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OKLAHOMA GEOLOGICAL SURVEY.

CIRCULAR NO. 8.

METHODS OF EXPLORING FOR OIL AND GAS.

By GEORGE E. BURTON.

COSTS OF DRILLING OIL AND GAS WELLS.

Compiled by
OKLAHOMA GEOLOGICAL SURVEY.

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SCIENTIFIC STAFF.

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ILLUSTRATIONS.

Note.—Plates I and II furnished through courtesy of the Sullivan Machinery Company, Chicago, Illinois.

METHODS OF EXPLORING FOR OIL AND GAS.

By George E. Burton.*

PRESENT METHODS.

There are in Oklahoma at present two general methods of exploring for oil and gas: (1) securing a block of leases and making one or more churn drill tests; and (2) geological examination of the surface in search of anticlines or other favorable structures in which oil or gas might accumulate. Then, if favorable structure is found, churn drill holes are drilled at favorable locations on the structure.

Although the first method has to its credit a long list of dry holes, the great Glenn pool, the Healdton field, and other pools were discovered in this way. However, the chances of finding production by this method of exploration are small. The second method has to its credit the discovery of several oil and gas pools, among which are parts of the famous Cushing field, the Blackwell and Ponca City fields, and the new Garber and Billings pools.

It is interesting to note that structure contours drawn at the horizon of the productive sands in the Healdton field disclose anticlinal structure beneath the surface. This shows that anticlinal structure may exist at depth, in areas where there are no surface indications of such structure.

The first method of exploration, although it has some discoveries to its credit, is too expensive in proportion to the favorable results obtained, to remain in favor much longer with the increasing price of supplies and the cost of drilling.

It is generally conceded by petroleum geologists that the surface in the possible oil and gas territory in Oklahoma has been pretty thoroughly examined, that most of the favorable structures have been located, and that the lands overlying such structures have been practically all leased. So it seems that the end of the second method is in sight. The petroleum geologist using this method of exploration has been confined to those areas, within the probable oil and gas territory in Oklahoma, where there are **reliable outcrops.** Reliable outcrops are outcrops of those strata which were, during the process of sedimentation, deposited horizontally, but which may have since become inclined or folded. The positions of such strata, as observed at the surface outcrops, show their relation to the horizontal, a definite datum plane. Where sufficient outcrops of these reliable strata occur, the geologist can work out the structure and point out the location of anticlines or other folds, and make a fairly definite location for a test well.

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As mentioned above, however, this work is confined to areas where reliable outcrops occur. This method does not cover vast areas where there are no outcrops, or where the outcrops are not to be depended upon for the working out of structure. What, then, is to be the method of exploring areas of this sort?

DIAMOND DRILL METHOD.

The first method of exploration mentioned is slow and expensive, and the second method does not apply in some areas. A third method is therefore proposed for consideration—a method of exploration for areas in which there are few or no surface indications of the underground structure. The method proposed is the use of the diamond core drill in exploring for favorable structure in areas where there are no surface indications of its presence or absence.

At shallow depths in such areas there are, no doubt, strata which have considerable horizontal extent, which were deposited horizontally, and which could be recognized from core. By proper spacing and careful surveying of drill holes the underground structure could be determined from the position of such strata.

