DEPARTMENT OF THE INTERIOR
ALBERT B. FALL, SECRETARY
BUREAU OF MINES
H. FOSTER BAIN, DIRECTOR

PROSPECTING AND TESTING FOR OIL AND GAS

BY

R. E. COLLOM

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PROSPECTING AND TESTING FOR OIL AND GAS.

By R. E. Collom.

INTRODUCTION.

The commercial development of petroleum and natural gas fields has reached its present status within 60 years and is still considered by some operators to be "100 per cent wildcatting."[1] A tendency to drill for gusher production, the production that yields big returns in spite of any mechanical defects in drilling methods, has frequently caused drillers to pass by oil-bearing strata of comparatively small yield and actually to overlook rich oil zones in proved fields; in addition, whole fields have been ruined by water because development methods were never carried beyond a hole-in-the-ground stage.[2]

Unfortunately, the petroleum industry has no mine dumps or tailing piles as at metal mines to yield fortunes through later and better methods of treatment. The wasted oil and gas are gone, as are the time, money, and effort wasted in ill-advised or haphazard drilling. Probably as production costs increase less oil will be wasted, but the need to develop and produce from sands of low yield will become more urgent with the increase in consumption of oil and the decrease in supply.

Hundreds of wells are producing steadily as the result of months and perhaps years of careful prospecting and of tests during drilling. The Bureau of Mines has studied the testing and drilling methods used at such wells, and presents in this paper a criticism of these methods and suggestions on future work. The term *prospecting* here means correct identification and measurement of strata as they are exposed by the drill. The term *testing* means the determination of the kind and amount of fluid stored within the pores or crevices of any stratum exposed in the hole.

[1] Mining and Oil Bulletin, Future of oil industry depends on equitable revenue tax: Vol. 4, November, 1918, p. 528.

[2] Arnold, Ralph, and Clapp, F. G., Wastes in the production and utilization of natural gas, and methods for their prevention: Tech. Paper 38, Bureau of Mines, 1913. 29 pp. Arnold, Ralph, and Garfias, V. R., The prevention of waste of oil and gas from flowing wells in California, with a discussion of special methods used by J. A. Pollard: Tech. Paper 42, Bureau of Mines, 1913, 15 pp. Blatchley, R. S., Waste of oil and gas in the Mid-Continent fields: Tech. Paper 45, Bureau of Mines, 1914, 54 pp.

Part I of this paper discusses briefly some of the features of oil and gas accumulation and describes certain oil-field rocks and minerals. Part II deals with the kinds of tools that should be used and the information necessary for selecting proper tools. In "wildcat," or partly developed territory, or areas of complex rock structure, the need for complete information is far more important than are economies in drilling and casing. The mechanical details of well-drilling methods have been covered by a number of writers.[3]

Part III discusses the accurate testing of strata for oil or gas and states principles based on conditions that have frequently existed in well drilling. Some of these principles are illustrated by specific examples.

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[3] Bowman, Isaiah, Well-drilling methods: U. S. Geol. Survey Water-Supply Paper 257, 1911, 139 pp. Thompson, A. Beeby, Oil-field development, 1916, pp. 307–452. Westcott, Henry P., Handbook of natural gas, 1915, pp. 107–162. Bacon, Raymond Foss, and Hamor, William Allen, The American petroleum industry, 1916, pp. 272–344. Redwood, Boverton, A treatise on petroleum, 1913, vol. I, pp. 284–367. Paine, Paul M., and Stroud, B. K., Oil-production methods, 1913, pp. 87–129. Johnson, Roswell, and Huntley, L. G., Oil and gas production, 1916, pp. 114–132. Lewis, J. O., and McMurray, W. F., The use of mud-laden fluid in oil and gas wells: Bull. 134, Bureau of Mines, 1916, 86 pp. Tough, F. B., Methods of shutting off water in oil and gas wells: Bull. 163, Bureau of Mines, 1918, 122 pp. Wagy, E. W., Perforated casing and screen pipe in oil wells: Tech. Paper 247, Bureau of Mines, 1920, 48 pp.

