
1 GAS INJECTION WELL
PRIMARY
0
5
10
15
20
25
30
35
1907
1911
1915
1919
1923
1927
1931
1935
1939
1943

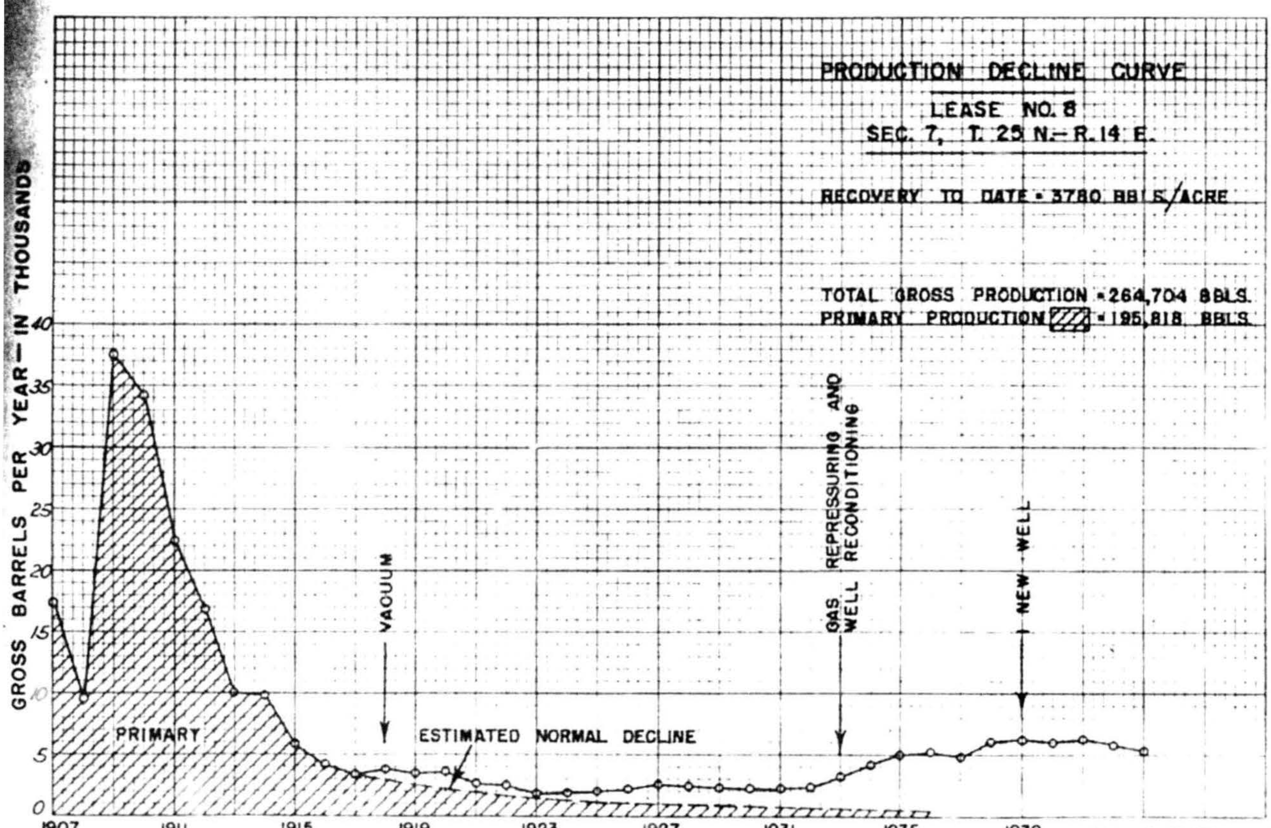

PRODUCTION DECLINE CURVE
LEASE NO. 8
SEC. 7, T. 25 N.– R. 14 E.
RECOVERY TO DATE = 3780 BBLS./ACRE
TOTAL GROSS PRODUCTION = 264,704 BBLS.
PRIMARY PRODUCTION = 195,818 BBLS.
GROSS BARRELS PER YEAR – IN THOUSANDS
VACUUM
ESTIMATED NORMAL DECLINE
GAS WELL REPRESSURING AND RECONDITIONING
NEW WELL
PRIMARY
0
5
10
15
20
25
30
35
40
1907
1911
1915
1919
1923
1927
1931
1935
1939

PLATE 13.

casing in adjacent producing wells, and improperly plugged wells on adjoining properties.

Character of Oil.

The following is an analysis of oil from the Bartlesville sand.

Analyses of Oil From Bartlesville Sand 11/

Location: T. 26N., R. 14E.

Specific Gravity 0.853

Sulfur, percent 0.24

Saybolt Universal Viscosity at 77°F. - 62 Sec.
at 100°F. - 52 Sec.

	Percent	Specific Gravity	°A.P.I.	Viscosity Saybolt Seconds
Light gasoline	1.9	0.882	73.6	
Total gasoline and naphtha	22.6	0.755	55.9	
Kerosene distillate	12.1	0.812	42.8	
Gas oil	16.5	0.844	36.2	
Non-viscous lubricating distillate	11.3	0.861 - 0.882	32.8-28.9	50 - 100
Medium lubricating distillate	8	0.882 - 0.896	28.9-26.4	100 - 200
Residuum	28.9	0.938	19.4	
Distillation lost	0.6			

BARTLESVILLE SAND BODY CONDITIONS

The depositional history of the sand bodies in the Cherokee shale (Pennsylvanian series) has recently been studied in detail by N. Wood Bass 12/, and by others in the past. The purpose of this section

11/ Oakes, M.C., Geology and Mineral Resources of Washington County, Okla.: Oklahoma Geological Survey, Bull. 62, pp. 111-112, 1940.

12/ Bass, N. Wood, Origin of the Shoestring Sands of Greenwood and Butler Counties, Kansas. Bull. 23, State Geological Survey of Kansas, 1936.

is to describe briefly the relation of oil, gas, and water to the Bartlesville sand in the Hogshooter field, and in particular to describe indirect methods for determining relative values of the permeability-porosity features of this sand body.

Oil, Gas, and Water Relations

The greater part of this field is underlain by the Bartlesville sand which has a thickness of about 23 feet, and is found at a depth of approximately 1,150 feet. Dry holes do not mean the absence of oil or the presence of water in the Bartlesville sand, but rather that the sand is too tight to produce.

Approximately 875 drillers' logs were examined, and not more than a dozen of them showed the absence of the Bartlesville sand. These logs showed good correlation as to the position of the "Big Lime" and the "Oswego Lime". Gas was reported frequently in the top of the oil sand and a few logs showed the Bartlesville as a gas sand. This matter of gas occurrence is taken into consideration elsewhere in this report.

The Bartlesville sand of northeastern Oklahoma does not have a water history, although most of the wells producing from the Bartlesville sand show some water. The general opinion is that this water, with a few exceptions, is caused by leaking strings of casing. Some edge water is reported for the Delaware field extension of the Nowata district. Relative to the Hogshooter field, a recent well drilled close to an old well produced about ¼ barrel of water per day from the Bartlesville sand. In this case the water may very well be upper water introduced into the Bartlesville sand from leaking casing in old wells. In other areas in Oklahoma, edge water in the Bartlesville sand is not uncommon and in southeastern Osage County the Bartlesville sand makes considerable water. The following analyses show evidence of diluted water due to leaking casing.

Partial Water Analyses from
Northeastern Oklahoma Bartlesville Leases

Location	Number of wells (average)	Total solids 1/ grams/liter
Sec. 12, T. 25N., R. 16E.	14	58.0
" 17 and 22, T. 24N., R. 17E.	72	23.0
" 18, T. 26N., R. 16E.	2	33.0
" " " "	1	54.0
" " " "	1	27.0
" " " "	1	33.0
" " " "	1	31.0
" 14, T. 24N., R. 16E.	1	54.0
" " " "	1	23.0
" " " "	1	11.0
" " " "	1	10.0
" " " "	1	14.0
" " " "	1	12.0
" 22, T. 24N., R. 16E.	1	25.0

1/ Total solids expressed in round numbers.

The following are the analyses of two salt water samples collected from Bartlesville leases in the Hogshooter field, March 27, 1944, and analyzed by the U. S. Geological Survey laboratory at Casper, Wyoming.1/

Sample	1		2	
Location	Sec. 13, T. 25N., R. 13E.		Sec. 12, T. 25N., R. 13E.	
Source	Bartlesville sand		Bartlesville sand	
Depth	1,145 to 1,170 feet		1,145 to 1,175 feet	
	Ppm	RV%	Ppm	RV%
Calcium (Ca)	5,860	7.28	6,790	7.71
Magnesium (Mg)	1,790	3.67	1,460	2.73
Alkalis (Na)	36,058	39.05	39,992	39.56
Chloride (Cl)	71,000	49.86	77,500	49.71
Sulfate (SO_4)	97	0.04	159	0.07
Bicarbonate (HCO_3)	230	0.09	585	0.22
Total solids	114,918	100%	126,189	100%

Ppm - Parts per million
RV% - Reactive value (percent)
1/ Analyst: J. G. Crawford

The attitude taken in this report is that the physical condition of the Bartlesville sand of the Hogshooter field should be similar to the general condition of this sand body in northeastern Oklahoma. Many conventional core analyses of good pay sections in this part of the state show interstitial (connate) water saturations ranging between 30 and 40 percent of pore space. These water determinations, hoever, are not corrected for drilling water. Accordingly, 30 percent interstitial water saturation was selected as a conservative figure for the Bartlesville sand of the Hogshooter field.

Physical Conditions

The principal approach in this report is to ascertain the conditions of the Bartlesville sand with the view of applying the water-flood as a secondary recovery method. It is considered that the two main controlling factors for a successful water-flood are (1) sufficient oil reserve per acre, with 30 percent or more pore space saturation, and (2) the physical conditions of the sand body with respect to the permeability and the uniformity of the pay section. Both of these factors are considered to be of equal importance.

Many Bartlesville sand core analyses are available for northeastern Oklahoma, but there are none available from the Hogshooter field. A few clean-out samples were collected which were analyzed by the U. S. Geological Survey laboratory at Casper, Wyoming, and these will be described at the close of this section. It is because of the absence of adequate core analyses that the following described hypothetical methods have been used. Engineers who have used such methods in other fields have found the results to be fairly satisfactory when applied to lenticular sand reservoirs, particularly in northeastern Oklahoma.

Obviously the behavior of a lease is an index of the permeability and porosity features of the sand body, and the problem presented was to find some feature or combination of features that could be used as an index for all the leases of the Hogshooter field.

Well-initials for many years have been of value in estimating the relative permeabilities of oil sands. This information is of particular value when distance between wells and completion dates are known. Although 250 well initials were available, these data were not sufficiently spread to serve as a guide for the field. It will be noted that the well initial map (pl. 6) is in agreement with the sand body condition map (pl. 14). Furthermore, a fair relation exists between the isopach map (pl. 5) and the production map (pl. 7).

Specific Indirect Methods of Study

Factor A

The next feature examined was the total production obtained from the lease during the peak year, expressed as barrels per well per foot of sand. This value, designated as "Factor A", is the square root of the bbl. per well per foot for the peak production year divided by 10. The factor is related to permeability as it embodies rate; however, the application of this factor was limited as reliable data from less than 20 leases were available.