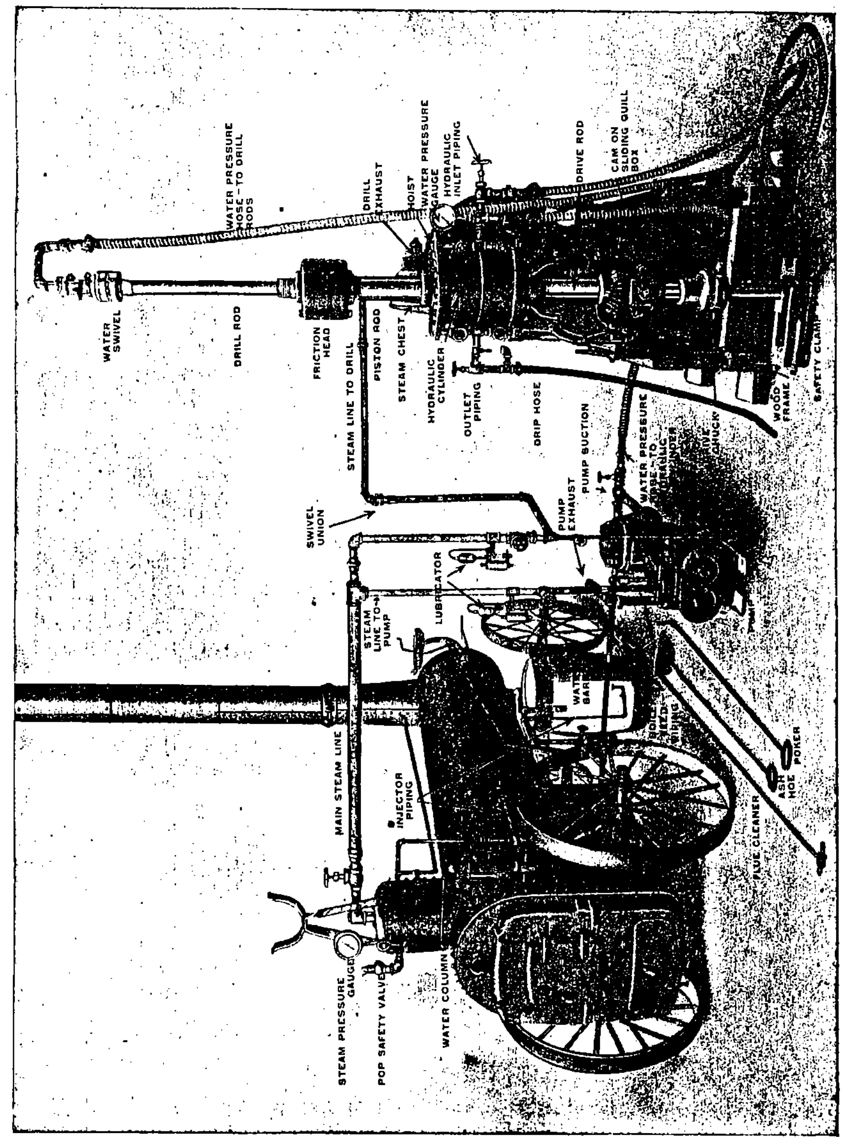
The cost of this kind of exploration is entirely proportionate to the reward sought. A churn drill hole costing $20,000 was drilled in the NW. cor. sec. 30, T. 23 N., R. 6 W., by the city of Enid, Oklahoma, to a depth of 3,000 feet. This well is located in an area where there are very few outcrops, and consequently the underground structure cannot be determined from the surface. The sum total of information gained for an expenditure of $20,000 is that this particular hole is dry. There may be oil or gas within a few hundred feet in any direction from this hole. This method of exploration is obviously too expensive to continue.

As shown by the log of the Enid well, there is at a depth of 830 feet a limestone 2 feet thick, which has, no doubt, considerable horizontal extent. The Duluth Diamond Drill Company of Duluth, Minnesota, contract diamond and churn drillers, roughly estimated that they could drill with diamond drill to a depth of 1,000 feet at a cost of from $1.00 to $2.00 per foot.*

At the maximum charge per foot, the writer estimates that twelve drill holes could be put down to the 830-foot "lime" stratum in the Enid well for $20,000. By properly placing and carefully surveying these holes the attitude of this stratum could be determined over a considerable area in the vicinity of the Enid

*Note: The prices for all kinds of drilling have gone up considerably since the above estimates were made. Since, however, all kinds of drilling have been influenced, the general conclusions from a comparison of figures will be the same.

PLATE I



DIAMOND DRILL AND EQUIPMENT.

well. It is to be understood that these figures are probably extreme. I feel sure that from the core a reliable stratum could be recognized at considerably less depth. This would permit the exploration of a larger area for the same amount of money.*

THE DIAMOND CORE DRILL.