PART I.—ACCUMULATION OF OIL AND GAS.

FEATURES OF ACCUMULATION.

VALUE OF SIGNS OF OIL AND GAS.

The geologic facts that influence a prospector in selecting a drill site and in continuing or abandoning work ranges from such simple, commonplace evidence as seepages, gas "blows," and deposits of asphaltum and other associated minerals to obscure details of stratigraphy. The simple geologic evidence can be read by all; however, special training in geology is necessary to interpret many of these signs correctly.

As abundant literature on oil-field geology is available, theories of the origin or the accumulation of oil and gas or possible methods of solving problems in areal geology will not be discussed here. Certain broad principles relative to the attitude and nature of rocks necessary to afford a reservoir have been established, but are constantly subject to study and modification [4] by geologists and petroleum engineers. Rock structures differ in each new field. Generally, surface evidence, derived from outcropping rocks, has had to be supplemented by data from drilling in order to determine correctly the geologic age and structural relations of oil and gas-bearing strata. In southern Illinois,[5] for example, the older rocks do not outcrop at the surface and are known only from the cuttings from drill holes and from outcrops in adjoining States. The mining of another mineral, such as coal, salt, or sulphur, or the flow of artesian water, has often led to the chance discovery of oil and gas.

Oil seeps, brea deposits, and the like do not indicate proper places for tapping possible productive oil strata. Some wells drilled near "seeps" or brea have been productive, but usually the productive strata lie uneroded below those in which the oil seeps or other signs originate. In following seepages many wells have been drilled on "the wrong side of the dip."

The geologist, prior to drilling, is as much needed to advise the prospector not to drill in unfavorable areas, such as those of meta-

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[4] Clapp, Frederick G., Revision of the structural classification of petroleum and natural gas fields: Bull. Geol. Soc. America, vol. 28, 1917, pp. 553–602.

[5] Lee, Wallace, Oil and gas in Gillespie and Mount Olive quadrangles, Illinois: Illinois Geol. Survey Bull. 31, 1914, p. 74.

morphic, igneous, or highly tilted sedimentary rocks, as to indicate favorable areas. In this paper the operator is assumed to have had the benefit of such advice before starting the actual work of prospecting with the drill.

GEOLOGIC STRUCTURES.

Sometimes the term "geologic structure" is used loosely and incorrectly to mean a determined or probable accumulation of oil and gas. This misuse results largely from popularization of the anticlinal theory of accumulation. Oil and gas must of necessity accumulate in some kind of a geologic structure, for the earth's crust is made up of geologic structures which include igneous, sedimentary, and metamorphic rocks. As applied to oil and gas deposits, a geologic structure may, therefore, range from a great geosyncline to a minor crumple or terrace on the flank of a small anticline and may comprise igneous and metamorphic rocks as well as faults and other results of movement.

Wherever used with reference to an oil and gas area, the term "geologic structure" is subject to definition as to vertical and lateral extent. The areal extent of an oil and gas reservoir rarely, if ever, can be determined by surface evidence. In many fields deeper drilling will develop new productive zones, lying perhaps unconformably below present development. Practically such zones, if properly drilled, are equivalent to new and distinct pools.

For the oil man the limits and recoverable content of any pool will be determined by such economic factors as the productiveness of different parts of the stratum and the limits of accessibility by drill and pump. These factors may fall short of covering the areal extent of a so-called geologic structure.

It is the intimate structure of oil and gas-bearing strata that interests the oil operator. Variations in porosity of reservoirs because of local alterations or gradation from coarse to fine sediments or the reverse, the proximity of "mother" formations to porous rocks, the presence or absence of water in related beds or in the oil sands themselves, or the effectiveness of impervious beds sealing the oil and gas in certain strata, often influence accumulation more than the attitude of beds.

DEFECTS OF THE ANTICLINAL THEORY.