Factor B

This item represents an attempt to place all the leases on an equitable basis by excluding secondary development, owing to either the later drilling of new wells, or the application of vaccum, or both. Thus the primary production for leases on which secondary development was used was obtained by extrapolation of the decline curve to the economic limit from the date of the beginning of the secondary development. For some leases the primary production is the same as the total production. This factor, on the basis of primary production, is designated as bbl. per well per foot of sand and the actual number used is the square root of bbl. per well per foot divided by 10. "Factor B" is related to porosity to a greater extent than it is related to permeability. Nevertheless, it was found applicable to the field as a whole.

Factor C

Further, on the basis of primary production, an additional step toward improving the equitability of lease comparisons was made by calculating the primary production on the basis of constant well density. It has been found 13/ that for many sand bodies the total production is a linear function of the reciprocal of the square root of the well density (acres per well); i.e, bbl. per acre-foot plotted against the reciprocal of the square root of the well density. It is realized that broad application of this premise is questionable, particularly for sand bodies that lie several thousand feet in depth, and show high permeability and accompanying high formation pressure. Engineers are familiar with other examples of reservoir conditions that

---

13/ Clark, Stuart K., Tomlinson, C. W., and Royds, J. S., Well Spacing: Bull. American Assn. Petrol. Geol. Vol. 28, No. 2, p. 231, 1944.

bring into play structural attitudes that do not agree with this premise. However, for lenticular type sand bodies at shallow depths with weighted average permeabilities of less than 50 millidarcys and with formation pressures in the neighborhood of 500 pounds, the relation of production (bbl. per acre-foot) to well density, as mentioned above, appears not only reasonable but applicable, and in this report is so used for the Bartlesville sand in the Hogshooter field. A constant well density of 5 acres per well was arbitrarily selected, and on the basis of primary production, "Factor C" is designated as bbl. per acre-foot, at a well density of 5. The actual number used for this factor is the square root of bbl. per acre-foot at a well density of 5 divided by 10. "Factor C" is closely related to porosity and to some extent permeability. "Factor C" values were calculated for all the leases on the basis of primary production and the producing acreage. The sand body condition map (pl. 14) was constructed from "Factor C".

Porosity Estimates.

Clean-out samples of the Bartlesville sand were collected from 3 wells in sec. 18, T. 25N., R. 14E.; 1 well in sec. 12, T. 25N., R. 13E.; 1 well in sec. 7, T. 25N., R. 14E.; and 1 well in sec. 6, T. 25N., R. 14E. Laboratory analyses[14] of these samples considered to be representative of the pay section disclosed porosity values ranging from 15 to 22 percent; however, the samples were too small for permeability determinations.

Inasmuch as the individual leases of the field were studied, the arbitrary assignment of a single figure as an estimated porosity is

---

14/ U. S. Geological Survey Laboratory, Casper, Wyoming. J. G. Crawford, analyst.

obviously approximate. For want of a better procedure the average of the four highest "Factor C" values was taken as equivalent to 20 percent porosity, and the porosities were estimated as being directly related to "Factor C", as found for the particular lease. It will be observed that all production data in this report that embody percent pore volume are reasonable, and further, the low estimated porosities appear consistent when it is considered that those porosities imply a weighted average concept for the tight shaly phases and the good part of the sand body.

Table 6, covering only a few leases, is offered to show the varying values of the total production (bbl. per acre) and the calculated sand body condition "Factor C."

Figure 1, plate 15, shows the relation of "Factor A" to "Factor C". Only about 20 percent of "Factor A" data are considered to be reliable, the rest are estimates. Although the points are scattered, some relationship is shown.

Figure 2, plate 15, shows the relation between "Factor B" and "Factor C".

The sand body condition map (pl. 14) shows the relative producing characteristics of the Bartlesville sand in the Hogshooter field by areas. Areas 1, 2, and 3, consisting of 6,783 acres, are oil productive.

Area 1 (1,393 acres) represents the area of the best sand body conditions, whereas area 2 (2,248 acres) shows less favorable sand conditions. Area 3 (3,142 acres) displays the shaly area of the sand body, and area 4 represents the dry-hole and unknown area.

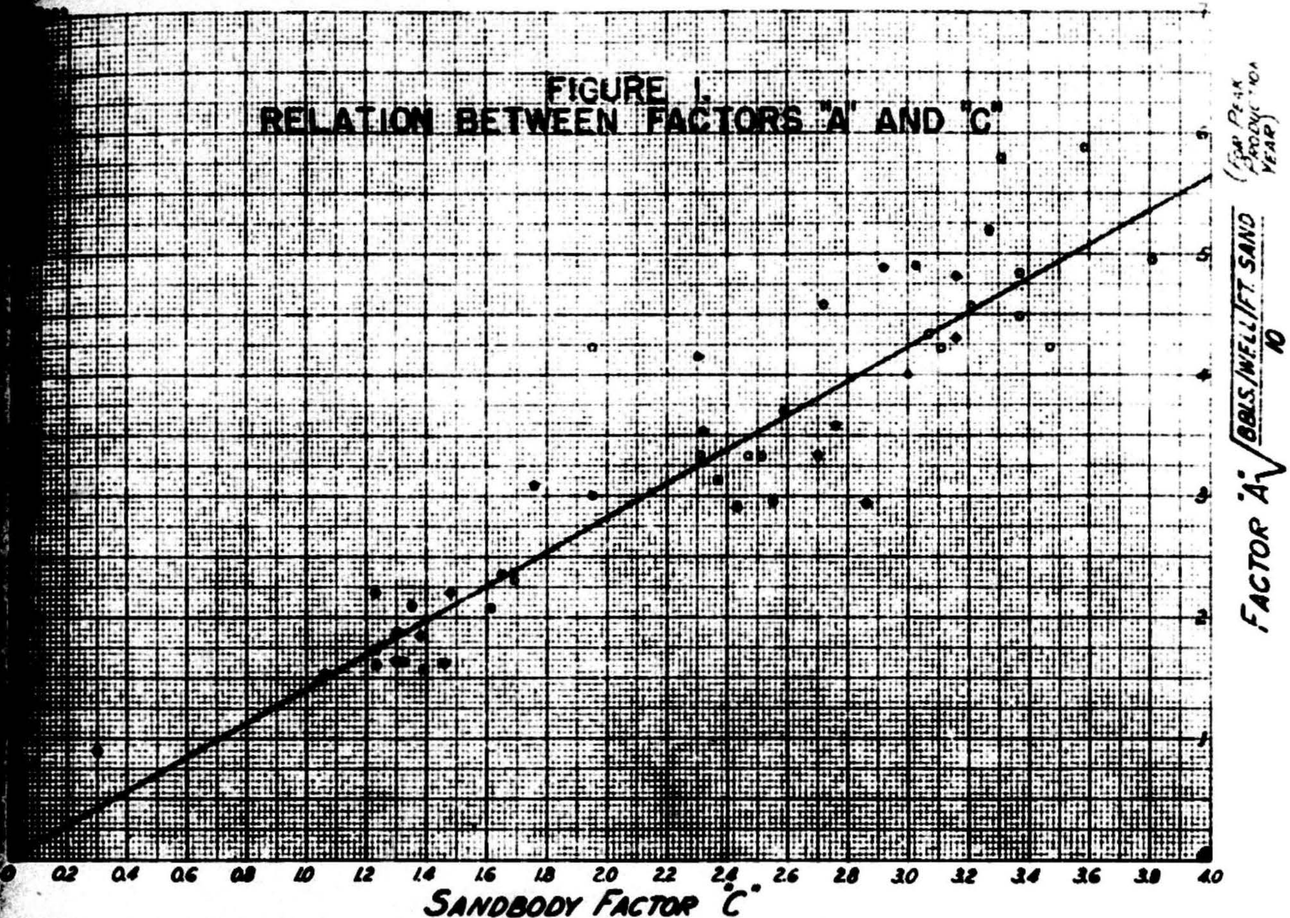


FIGURE 1.
RELATION BETWEEN FACTORS "A" AND "C"
(FOR PEAK PRODUCTION YEAR)
FACTOR "A" √(BBLS./WELL/FT. SAND / 10)
0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0
SANDBODY FACTOR "C"

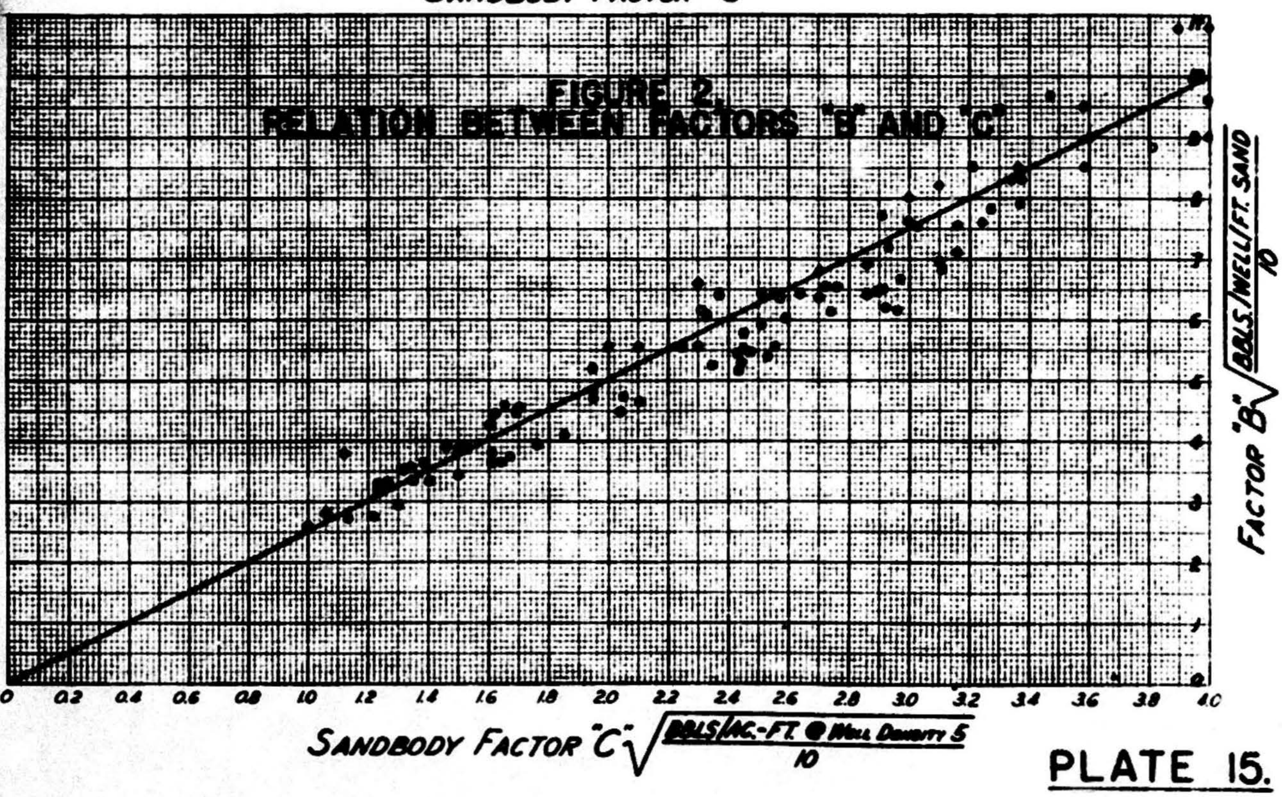


FIGURE 2.
RELATION BETWEEN FACTORS "B" AND "C"
FACTOR "B" √(BBLS./WELL/FT. SAND / 10)
0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0
SANDBODY FACTOR "C" √(BBLS./AC.-FT. @ WELL DENSITY 5 / 10)

PLATE 15.