The Diamond Core Drill consists essentially of a bit, which is a circular ring of especially prepared steel, in which are set varying numbers of black diamonds. All the remainder of a diamond drill outfit consists of devices necessary to rotate this diamond bit against the rock stratum, provide for a circulation of water down through the bit, furnish a means of recovering core, and provide for hoisting the bit from the hole. (See Plate I.)

The rotation of the bit is accomplished by an engine connected to the bit with rods. These rods are usually in 10-feet lengths. Rods are added as the depth of the hole increases. These rods are hollow. A circulation of water down through the bit is maintained by a pump connected by a hose to the upper end of the uppermost rod. The water escapes to the surface through the hole on the outside of the rods. This circulation of water accomplishes two things—keeps the bit cool and brings to the surface the "cuttings."

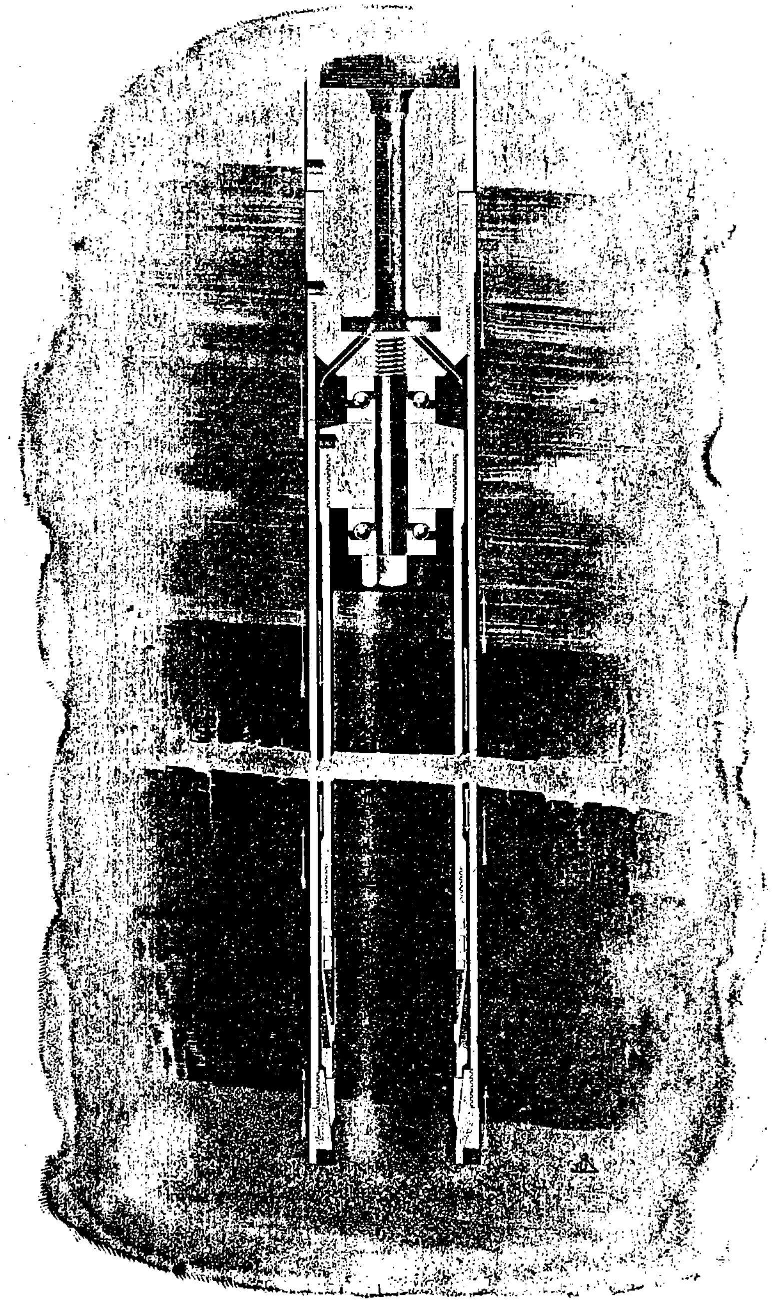
The core is recovered by means of a core barrel five feet long, which takes the place of the rod next to the bit. The opening in the core barrel is larger than it is in the rod. Core barrels are of two kinds, single-barrel and double-barrel. In the single-barrel type ,the water washes down around the core. This type of barrel is used when drilling in rocks hard enough to resist the washing of the water in the barrel. In the double-barrel type, the chamber in which the core accumulates is separated from the chamber in which the water circulates, except at the very bottom of the core chamber, where the water is permitted to enter near the cutting point of the bit. This arrangement permits the water to pass through the cutting part of the bit without washing down around the core. This type of core barrel is used for recovering core from very soft rocks. (See Plate II.)

The hoisting device for removing the bit from the hole consists of a derrick, in the top of which is a pulley through which operates a cable, and a drum attached to the engine. The derrick usually consists of a tripod, made of three poles, 6 to 8 inches in diameter. In hoisting, the rods are broken in ten, twenty or forty feet lengths, according to the height of the derrick.

Since diamond drill holes are apt to deflect from the vertical it is almost necessary to have a device for surveying drill holes.

*Engineering and Mining Journal, 1917.

PLATE II



DOUBLE-TUBE CORE BARREL, SHOWING CORE OF MATERIAL PASSED THROUGH.

Such a device is the Mass compass. This compass is attached to a cork in such a way as to permit its needle free motion in gelatin. The compass is placed in liquid gelatin in one end of a glass tube. The other end of the tube contains hydroflouric acid. A rubber stopper separates the two liquids. The tube with its contents is placed in a specially designed case, which is lowered to the place in the drill hole, the position of which is desired. This is permitted to stand for some time—the time depending on the depth, permitting the gelatin to "freeze." The hydrofluoric acid etches a ring around the tube, thus showing the vertical variation; and the position of the compass in the gelatin shows the horizontal variation. From these two readings, together with the distance to the point surveyed, it is possible to determine the exact position of that point

METHODS OF SHOWING THE ATTITUDE OF A STRATUM FROM DRILL-HOLE DATA.

There are two methods of showing the attitude of a stratum from drill hole data: (1) dip and strike readings; and (2) structural contours.

STRUCTURAL CONTOUR METHOD.

In the structural contour method the elevation of the point where the drill encounters the stratum is determined and lines are drawn at regular intervals through points of the same elevation on the stratum. The relation of these various lines indicate the attitude of the stratum.

DIP AND STRIKE METHOD.*

The following calculation is used to obtain the dip and strike of a stratum of rock from the data acquired in three drill holes:

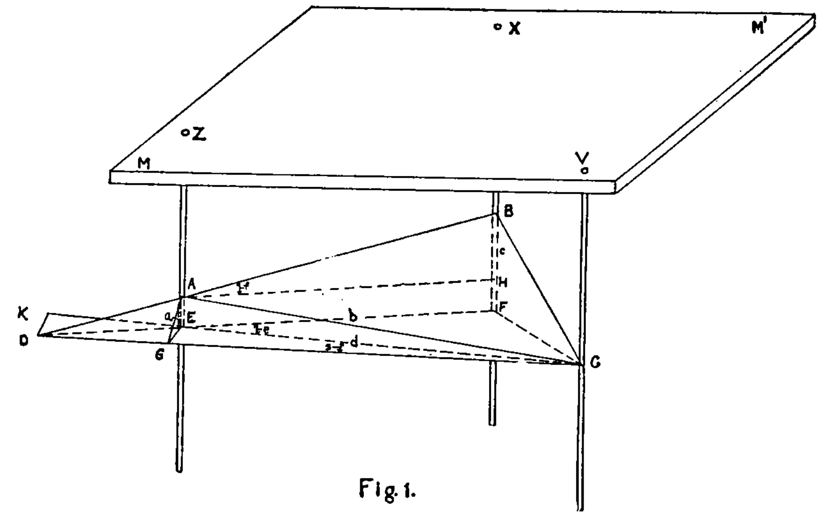


Fig. 1.

Let *MM'* (Fig. 1) represent the surface of the ground, and *V*, *Z* and *X* be three vertical drill holes which encounter the same stratum of rock at points *C*, *A*, and *B* respectively. Let point *C* have the lowest sea-level elevation, point *B* the highest, and point *A* intermediate between the two. Draw *AB*, *BC*, and *AC*.