Table 6.
Bartlesville Sand Body Factors

Lease No.	Producing acreage	Gross prod., bbl. per acre	Well density, acres per well	Bbl. per acre-ft.	Bbl. per acre ft., at well density 5	Sand body Factor C
Col. 1	2	3	4	5.	6.	7
1	50	1,431	6,2	68,2	76,0	2,76
2	60	1,730	6,0	96,0	105,0	3,24
3	50	3,095	6,2	90,0	100,0	3,16
4	95	2,934	7,9	103,0	129,0	3,59
5	60	3,760	6,7	140,0	162,0	4,02
6	20	3,880	5,0	100,0	100,0	3,16
7	60	2,256	7,5	75,0	91,7	3,03
8	70	3,780	5,8	106,0	114,0	3,37
9	80	2,890	4,7	100,0	97,0	3,11
10	20	2,590	20,0	54,6	109,0	3,31
11	40	2,270	10,0	91,0	128,0	3,58
12	120.	1,605	10,9	38,1	56,0	2,37
13	70	1,070	14,0	31,6	53,0	2,30
14	15	1,876	5,0	75,0	75,0	2,74
15	65	2,120	6,5	94,0	107,0	3,27
16	60	2,795	12,0	78,0	120,0	3,47
17	45	2,029	7,5	92,0	112,0	3,35
18	100	2,461	7.7	90.0	112.0	3.35
19	65	1,802	8.1	58.0	73.0	2.71

All data are on the basis of primary production with the exception of Column 3. Column 6 is based on well density of 5.

Decline curves and discussion for leases 1 to 8 as shown by Table 6, are found elsewhere in this report. (pl. 10-13).

The distribution of the Bartlesville sand areas is given in the following summary:

	Acres	Percent
Area 1	1,393	20,55
Area 2	2,248	33.17
Area 3	3,142	46.28
Total	6,783	100,00%
Developed area	5,610	82.80
Proved area	1,173	17.20
Total	6,783	100.00%

Lithology (Binocular Examination)

The majority of the Bartlesville sand clean-out samples from sec. 18, T. 25N., R. 14E., and sec. 12, T. 25N., R. 13E., were thin-bedded, friable, and reasonably porous. The interstitial material consisted predominantly of a soft granular clay type of mineral that does not greatly reduce the porosity. The same description applies to the samples collected from the well in sec. 12, T. 25N., R. 13E.

About half of the samples from the well in sec. 6, T. 25N., R. 14E., were friable and porous, and contained the same type of clay mentioned previously. The other half consisted of more massive beds that were hard and tight, owing to calcite cementation. Siderite was also quite common in the samples from this well.

Sand Grains.

Relative to all the samples, the grain size ranged from medium fine to medium. The grains were well rounded as compared to the general average for the Bartlesville sand, and the sorting of the majority of the samples was fair.

Associated Minerals.

Muscovite, glauconite, and carbonaceous plant fragments were quite common in the friable sand samples.

Argillaceous Material.

The light colored soft granular clay type of mineral mentioned in the sample description deserves some specific comment. Under the microscope the surfaces show luster. The material is not contaminated and the aspect of purity is quite pronounced. This type of clay-like mineral, associated with appreciable amounts of muscovite, has frequently been found in other sand bodies of Pennsylvanian age, such as the Dutcher and the Burgess. The study of a number of cores from these formations, including a number of Bartlesville cores, has shown appreciable permeability and porosity present in the pay section that contains the argillaceous mineral. The tight clay-bearing sections of these Pennsylvanian formations, not necessarily in the same core, clearly indicate to the practical observer that this non-granular, fine, and often dirty type of clay is primary, and the pores of the sand body are actually clogged with this clay that was mud when the sand was deposited. It is presumed that the granular clay-like mineral is secondary, possibly altered muscovite.

This notation on the granular lustrous clay is offered because lithologic aspects of oil-producing formations are gradually taking shape and demonstrating correlation with the physical properties of the pay zone, and these physical properties are directly related to the well behavior.

OIL RESERVES (Estimated)

For the purpose of estimating recoverable oil reserves, it is preferable to have core analysis data of the producing formation. However, this information was not available and the estimated recoverable oil reserves in this report should be regarded as preliminary and subject to final correction warranted by any core analyses that may be made in the future. In arriving at conclusions on what were believed to be reasonable recoverable reserve estimates, due consideration was given to Bartlesville sand secondary recovery projects operated in northeastern

Oklahoma. Consideration was also given to the principle that under open flow conditions (taking into account primary production per acre, primary well density, date of completion, and present production status) the best productive areas reflect more favorable sand body conditions, and thus should be more susceptible to application of secondary recovery.

Core analyses of the producing sand in this particular area were not available for the purpose of reserve calculations. However, in order to give a reasonably broad picture of the oil reserves, it was necessary to study the past reservoir performance as completely as available data would permit, together with Bartlesville sand core analyses in adjacent areas, and from these studies to draw conclusions as to some reasonable estimates to be applied to the Bartlesville sand of the Hogshooter field.

Referring to plate 9 (Production rate of decline curve) it is evident that unrestricted flow was the common operating practice in the early life of the field. Under such methods of operation the reservoir pressure was quickly depleted and this resulted in rapid liberation of solution gas. Consequently, large volumes of oil were left in the reservoir with no motivating force left to drive it to the well bores.

The reserve data herein were computed by estimating porosities, interstitial water (connate), and the formation volume factor. The detailed method used for porosity estimates is explained earlier in the report. A study of Bartlesville sand core data and bottom-hole analyses from nearby areas was used as a guide in establishing an estimate of 30 percent connate water and a formation volume factor of 1.18.

Table 3 indicates residual reserve estimates by quarter sections. Table 4 is a recapitulation of data from table 3, and the data compiled therein are representative of the field. As can be seen from table 4, it is estimated that of the original 73,669,000 barrels of oil in place (corrected to standard conditions) only 10.3 percent or 7,566,000 barrels has been recovered to date. This leaves approximately 66,103,000 barrels of oil in the reservoir, or 90 percent of the original reservoir oil content.

Table 5 shows oil production and residual oil reserve data of the three best productive areas presented on plate 7. Area 1, consisting of 400 acres, has produced to January 1, 1944, a total of 3,534 barrels per acre, or 16.4 percent of its original reservoir oil content of 21,603 barrels per acre. This leaves an estimated residual oil content of 18,069 barrels per acre. Area 2 has recovered 2,402 barrels per acre from 1,000 acres, or 12.5 percent of its original per acre reservoir oil content of 19,147 barrels. The estimated residual oil content amounts to 16,745 barrels per acre. Area 3 embraces 1,775 acres and has produced 1,453 barrels per acre, or 10.2 percent of its original reservoir oil content of 14,271 barrels per acre. This leaves an estimated residual oil content of 12,818 barrels per acre.

Plate 14 is a sand body condition map which defines the more favorable areas that could be expected to respond to secondary recovery, particularly water-flooding. A detailed explanation of the map is given earlier in this report. With reference to this map, area 1 has more favorable sand body conditions than area 2, which in turn has more favorable sand body conditions than area 3.

Following is the recoverable oil estimates for area 1 and area 2 by water-flooding.

Area 1

Area in acres	1,393
Estimated recoverable oil, bbl. per acre	3,500
Estimated recoverable oil, bbl.	4,875,000

Area 2

Area in acres	2,248
Estimated recoverable oil, bbl. per acre	2,500
Estimated recoverable oil, bbl.	5,620,000
Estimated recoverable oil, bbl., (area 1 and area 2)	10,495,000 barrels

The oil recovery from an active water-flood, approximately three miles east of the Hogshooter field, is shown in table 7.

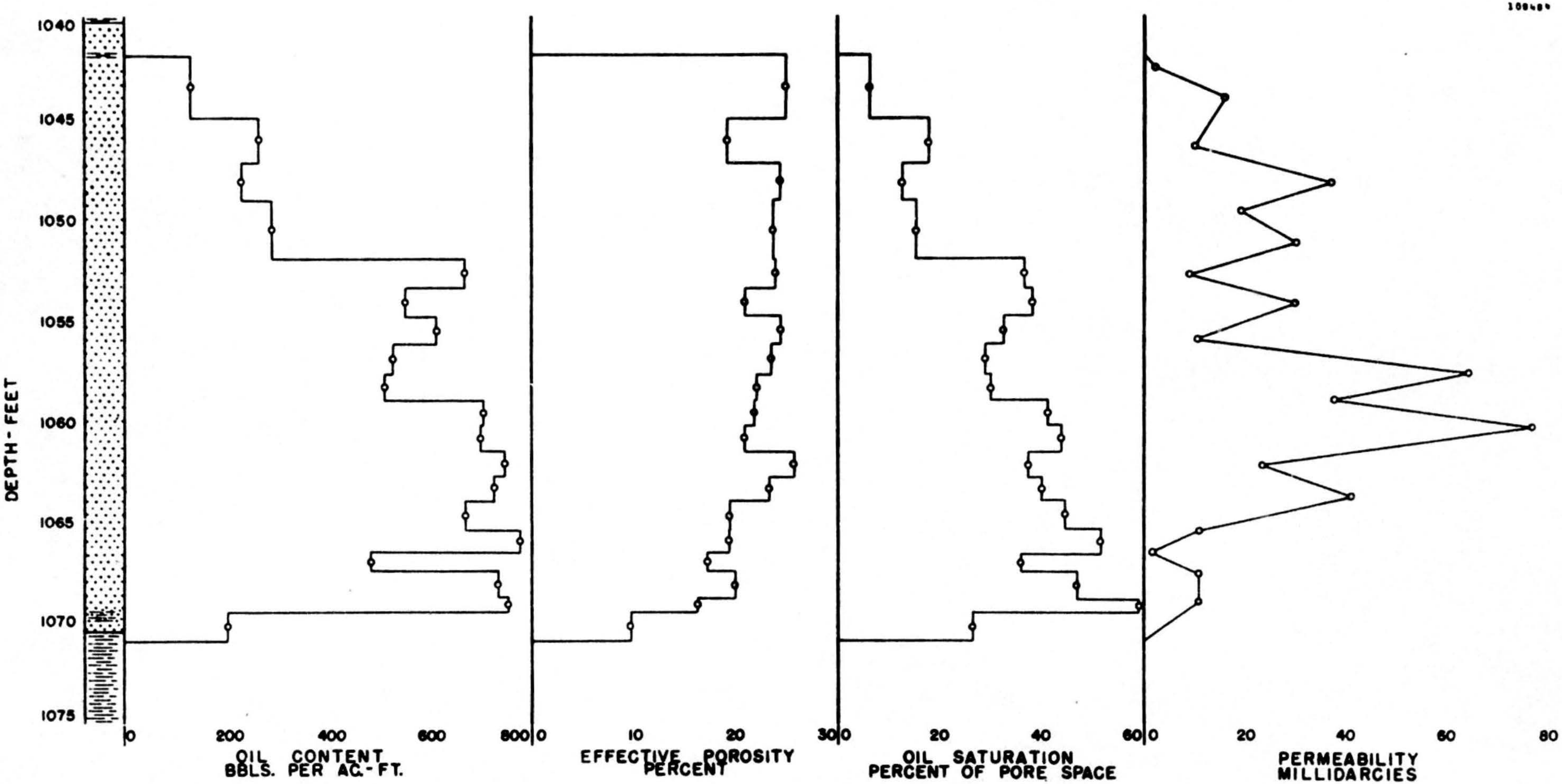
Table 7.
Flood Property in sec. 36, T. 26N., R. 14E.