Pass the plane *EFC* through the point *C* perpendicular to the drill holes *Z* and *X*, cutting *Z* at point *E* and *X* at point *F*. Draw *EF*, *EC*, and *FC*. Draw *AH* parallel to *EF*. Extend *AB* until it intersects the plane determined by the points *E*, *F*, and *C* at *D*. Draw *DC*; the bearing of the line *DC* is the strike of the stratum *ABC*, since it is the line of intersection of the plane *ABC* with the horizontal plane *DFC*. The bearing of the line *EC* is known, so to calculate the bearing of the line *DC* it is necessary only to find the angle *ECD*.

Draw *EG* perpendicular to *DC*. Draw *AG*, then angle *AGE* measures the dip of the stratum as it measures the dihedral angle *B-DC-F*, and this dihedral angle is formed by the intersection of the plane of the stratum *DBC* with the horizontal plane *DFC*. Therefore, to find the dip of the stratum it is necessary only to find the angle *AGE*. In the right triangle *A B H*,

*Engineering and Mining Journal, July 15, 1916.

AH and BH are known, and angle BAH can be found from the formula: Tan $BAH = BH \div AH$. But angle $BAH =$ angle ADE (alternate interior angles.)

In the right triangle AED, AE and angle ADE are known, and DE can be found from the formula, Cot $ADE = DE \div AE$. In the triangle DEC, DE and EC are known, and the angle $DEC = 180° -$ angle FEC. Since angle FEC is known, angle DEC can be found. We have given, then, an oblique triangle with two sides and the included angle known. From D let fall a perpendicular in the horizontal plane cutting the line EC (extended) at point K. In the triangle DKC,

Tan $ECD = DK \div (KE + EC)$
Sin $(180° - DEC) = DK \div DE$
$DK = DE \sin (180° - DEC)$
but $180° - DEC =$ angle FEC
therefore $DK = DE \sin FEC$

Cos $(180° - DEC) = \cos FEC = KE \div DE$
therefore $KE = DE \cos FEC$
Substituting in Tan $ECD = DK \div (KE + EC)$
Tan $ECD = (DE \sin FEC) \div (DE \cos FEC + EC)$
Substituting knowns for unknowns in the foregoing equation:
Tan $ECD = (AE \cot BAH \sin FEC) \div (AE \cot BAH \cos FEC + EC)$

$$\text{Tan } ECD = \frac{AE \times \dfrac{AH}{BH} \times \sin FEC}{AE \times \dfrac{AH}{BH} \times \cos FEC + EC}$$

In order to simplify the formula, let:

$AE = a$, the difference in elevation between the stratum in hole V at C and in hole Z at A.

AH or $EF = b$, the surveyed distance between holes Z and X.

$BH = c$, the difference in elevation between the stratum in hole Z at A and in hole X at B.

$EC = d$, the surveyed distance between drill holes Z and V.

Angle $FEC = e$, the surveyed horizontal angle at hole Z.

Angle $BAH = f$, the angle included between a line drawn in the plane of the stratum connecting holes Z and X and a line drawn from the point of intersection of this line with hole Z, perpendicular to hole X.

Angle $ECD = S$, the angle to be added to or subtracted from the bearing of the horizontal line connecting holes Z and V to determine the strike of the stratum.

Angle $AGE = D$, the angle of dip of the stratum. Then:

$$\text{Tan } S = \frac{a \times \dfrac{b}{c} \times \sin e}{a \times \dfrac{b}{c} \cos e + d} = \frac{\dfrac{ab \sin e}{c}}{\dfrac{ab \cos e + cd}{c}}$$

$$\text{Tan } S = \frac{ab \sin e}{ab \cos e + cd}$$

the angle to be added to or subtracted from the bearing of the line EC to determine the strike of the stratum.

In the right triangle CEG, EC (d) and angle ECG (S) are known, and EG can be found from the formula $\tan S = EG \div d$. $EG = d \tan S$.

In right triangle AEG, AE (a) and EG $(d \tan S)$ are known, and the angle AGE (D) can be found from the formula (for finding the dip of the stratum), $\tan D = a \div (d \tan S)$.

There are two special cases to the foregoing: Case 1, where all three drill holes encounter the stratum at the same sea level elevation, in which case the stratum is level and there is no dip or strike; case 2, where two of the drill holes encounter the stratum at the same sea level elevation, in which case the strike is the bearing of the horizontal line connecting these two drill holes and the dip can be calculated.

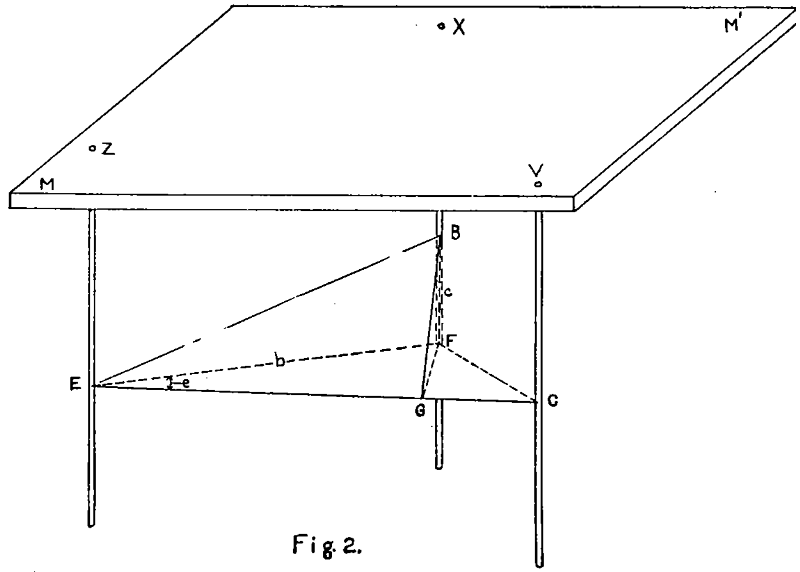


Fig. 2.

Let MM^1 (Fig. 2) represent the surface of the ground, and let the vertical drill holes V and Z encounter the same stratum of rock at point C and E, which have the same sea level elevation, also let drill hole X encounter the stratum at point B, which has either a higher or lower sea level elevation than points E and C.

Pass the plane EFC through the line EC perpendicularly to drill hole Z and cutting hole X at point F. Draw FG perpendicular to line EC and connect B and G. The bearing of the line EC is the strike of the stratum. The angle BGF (D) is the angle of dip as it measures the dihedral angle $B\text{-}EC\text{-}F$, and this dihedral angle is formed by the intersection of the plane of the stratum EBC with the horizontal plane EFC.

In the right triangle EGF angle e and the hypotenuse b are known, and leg FG can be found from the formula $\sin e = FG \div b$. $FG = b \sin e$.

In the right triangle BFG, c and FG are known, and angle BGF (D) *can be found from the formula*, $\tan D = c \div (b \sin e)$ which is the formula for finding the dip of the stratum.

COST OF DRILLING WELLS IN TEXAS AND OKLAHOMA.

Compiled by

Oklahoma Geological Survey.

GENERAL STATEMENT.

The following figures on the cost of drilling are given with the hope that they will be of some assistance to citizens of the State who are contemplating drilling. In so far as possible, prices are given for February 22, 1916; June 23, 1917, and July 27, 1917. These prices show a great increase in the price of drilling and drilling material.

CONTRACT DRILLING.

In regions where the formations are generally familiar to the drillers, the contractor makes a special rate per foot with the rig, fuel, casing, water, and transportation furnished by the producer. Where the formations are not known, or for deepening old wells, a general rate per day is charged, with the same materials furnished.

The following table shows the rate for drilling in various fields:

TABLE SHOWING PRICE PER FOOT FOR DRILLING OIL AND GAS WELLS IN VARIOUS FIELDS.