Date	Acres Flooded	Input wells	Oil wells	Cumulative Oil recovery bbl. per acre	Cumulative Water-oil ratio
Jan. 1, 1938	5	4	1	0	0
" 1939	5	4	1	1,154	19.1
" 1940	20	10	2	1,380	9.5
" 1941	40	12	8	1,592	9.1
" 1942	50	15	12	2,141	9.2
" 1943	65	15	14	2,260	9.8
" 1944	75	18	17	2,420	10.0

Total oil production to January 1, 1944 . . . 181,202 bbl.
Total injected water to January 1, 1944 . . 1,812,000 bbl.

Owing to the proximity of the properties to the Hogshooter field, summary data on the following 4 cores from wells approximately 3 miles from the field are presented in table 8.

Plate 16 (core 4, table 8) is a core analysis from the "flood" property in sec. 36, T. 26N., R. 14E.



TOTAL OIL CONTENT:
NON-FLOODABLE (ABOVE 1052') = 2,248 BBLS.
FLOODABLE (1052'-1069.5') = 11,911 BBLS.

BARTLESVILLE - SAND CORE ANALYSIS
FROM
SEC. 36, T. 26 N.- R. 14 E.
APPROXIMATELY 3 MILES EAST OF HOGSHOOTER FIELD

PLATE 16.

It is not to be inferred that the specific core data in table 8 represent the identical physical characteristics of the Bartlesville sand in the Hogshooter field.

Table 8.

Core	Total sand, feet	Floodable sand thickness, feet	Average porosity, percent	Average permeability, Md.	Oil reserves, bbl. per acre-ft.	Oil saturation, percent
1	12.7	8.9	17.0	18.2	420	35.0
2	30.5	24.9	19.0	31.9	486	27.6
3	23.4	20.4	18.3	41.5	430	29.5
4	29.0	17.5	21.5	30.0	624	39.6

For all practical purposes the Bartlesville sand of the Hogshooter field has reached its primary producing economic limit. Some of the operators live in the field and have a livelihood and partial source of income other than from oil. Approximately 75 percent of the present daily oil production is being produced from less than 50 percent of the present producing wells by an operator who is injecting a small amount of repressure gas. It is believed that were it not for these existing conditions, all of the Hogshooter Bartlesville sand producing wells would have already been plugged and abandoned. The recovery of oil under the present operating practice is expected to be quite small in comparison with expected recoveries under a sound water-flooding project.

GAS RESOURCES

The gas-productive zones of the Hogshooter field do not offer a source of gas reserve sufficient in volume for any sizable gas-repressuring project. The once prolific Burgess gas sand has been depleted, and records of recent wells testing this sand have reported water from the Burgess sand filling the hole to within a few hundred feet of the surface.

As of January 1, 1944, three productive gas wells were reported, all of which produced from zones other than the Burgess. One well was producing from the Tucker sand zone, which is below the Bartlesville sand and above the Burgess sand, and the gas produced from the Tucker sand is injected into the Bartlesville sand as a means of local gas-repressuring.

The other gas wells are producing from the "Chat" formation, which is at the top of the "Mississippi Lime" and directly under the Burgess sand. These wells, completed in 1937, had an initial open-flow capacity of 1,500,000 to 2,000,000 cubic feet of gas per day. Some of the gas from these wells is being injected into the Bartlesville sand.

As of January 1, 1944, there was available for fuel and lease operations approximately 10,000,000 cubic feet of gas per month. This gas is produced in and near the Hogshooter area and its market value is approximately 6 cents per thousand cubic feet.

In addition, there is a high-pressure gas line along the north edge of the field, operated by a major oil company, which offers a possible source of purchased gas for use in future field operations.

WATER RESOURCES FOR FLOODING

Surface Water.

Surface supplies have some advantages over subsurface salt water supplies, mainly because they are less corrosive. The main disadvantage of the surface supply, particularly a river supply, is that the treatment changes frequently with the change of the water chemical content as well as the turbidity. Thus stream or river supplies require constant supervision. However, the cost of producing river supplies is usually much less than the cost of drilling water wells, unless an ample supply of water can be obtained at depths of only a few hundred feet.

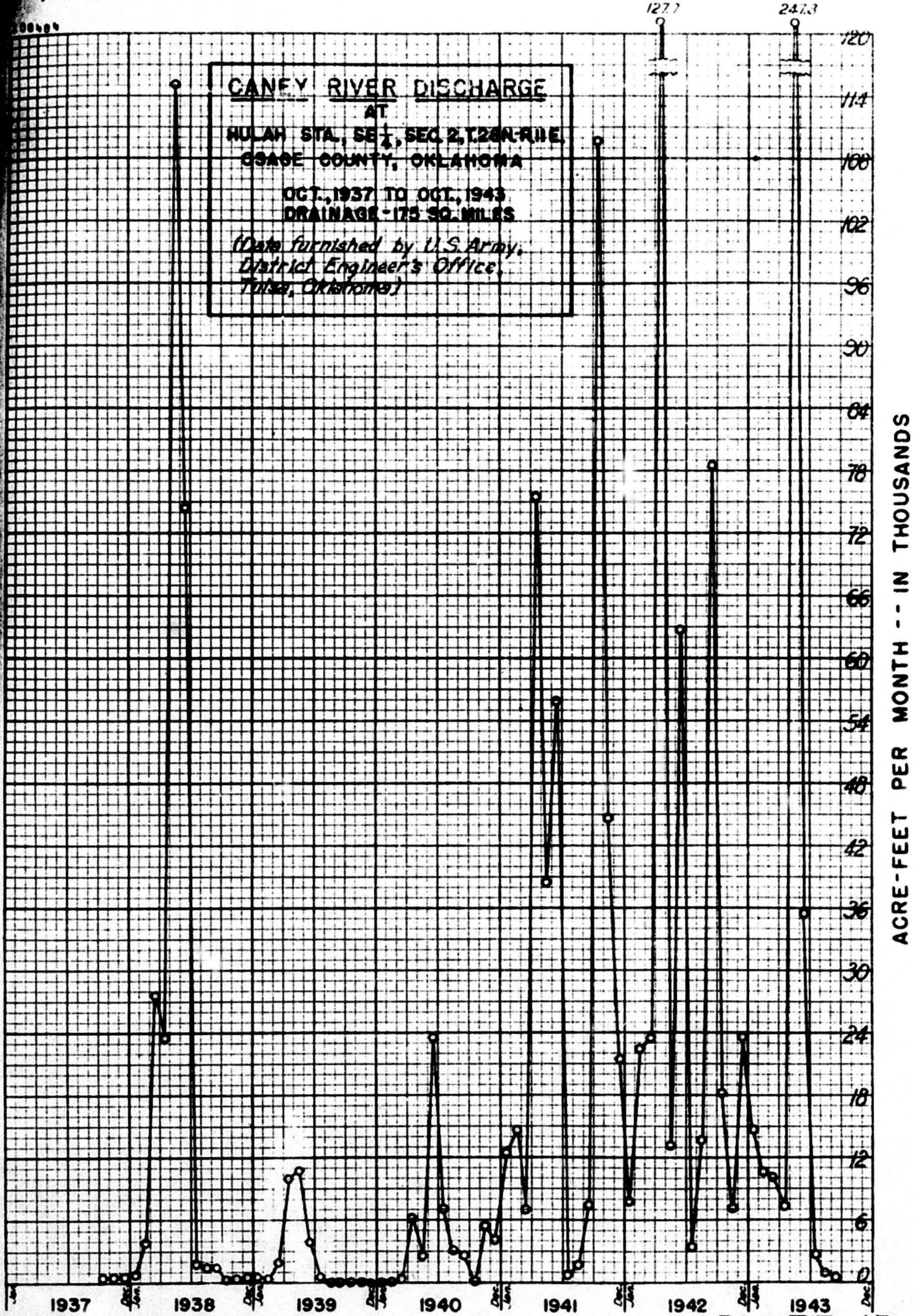
Relative to a stream supply for the Hogshooter field, the most feasible source is believed to be the Caney River which flows southward along the west side of Washington County to the center of sec. 12, T. 25N., R. 13E., and thence southeastward across Washington County. The nearest contact with the Caney River from the common township corner (Tps. 25 and 26N. and Rs. 13 and 14E.) is near the NE¼NW¼NW¼ sec. 23, T. 25N., R. 13E., which is a distance of approximately 3½ miles.

The Caney River discharge measurements from 1937 to 1943 inclusive, given in table 9, were furnished through the courtesy of the U. S. Army Engineers' Office, Tulsa, Oklahoma. The Caney River discharge profile, as shown by plate 17, illustrates the erratic flow of the stream during the seasonal periods of the year.

The monthly requirement of 10 quarter sections under flood (330 ft. water well to water well/5 spot pattern/50 bbl. water per well per day) is 128 acre feet. The following list shows the number of months with flows less than 2½ times the required water volume given above:

Date	Months
1937 data for only 3 months	0
1938	3 in sequence
1939	5 " "
1940	4 " " 3 mo.
1941	0
1942	0
1943 data for 1st 9 mos.	0

The preceding table shows that flood properties, as outlined above, would have required auxiliary storage in 1938 amounting to a 3 months' supply; in 1939, a 5 months' supply, and in 1940, a 3 months' supply. A 30- or even 60-day auxiliary storage supply would not be prohibitive, but



CANEY RIVER DISCHARGE
AT
HULAH STA., SE 1/4, SEC. 2, T.28N-R11E.
OSAGE COUNTY, OKLAHOMA
OCT., 1937 TO OCT., 1943
DRAINAGE - 175 SQ. MILES
(Data furnished by U.S. Army, District Engineer's Office, Tulsa, Oklahoma)
127.7
247.3
120
114
108
102
96
90
84
78
72
66
60
54
48
42
36
30
24
18
12
6
0
ACRE-FEET PER MONTH -- IN THOUSANDS
Jan.
Dec.
1937
1938
1939
1940
1941
1942
1943

PLATE 17.