FIELD.	RATE. February 22, 1916.	RATE. June 23, 1917.	RATE. July 27, 1917.
To shallow sand in Bartlesville, Nowata and Tulsa districts	$0.80 to $1.00	$1.00 to $1.25	$1.25
To Layton sand in Cushing field	1.35	1.50	2.50
To Bartlesville sand in Cushing field, northeast	1.50	2.00	3.50
To Bartlesville sand in Cushing field, southeast	2.00	2.25	3.50—4.00
To the shallow sands in Newkirk, Ponca City and Garber fields	1.50	1.50	1.50
To the deeper sands in Newkirk and Ponca City fields	2.50	3.50 (above 2,500 ft.)	3.50—4.00
Healdton field	1.40 to 1.50	1.75	1.75
Electra and Burkburnett to 1,200-foot depth	2.00		
Electra and Burkburnett to 2,100-foot depth	8.50	Note.—Price for rotary drilling to 2,000 feet is $3.00.	
Electra and Burkburnett to more than 2,500-foot depth	5.00		

The regular charge for work by the day, February 22, 1917, was $50 for a double shift. This held good throughout the above fields. All wildcat propositions some distance (50 miles or more) from any of the above-mentioned fields demanded $3.00 per foot.

AMOUNT OF CASING USED IN THE WELLS.

The following table shows the amount of casing used in wells in the various fields:

Field.	Depth.	Size of Casing.	Weight.
Shallow field in northeast Oklahoma.	1,000 ft.	8 in.	28 lbs.
	To bottom	6 in.	24 lbs.
Healdton field.	400 ft.	10 in.	40 lbs.
	600 ft.	8 in.	28 lbs.
	1,000 ft.	6 5/8 in.	24 lbs.
	1,200 ft.	5 3/16 in.	
South end of the Cushing field.	100-400 ft.	15 1/2 in.	70 lbs.
	400-800 ft.	12 1/2 in.	50 lbs.
	800-1,400 ft.	10 in.	40 lbs.
	1,200-2,000 ft.	8 in.	28 lbs.
	2,000-2,800 ft.	6 5/8 in.	24 lbs.
	2,400-3,000 ft.	5 3/16 in. liner	
North end of the Cushing field.	200-300 ft.	15 1/2 in.	70 lbs.
	400-500 ft.	12 1/2 in.	50 lbs.
	1,000 ft.	10 in.	40 lbs.
	1,600 ft.	8 in.	28 lbs.
	2,200-2,300 ft.	6 5/8 in.	24 lbs.
	To bottom	5 3/16 in. liner	
Northwest of Cushing field.	500-600 ft.	15 1/2 in.	70 lbs.
	800 ft.	12 1/2 in.	50 lbs.
	1,100-1,300 ft.	10 in.	40 lbs.
	1,800-2,000 ft.	8 in.	28 lbs.
	2,800 ft.	6 5/6 in.	24 lbs.
	2,900 ft.	5 3/16 in. liner	

Field.	Depth.	Size of Casing.	Weight.
Northwest Texas Region.* Maximum amount.	80-100 ft.	15 1/2 in.	70 lbs.
	400 ft.	12 1/2 in.	50 lbs.
	1,000 ft.	10 in.	40 (or 28) lbs.
	1,500 ft.	8 in.	20 lbs.
	1,800 ft.	6 5/8 in.	17 lbs.
	2,200 ft. (?)	5 3/16 in. liner	
Northwest Texas Region.* Minimum amount.	800 ft.	10 in.	28 lbs.
	1,500 ft.	8 in.	20 lbs.
	2,000 ft.	6 5/8 in.	17 lbs.

*Note.—Some rotary drilling in this district, consequently the variation in amount of casing, the rotary method using only about one-half as much as the churn-drill method.

PRICE OF CASING.

At the present time (July, 1917) any quoted price on casing holds good for only a few days at a time. The standard length of casing is 20 feet. The tables below give prices of casing at Tulsa, Oklahoma, and Wichita Falls, Texas. There is a 5 per cent to 10 per cent cut on carload lots. All measurements given below are inside diameter.

Price of Casing F. O. B. Tulsa.