Table 9.
Caney River Discharge at Hulah Station
Sec. 2, T. 28N., R. 11E, Osage County, Oklahoma
Drainage basin 175 square miles
(Discharge rate given in acre-feet per month)

Month	Year 1937	1938	1939	1940	1941	1942	1943
January		887	321	0	12,450	7,970	14,980
February		3,920	284	24	14,830	22,460	10,870
March		27,540	1,970	50	7,000	23,560	10,160
April		23,640	9,990	6,010	75,440	127,700	7,250
May		115,210	10,700	2,750	38,500	13,180	247,300
June		74,390	3,970	23,450	55,910	62,890	35,780
July		1,880	549	7,000	873	3,430	2,980
August		1,460	38	3110	1,710	7,830	1,020
September		1,400	0	2,790	7,410	78,730	432
October	300 (24 days)	127	0	0	109,700	18,200	
November	305	236	0	5,530	42,830	7,180	
December	662	256	0	4,140	21,500	23,760	

the river record does not show this possibility. These records probably will preclude the Caney River from consideration as an ample source of water for flooding the Hogshooter field. However, if any river pump station installation should become feasible in the future, the investment would include a motor driven centrifugal pump and 3½ miles of pipe line. The pumping equipment would be housed in a water proof well in the river bed.

Conditions assumed in making the cost estimate:

Water requirements for flooding 10 quarter sections, ("five spot" pattern, 330 foot well spacing), bbl. per day	40,000
Static head, feet	100
Friction head for 3½ miles of pipe, feet	103
Total head, feet	203
Theoretical liquid horsepower	61
Efficiency, percent	61
Actual horsepower required	100

Estimated Installation Costs

(1)	3½ miles 12-inch dia., 27 pound pipe @ $75 per ton(new)	$18,750
(2)	Motor and pump (new)	1,500
(3)	Well housing for pumping equipment	1,500
(4)	Laying pipe and backfilling ditch	8,000
	Total Cost	$29,750

Note: The above estimate assumes that electric power is available.

In connection with impounding surface waters in earthen reservoirs, soil samples from sec. 2, T. 25N., R. 13E., and sec. 17, T. 25N., R. 14E., were examined and found suitable for this purpose.

Subsurface Water

Many of the Hogshooter logs show water in the sands above the Bartlesville, but the information is not sufficient to evaluate or measure the water from these sands.

In sec. 7, T. 25N., R. 14E., two wells were drilled into water in the Burgess sand at a depth of approximately 1400 feet, and the water filled the hole to within 200 feet of the surface. It is quite possible that the Burgess in restricted areas is capable of furnishing considerable water for flooding.

Below the Burgess the Arbuckle lime is found at an approximate depth of 1700 feet, and in northeastern Oklahoma the Arbuckle usually carries water under considerable head.

A few miles east of the Hogshooter field (sec. 36, T. 26N., R. 14E.) a well drilled to the Arbuckle lime encountered water in the top of the Arbuckle at a depth of 1706 feet, and this well pumps 2,200 barrels per day with a constant fluid level of 1560 feet. This water is used for flooding an 80-acre Bartlesville sand property. Sufficient Arbuckle water has also been reported for the Nowata district.

On the basis of records at hand, the Arbuckle appears to be the most dependable source of water for flooding the Hogshooter field. As the top of the Arbuckle is an erosional unconformity of major proportions the chances of not finding water in the Arbuckle are remote. In this region, the salt water of the Arbuckle usually carries hydrogen sulfide, and objections to this water have been raised because of its corrosive nature. However, this objection is not unsurmountable as conventional treating methods are available and the water reacts favorably to chemical treatment. Furthermore, in sec. 36, T. 26N., R. 14E., Arbuckle lime water which contains some hydrogen sulfide has been used for several years on a water flood project.

The following plan of obtaining Arbuckle water in the Hogshooter field and the estimated costs were obtained from a large operator who at the present time is actively engaged in deepening and reconditioning old wells on his property. The suggestion in outline form is that the old 6 5/8-inch pipe in Bartlesville wells selected for deepening to the Arbuckle be pulled; 8-inch hole then be reamed down from the surface to the old total depth; the old shot hole in the Bartlesville be cleaned out and new hole with a cable-tool 8-inch bit be drilled to the Arbuckle, which should be found at a depth of approximately 1700 feet in the Hogshooter field. If water is found in the Burgess the well can be completed at that depth. If the Burgess later fails to furnish sufficient water, then the same hole can be carried on to the Arbuckle lime. The next step would be the setting of good used 6 5/8-inch casing at the top of the Burgess, or in the "Mississippi Lime", followed by cementing the string to the surface. A casing pump and a conventional surface pumping unit would be installed.

Relative to the pulling of this old pipe, the chances of success or failure are considered to be about equal, particularly so, if the old Bartlesville wells still have some surface pipe in the well. Also, in case of a twist-off or other trouble the operator can probably afford to spend an additional $500 before abandonment, as many of these troublesome holes are successfully handled at these depths within this range of additional cost.

Estimated Costs of Reconditioning Old Bartlesville Well and Deepening to the Arbuckle:

(1)	Pulling 1050-1100 feet of old 6 5/8 inch pipe	$225.00
(2)	Reaming hole from surface to top of old shot-hole and cleaning out old hole	140.00
(3)	New hole to top of Arbuckle (600 feet @ $1.50 ea.)	900.00
(4)	Used casing (good condition), 6 5/8 inch, (1700 feet @ 60¢ per foot). Note: Only 1400 or 1500 feet of casing if set in the "Mississippi Lime".	1020.00
(5)	Running above 6 5/8 inch casing	116.00
(6)	Cementing	472.00
(7)	Casing pump for 6 5/8 inch casing	500.00
(8)	Rods (700 feet)	170.00
(9)	Pumping unit (jack and prime mover)	2500.00
(10)	Foundation and miscellaneous items	500.00
	Total	$6463.00

Rating the water production from the Arbuckle at 2000 bbl. per day, per well, a quarter section flood property will require 2 wells at a total cost of around $13,100. The next item included in water cost is the water treating plant.

Water Treating Plant

For a small plant handling only 3,000 to 4,000 barrels of water per day, using new equipment, the estimated cost for installation is approximately $6.25 per barrel per day capacity. The cost of a larger water treating plant, handling approximately 40,000 barrels of water per day, would probably be close to $75,000 or only $1.87 per barrel per day plant capacity.

Essentially the equipment of a water treating plant consists of the following: settling tanks, chemical dry-feeder machines, filters, back-wash pumps, and high pressure pumps that serve the in-put wells,

The individual operator who has access to good used equipment will materially lower this estimated cost of a 3,000 to 4,000 barrel per day plant. Partial water analyses of Arbuckle lime water are shown as follows:

Arbuckle Water Analyses

District	Nowata, Okla.	Claremore, Okla.
Calcium (Ca)	903 Ppm	1,939 Ppm
Magnesium (Mg)	502 "	712 "
Alkalis (Na-K)	10,625 "	16,982 "
Chloride (Cl)	19,080 "	31,320 "
Sulfate (SO_4)	51 "	99 "
Bicarbonate (HCO_3)	574 "	531 "
Total	31,735 Ppm	51,583 Ppm
Hydrogen sulfide	present	109 Ppm

Pm, - parts per million

SUMMARY

(1) On the basis of 40,000 barrels of water per day (10 quarter sections under flood) it is noted that the investment necessary to procure this supply from the Arbuckle lime is approximately $130,000, whereas if the Caney River supply were adequate, the cost of procuring this amount of water would be about one-fourth of that sum. Water treating plant costs are in addition to the investment necessary to obtain the water supply.

(2) Experience in the Hogshooter field may very well prove the Burgess sand as an ample source of water.

(3) Examination of the Nowata Quadrangle topographic sheet indicates the possibility of an impounded water supply. For example, a possible

dam site is indicated at or near the northwest corner of sec. 21, T. 26N., R. 14E., and sketching in the divides of the Hogshooter Creek ravines, north of this location, gives a water shed of 22 sections. The Hydrology Division of the United States Army Engineers' Office should be consulted relative to precipitation, run-off, and possible impounding areas of this region.

(4) Several flood operators of northeastern Oklahoma have been hampered because of water shortage and the same trouble has been reported for some southeastern Kansas water-flood projects.

DEVELOPMENT AND OPERATING PRACTICE

Conventional cable tool drilling methods were practiced in all development operations in the Hogshooter field. An $8\frac{1}{4}$-inch conductor pipe was set at approximately 30 feet to exclude surface waters. Full hole was drilled to within 100 feet of the top of the producing oil formation, where the hole was reduced and the $6\frac{1}{4}$-inch casing landed. Drilling was continued to the Bartlesville sand through open hole and extended below the sand to form a pocket for cavings. In some instances water has been reported in the Oswego lime, above the Bartlesville sand, but the influx of water into the hole has not been sufficient to cause drilling difficulties. The oil string was set according to early practice without the use of cement behind the pipe. The producing sand was shot with 100 to 110 quarts of nitroglycerine and the wells were produced through 2-inch standard tubing often run with a burlap or "bootleg" packer. Drilling and completion time for a well required about seven days.

Well spacing in the Bartlesville sand has been varied. Many leases have been completely developed; however, on others the line wells only have been drilled. In general, the line wells have been drilled approximately 150 to 200 feet from the property line and the original well spacing closely approaches one oil well to 6.4 acres for the field as a whole.

The leases are still produced in accordance with conventional shallow oil field practice. Multiple pumping by jack line from gas engine driven central powers is resorted to on all leases. The oil production on the majority of the currently operated leases has been stimulated by gas repressuring, to a minor degree, under present-day operations. In some cases considerable operating difficulty is experienced by the entrance of water from formations above the Bartlesville sand through holes in the casing caused by the corrosive action of these waters. To maintain normal oil production, the wells are pumped sufficiently to lower the water head and prevent interference with the gravity drainage of oil to the well. However, when pumping does not remedy the existing condition, it becomes necessary to shut off the water, or abandon the well. When the casing can be pulled successfully, a few sections of new pipe inserted in the casing string can sometimes complete the shutoff and restore the well to a normal operating condition. Inasmuch as the wells are often lost when the casing is pulled, some operators resort to the use of a smaller string of pipe, such as 5 3/16-casing or 4-inch line pipe with a packer installation, in order to complete successfully a water shutoff. Shutting off the water and cleaning out frequently return the well to profitable production.

WATER-FLOOD DEVELOPMENT PRACTICE

The common spacing pattern for water-flooding projects in Oklahoma is the "five spot" arrangement of wells wherein 4 intake water wells are drilled in the form of a square with a producing well located in the center. This pattern, when used on a 160-acre tract, gives a ratio of one water well to one oil well. In most of the present water-flooding projects in northeastern Oklahoma, the distance between like wells is 330 feet. However, 440-feet spacing between like wells is used on a few projects. Depth is a very important factor in determining the distance between wells. A spacing distance of 440 feet between like wells is used on some present Bartlesville sand water-flooding projects with sand depths comparable to Hogshooter.

Two methods are used in producing a water-flooding project: the "delayed drilling," or flowing method; and the pumping method. Operators, desiring to flow their production, drill the water intake wells first. The oil wells are drilled after the reservoir pressure has reached the necessary magnitude to result in natural flow. Flowing water-floods result in lower development cost; however, there is difference in opinion as to which method of production will result in the greater recovery. Some successful water-flood operators use the "delayed drilling" or flowing method, whereas others pump their production by jack lines from central powers, or by individual pumping units at the well.

The general procedure followed in drilling and completing a water-intake well is to set about 30 feet of surface casing. In many cases, when the hole is drilled to the desired depth it is shot with nitro-glycerine and a string of 1½-or 2-inch tubing is run in conjunction with either a burlap or a standard type flood packer, and cemented. It is common practice to set a left-hand thread nipple in the 1½- or 2-inch tubing string above the top of the cement. Recovery of almost the entire tubing string at time of abandonment is thus facilitated. No other casing is used except where it is necessary in drilling the well. In such instances the casing is pulled after the well has been equipped with tubing.

Flowing oil wells are completed and equipped in the same manner as a water-intake well, that is, without a production string of casing. Pumping wells are equipped with casing set on top of the oil sand, and produced through a 2-inch producing string.

ECONOMICS OF WATER-FLOODING

Water-flood projects, as previously mentioned, have varied widely in well spacing, but it has been the common operating practice to conform to a "pattern" type of layout. The most widely accepted form of "pattern" arrangement, mainly because of the ease of adaptation to the diversities of lease ownerships, has been the typical "five-spot" pattern. Moreover, the plan presents the opportunity for drilling and operation of joint interest wells along property boundary lines. These line wells will effect the recovery of additional quantities of oil from the sand reservoir which otherwise would remain unaffected by the water drive. It is further presumed that the "five-spot" pattern type of flood will conform to the operational and economic conditions of the Hogshooter field.

The estimates of recoverable oil reserves from areas 1 and 2 (see pl. 14) in the Bartlesville sand by water flooding are not precise, but expectancy will depend entirely upon prevailing sand conditions and the percentage of oil and water saturation present in the sand reservoir under a particular property. In the main the existing physical characteristics of the reservoir will require confirmation by cores and subsequent core analyses prior to establishment of definite recovery estimates from the two areas considered.

A cost analysis and valuation of a hypothetical water-flood in the field, comprising 160 acres and developed on a spacing of 440 feet between like wells, is presented in table 10. Preliminary estimates of expectancy are of the order of 3,500 barrels per acre for area 1 and 2,500 barrels per acre for area 2. It is estimated that the life of such a flood will not exceed 8 to 10 years, assuming that production will cease when the water-oil ratio reaches a stage where it is economically infeasable to continue operations.

The estimates given in table 10 by no means imply that the values will apply to any particular lease in the field, but are presented mainly to illustrate the relative costs of development and profits involved in a water-flood property under normal operating practices in the Hogshooter field. However, the values are considered to be applicable to areas 1 and 2 as a whole, and are comparable to other successfully developed water-floods in northeastern Oklahoma. Moreover, water-flood development costs vary somewhat with particular operators, and it is not unusual for the cost per acre of water-flood development to show variation, although the basic methods of operation are similar.

With reference to table 10, the profits derived by operational methods of pumping the oil wells in area 1 are very marginal, in comparison to the profitable income per acre attained by operation involving flowing methods. In area 2, profitable water-flood development is restricted to flowing operations at the current market price of crude oil. However, a minimum increase of 45 cents per barrel in

TABLE 10

VALUATION OF HOGSHOOTER WATER-FLOOD PROPERTY
(Based on 160 acre flood project - "5 spot" pattern - 440' x 440' W-W)

	AREA 1.				AREA 2.			
	Pumping Oil Wells		Flowing Oil Wells		Pumping Oil Wells		Flowing Oil Wells	
	New Equip.	Salvage Equip.	New Equip.	Salvage Equip.	New Equip.	Salvage Equip.	New Equip.	Salvage Equip.
A. COST OF DEVELOPMENT								
Investment (Per acre basis)								
Drill and complete 37 water input wells	$ 510	$ 480	$ 510	$ 490	$ 510	$ 490	$ 510	$ 490
Drill and complete 36 oil producing wells	770	590	505	460	770	590	505	460
Production equipment, (pumping or flowing eqpt., tanks, lines, etc.	130	95	75	60	130	95	75	60
Plant investment, (water system, pumps, treating eqpt., etc.)	200	180	200	180	200	180	200	180
	1,610	1,345	1,290	1,190	1,610	1,345	1,290	1,190
Less salvage value on proposed installation	80	35	35	20	80	35	35	20
Net cost of development	1,530	1,310	1,255	1,170	1,530	1,310	1,255	1,170
Operating (Per acre basis)								
Operating cost, (lifting, reconditioning, plant, treating, etc.)	1,295	1,295	1,080	1,080	1,295	1,295	1,080	1,080
Total development and operation cost	2,825	2,605	2,335	2,250	2,825	2,605	2,335	2,250
B. ESTIMATED INCOME FROM WATER-FLOODING								
Gross oil recovery, bbl. per acre	3,500	3,500	3,500	3,500	2,500	2,500	2,500	2,500
Less one-eighth royalty, bbl. per acre	438	438	438	438	313	313	313	313
Net oil recovery bbl. per acre	3,062	3,062	3,062	3,062	2,187	2,187	2,187	2,187
Gross income, per acre ($1.13 per bbl. less 5% gross prod. tax)	3,289	3,289	3,289	3,289	2,349	2,349	2,349	2,349
Net income (profit), per acre	464	684	954	1,039	-476	-256	14	99
Estimated profit or loss, 160 acres water-flood project	$ 74,240	$109,440	$152,640	$166,240	-$76,160	-$40,960	$ 2,240	$ 15,840

the present crude price structure would place area 2 on an equitable income status comparable to that of area 1. The income-producing status of the two areas, when considered as a whole, is quite marginal and any upward revision of the present crude price would place prospective water-flood development in the Hogshooter field in a more favorable position.

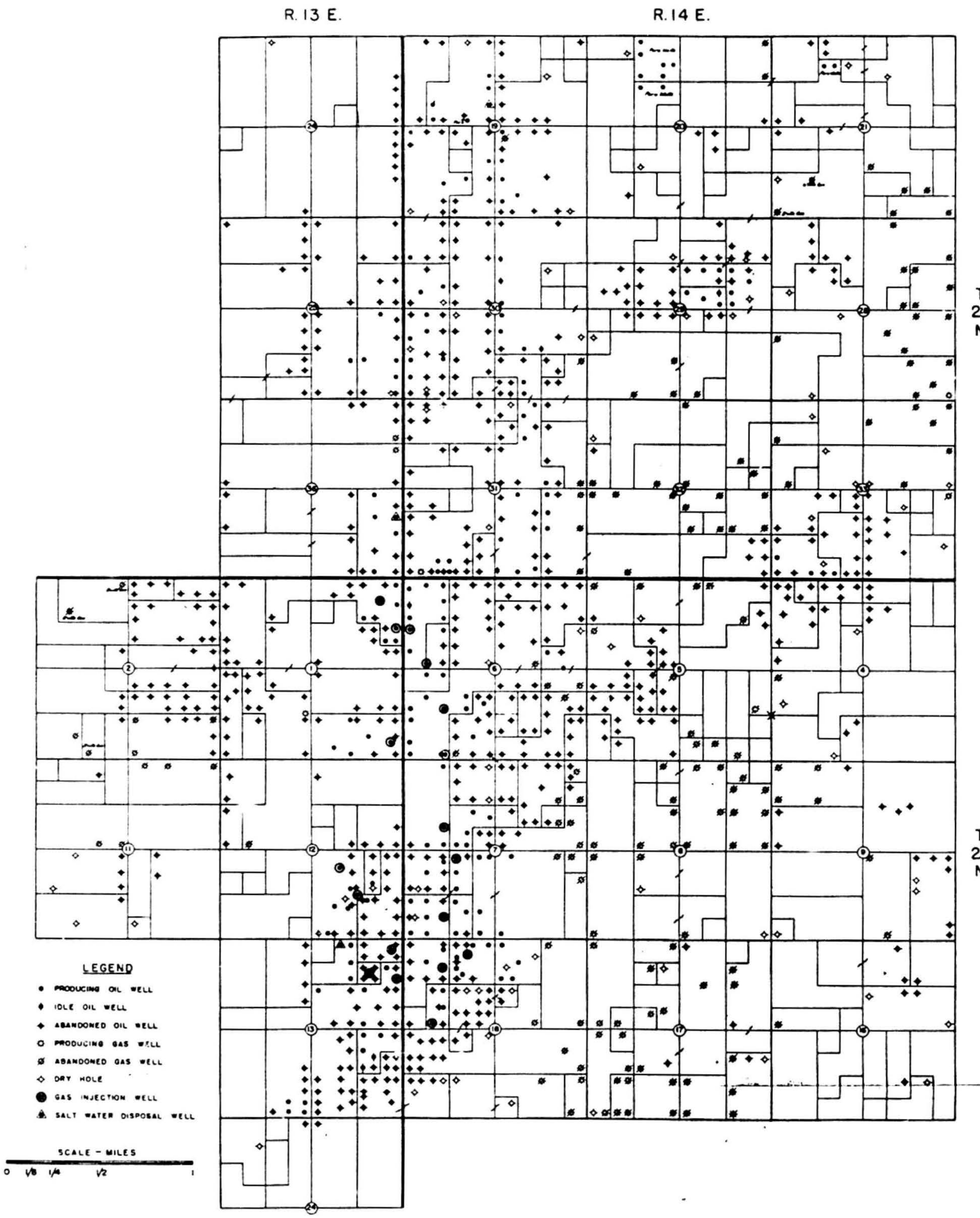
Furthermore, at the current market price of crude oil, the reserves of the Hogshooter field recoverable by profitable water-flooding are estimated to be approximately 4,875,000 barrels. The previously postulated increase in price of crude of 45 cents per barrel would place area 2 in the profitable flooding venture class, and increase the recoverable reserves by 5,620,000 barrels, for a total reserve of 10, 436,000 barrels recoverable by water-flooding in the field.

CONCLUSION

The production history of the Hogshooter field illustrates clearly the results of inefficient operating practices. Prevailing methods of uncontrolled withdrawal during the rapid early field development were responsible for the early exhaustion of reservoir energy, and resulted in only moderate recovery of oil even from the better sand areas, of the field, whereas the residual oil remaining in the reservoir is as much as half of the available reservoir void space.

Attempts to stimulate production by application of vacuum and air or gas-repressuring have resulted in marginal financial returns in relation to the investment involved. However, the residual reservoir oil represents a large oil reserve of which it is believed much can be recovered by other methods of secondary recovery, particularly water-flooding. Certain areas of the field indicate very favorable water-flooding conditions, and it is believed that oil production in such areas will respond readily to water-flooding.

45-37



UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
CONSERVATION BRANCH — OIL AND GAS LEASING DIVISION
MID-CONTINENT DISTRICT

DEVELOPMENT MAP OF
HOGSHOOTER FIELD
WASHINGTON COUNTY, OKLAHOMA

M. C. NO. SP 1401

APRIL 1944

PLATE 2.