Size.	Weight.	Price per foot.		
		Feb. 22, 1916.	June 23, 1917.	July 27, 1917.
15 1/2 in.	70 lbs.	$2.75	$5.34	$7.00
12 1/2 in.	50 lbs.	1.31	3.33	5.00
10 in.	35 lbs.	1.21	2.63	3.25
8 1/4 in.	38 lbs.	0.94	2.05	2.40
6 5/8 in.	20 lbs.	0.65	1.62	2.10
5 3/16 in.	17 lbs.	0.48	1.02	1.70

Price of Casing F. O. B. Wichita Falls, Texas.

Size.	Weight.	Price per foot.		
		Mar. 2, 1916.	June 23,* 1917.	July 27, 1917.
15 1/2 in.	70 lbs.	$3.53	$5.29	$5.34
12 1/2 in.	50 lbs.	2.15	3.27	3.43
10 in.	28 lbs.	1.12	----	----
8 1/4 in.	20 lbs.	0.76¼	1.24	1.30
6 5/8 in.	17 lbs.	0.64½	1.12	1.21
5 3/16 in.	13 lbs.	0.50½	0.98	1.02

*Estimated.

HAUL.

Throughout Oklahoma the cost of teams per day ranges from $5.00 to $6.00. Possibly in the Healdton field it might be safe to count on a team for $5.00, while elsewhere it would not. In Texas the cost per team per day ranges from $5.00 to $8.00. An average team is capable of hauling about 3,500 pounds per load. A 15-mile haul is a full day's work, especially in northern Oklahoma, where the roads are usually poor. Texas and Carter County, Oklahoma, roads are good and a team might be expected to haul more or cover a little more distance. The above figures give an average rate of 23 cents per ton per mile. The Gypsy Oil

Company has reduced its cost of haul to about one-fourth of the original cost by the use of tractor engines.

The following figures give the average number of loads necessary for moving the equipment of a drill: 23 loads for engine, boiler, tools, etc.; 18 to 20 loads for lumber; and 5 loads for casing. The casing could be grouped into loads as follows: 2 joints (20-foot lengths) of 15½-inch; 3 joints of 12-inch; 5 joints of 10-inch; 7 joints of 8-inch; and 9 joints of 6⅝-inch material.

TIMBER.

An ordinary 72- to 80-foot rig uses:

13,000 feet (board measure) pine @ $37 per M	$481
8,000 feet (board measure) rig timbers (oak) @ $50 per M	400
Labor on a new rig	300
Total	$1,181

Figuring a 15-mile round-trip haul, at the above figures, the equipment could be hauled and an 80-foot rig erected for approximately $1,500.

FUEL.

In the Cushing field and generally in northern Oklahoma, as well as in the Healdton field, gas is furnished a boiler for a standard rig at $5.00 per double shift. The amount of gas consumed by one boiler for 24 hours is 75,000 to 100,000 cubic feet.

In the Potato Hills region of Oklahoma wood was used. About 2 cords of this wood was consumed in 24 hours by one boiler.

In the Texas fields oil is the fuel used and the amount necessary for 24 hours is about 12 or 15 barrels.

Coal is generally considered out of the question in Oklahoma or Texas. However, the amount necessary to run a boiler 24 hours is about 2.5 tons of bituminous coal.

LENGTH OF TIME REQUIRED TO COMPLETE A WELL.

About 30 days is required to complete a well in the shallow fields of northeastern Oklahoma; 75 to 100 days in the Cushing field; 125 to 135 days in the Blackwell, or fields west of the Cushing; 18½ days in the Healdton field; 30 to 45 days in northwest Texas with rotary drill, or 60 to 75 days with cable tools.

WATER.

Water conditions vary considerably in each of the fields, so that only a general approximation can be made. Some water is pumped from shallow bored wells; some collected in surface reservoirs; some pumped from streams or springs; and some furnished by contract from sources most available. The average cost of a tank of water (250 barrels) is $7.00 or $8.00.

In the Cushing filed 150 to 250 barrels of water are necessary for each 24 hours of drilling; in the Healdton field 150 to 200 barrels; and in northern Texas more than 150 barrels.