45-37

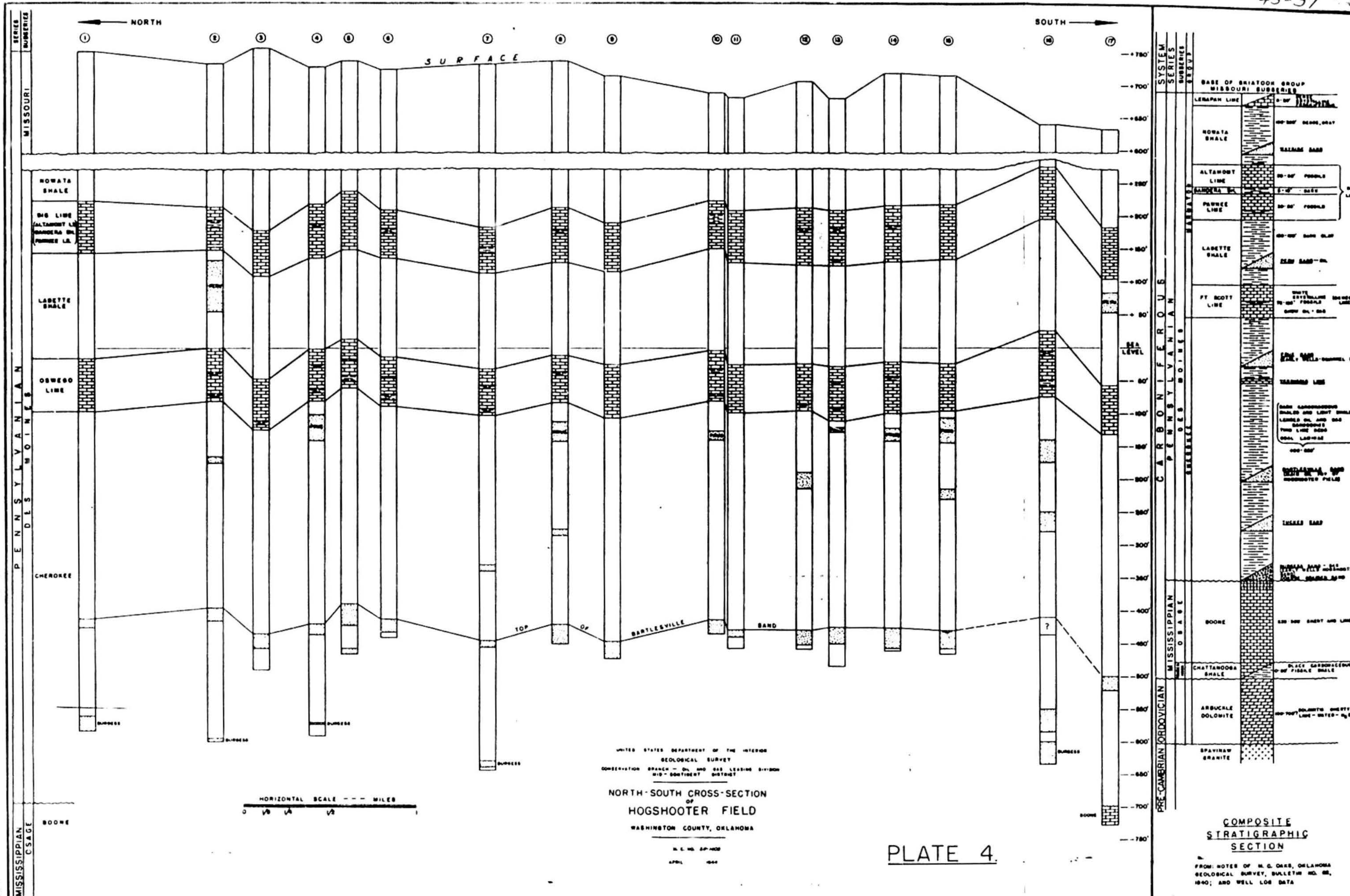
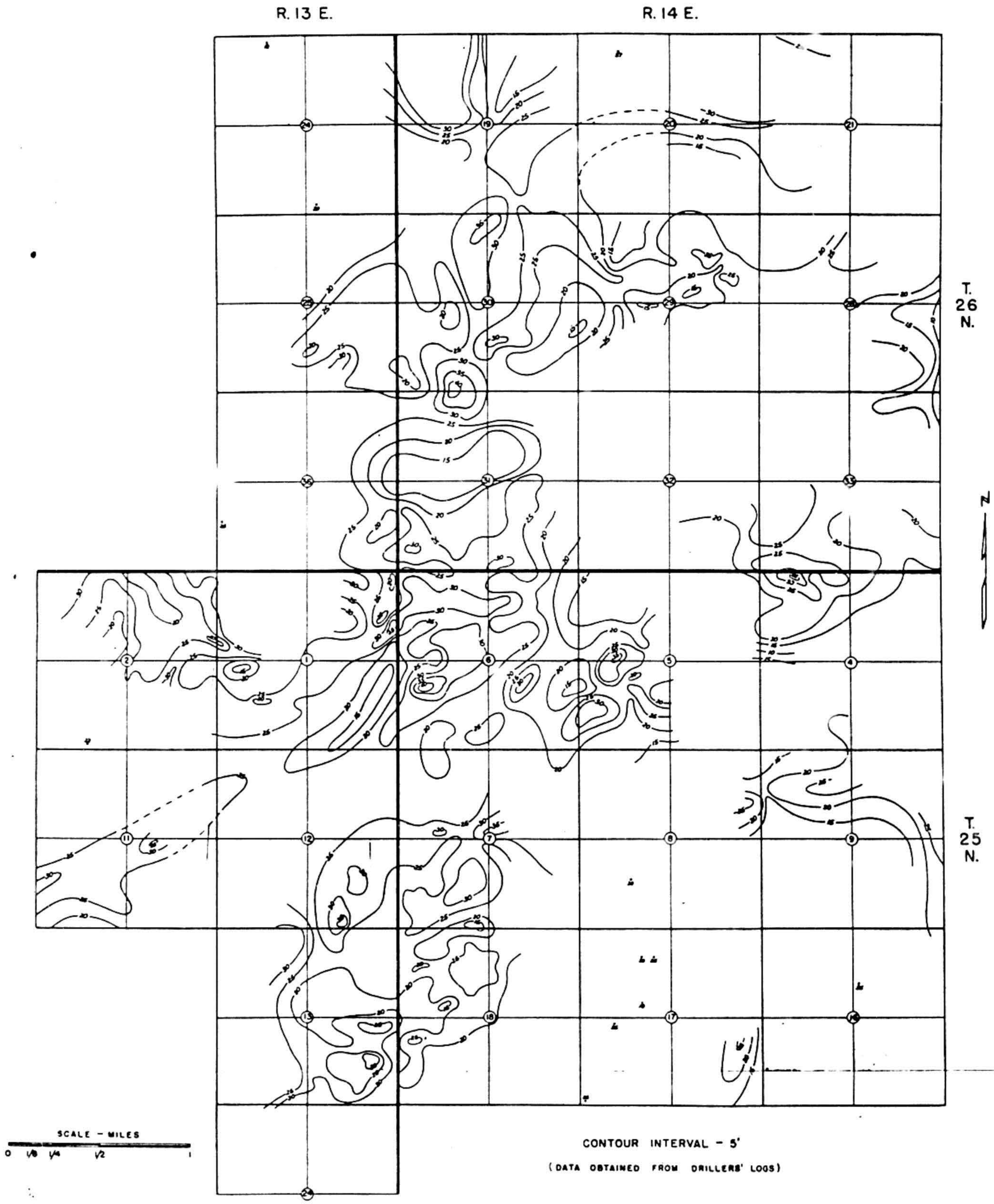

NORTH
SOUTH
SURFACE
SERIES
SUBSERIES
MISSOURI
PENNSYLVANIAN
DES MOINES
NOWATA SHALE
BIG LIME (ALTAMONT LS. BANDERA SH. PAWNEE LS.)
LABETTE SHALE
OSWEGO LIME
CHEROKEE
MISSISSIPPIAN
OSAGE
BOONE
SEA LEVEL
TOP OF BARTLESVILLE SAND
BURGESS
HORIZONTAL SCALE --- MILES
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
CONSERVATION BRANCH — OIL AND GAS LEASING DIVISION
MID-CONTINENT DISTRICT
NORTH-SOUTH CROSS-SECTION OF HOGSHOOTER FIELD
WASHINGTON COUNTY, OKLAHOMA
APRIL 1944
SYSTEM
SERIES
SUBSERIES
GROUP
BASE OF SKIATOOK GROUP MISSOURI SUBSERIES
LENAPAH LIME
NOWATA SHALE
ALTAMONT LIME
BANDERA SH.
PAWNEE LIME
BIG LIME
LABETTE SHALE
FT. SCOTT LIME
CARBONIFEROUS
PENNSYLVANIAN
DES MOINES
MARMATON
CHEROKEE
BOONE
CHATTANOOGA SHALE
ARBUCKLE DOLOMITE
SPAVINAW GRANITE
ORDOVICIAN
PRE-CAMBRIAN
COMPOSITE STRATIGRAPHIC SECTION
FROM: NOTES OF M. C. OAKS, OKLAHOMA GEOLOGICAL SURVEY, BULLETIN NO. 62, 1940; AND WELL LOG DATA

PLATE 4.



UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
CONSERVATION BRANCH — OIL AND GAS LEASING DIVISION
MID-CONTINENT DISTRICT

ISOPACH MAP OF BARTLESVILLE SAND HOGSHOOTER FIELD

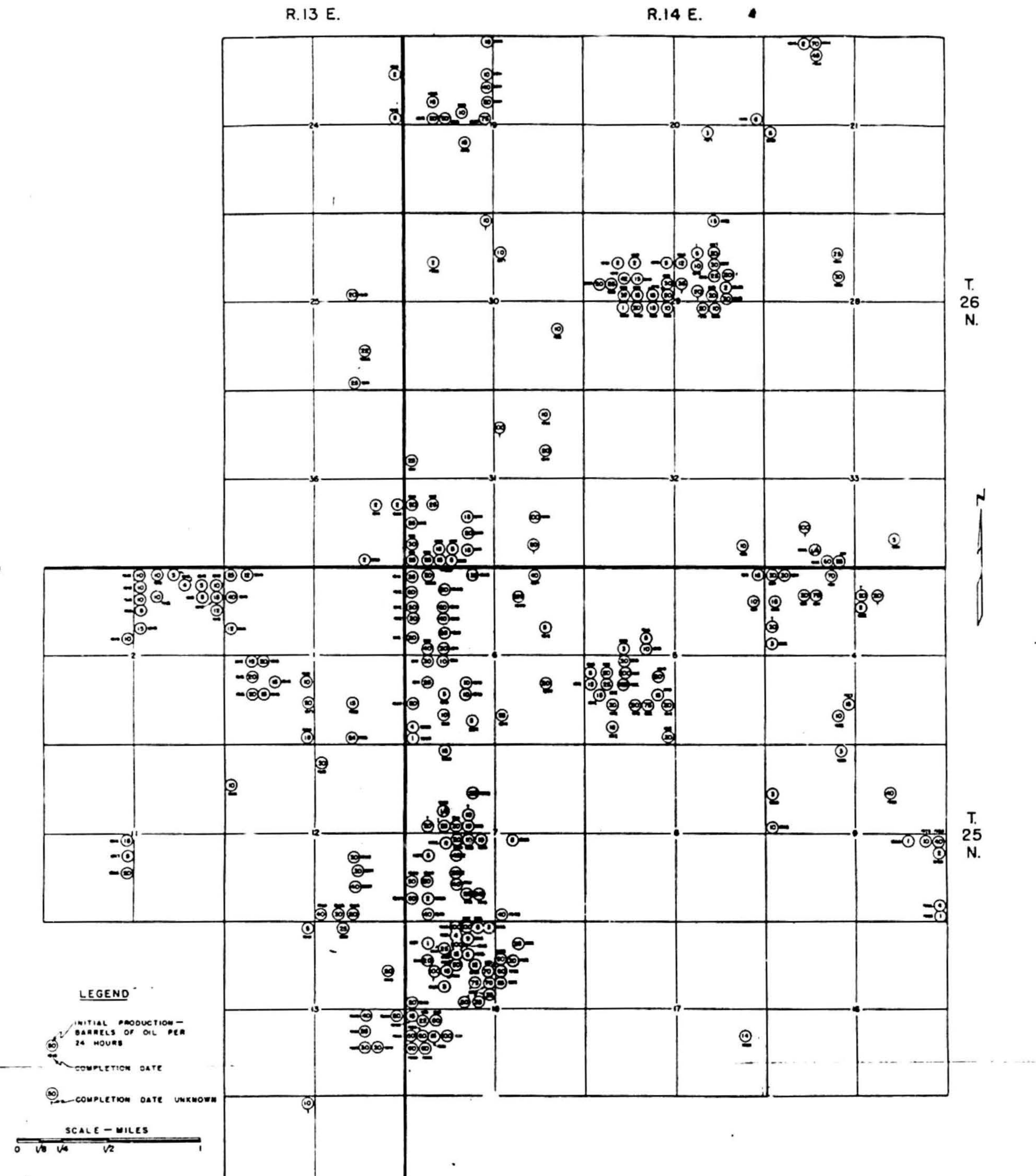
WASHINGTON COUNTY, OKLAHOMA

M. C. NO. 3P-1403

APRIL 1944

PLATE 5.

45-37



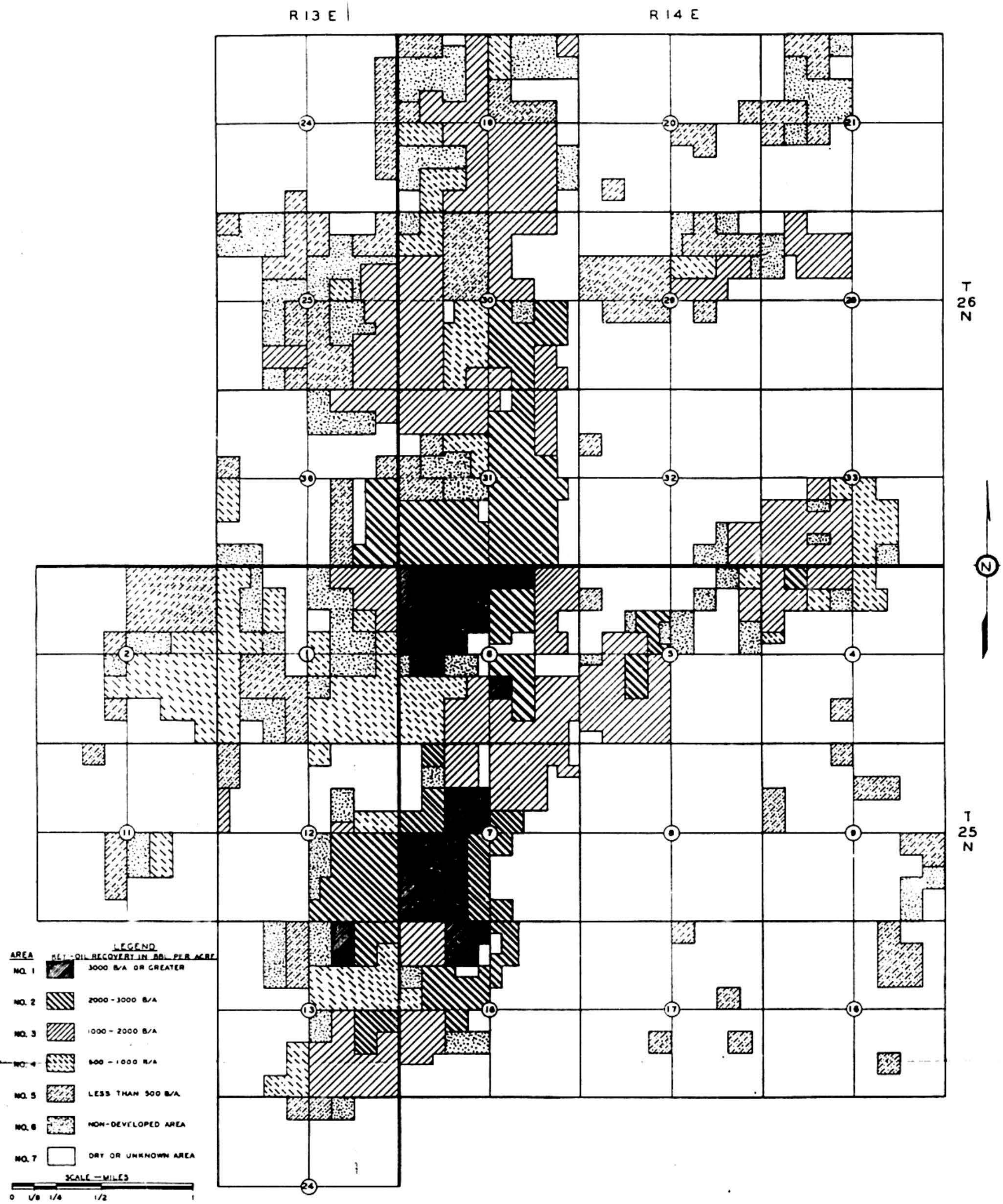
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
CONSERVATION BRANCH — OIL AND GAS LEASING DIVISION
MID-CONTINENT DISTRICT

INITIAL PRODUCTION MAP
OF
BARTLESVILLE SAND WELLS
HOGSHOOTER FIELD
WASHINGTON COUNTY, OKLAHOMA

M. C. NO. 5P 4434

APRIL 1944

PLATE 6.



UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
CONSERVATION BRANCH — OIL AND GAS LEASING DIVISION
MID-CONTINENT DISTRICT

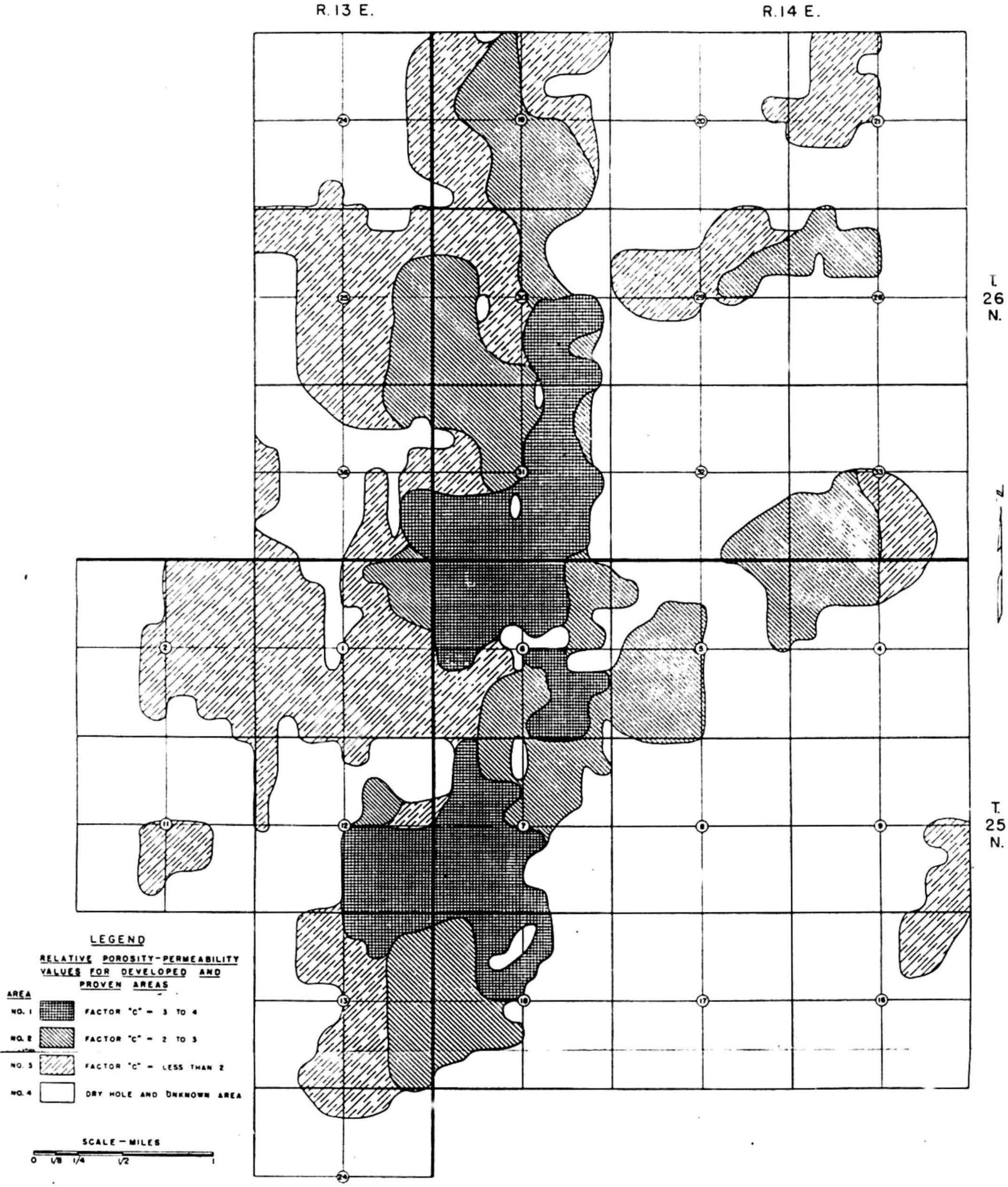
PRODUCTION MAP
of
BARTLESVILLE SAND
HOGSHOOTER FIELD
WASHINGTON COUNTY, OKLAHOMA

M. C. NO. SP-1405

APRIL 1944

PLATE 7.

45-37



UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
CONSERVATION BRANCH — OIL AND GAS LEASING DIVISION
MID-CONTINENT DISTRICT

SANDBODY CONDITION MAP
OF
BARTLESVILLE SAND
HOGSHOOTER FIELD
WASHINGTON COUNTY, OKLAHOMA

APRIL 1944

PLATE 14