The anticlinal theory and its variations, based upon gravitational principles, according to Munn,[6] have "not proved satisfactory in

[6] Munn, M. J., The Campton oil pool, Kentucky: U. S. Geol. Survey Bull. 471, 1912, p. 15.

accounting for (1) the closed pressure of gas pools (sometimes amounting to 1,500 pounds to the square inch); (2) the presence of oil and gas pools that occupy sandstone lenses of local extent which are surrounded on all sides by shale * * *; (3) the presence of oil and gas pools under high pressure in porous pay streaks within sandstone of ordinary texture and porosity; (4) the presence in a sand showing no water of large pools of both oil and gas that do not conform to structure lines, but extend across minor anticlines or synclines alike; (5) the relatively great variation in the porosity of pay streaks in which pools occur; and (6) the difference in the initial closed pressure in gas wells in a given area * * *."

DRY HOLES.

The number of "dry" holes drilled within various oil and gas areas indicates, in a limited sense, the variability of the factors of accumulation. Records of development in Kentucky[7] show that "out of 753 wells drilled in Estill County, 142 (18.9 per cent) were dry. Most of this drilling was supposedly inside the limits of the established field and was successful. The dry holes served to show the 'spotted' character of the sands." In Illinois[8] the total number of wells drilled to January 1, 1917, was 25,323, of which 4,645, or 18.3 per cent, were dry. Table 1, taken from reports of the United States Geological Survey,[9] gives a comparison of the percentages of dry holes to the total number of wells drilled in various States during the years 1916 and 1917. California and New York show the lowest percentage of dry holes of all the oil-producing States. Texas shows the highest percentage of dry holes, undoubtedly because of wildcat drilling. One large company operating in the new fields of north Texas drilled 364 wells up to the end of February, 1920, and 19.5 per cent of these were dry. This proportion is considerably less than the average (31 per cent) for the State.

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[7] Pemberton, J. R., Development in Kentucky: Bull. Amer. Assoc. Petroleum Geol., vol. 2, 1918, p. 43.

[8] Kay, Fred H., Petroleum in Illinois in 1916: Illinois Geol. Survey Bull. 35, 1917, p. 17.

[9] Northrop, J. D., Petroleum in 1916: U. S. Geol. Survey Mineral Resources of the United States, 1916, 1918, p. 704; Petroleum in 1917: U. S. Geol. Survey Mineral Resources of the United States, 1917, 1919, p. 696.

TABLE 1.—*Percentage of dry holes drilled in various States during years 1916–1917.*

State.	Completed wells.			Percentage of dry holes.
	Oil.	Dry.	Total completed.	
Alabama	0	4	4	100
Alaska	7	2	9	22
Arizona	0	1	1	100
Arkansas	0	10	10	100
California	1, 299	80	1, 379	6
Colorado	6	23	29	79
Florida	0	1	1	100
Illinois	1, 590	302	1, 892	16
Indiana	249	79	328	24
Kansas	4, 503	753	5, 256	14
Kentucky	1, 960	597	2, 557	23
Louisiana	789	263	1, 052	25
Missouri	0	5	5	100
Montana	7	2	9	22
New Mexico	0	3	3	100
New York	515	22	537	4
Ohio	2, 311	485	2, 796	17
Oklahoma	7, 269	1, 285	8, 554	15
Pennsylvania	3, 313	431	3, 744	12
Tennessee	3	23	26	90
Texas	2, 516	1, 112	3, 628	31
Utah	0	3	3	100
Washington	1	3	4	75
West Virginia	1, 739	257	1, 996	13
Wyoming	331	68	399	17
Total, all States	28, 408	5, 814	34, 222	17

To anyone familiar with developments in different parts of the United States, the percentages of dry holes shown for such States as Arkansas, Colorado, Missouri, New Mexico, Utah, and Washington, can not be regarded as indicating the possibility of getting oil in these States, for the amount of drilling was insufficient. The percentages, however, confirm the extra hazards of initial prospecting, as some of these wells are assumed to have been correctly placed geologically.

Dry holes result from drilling in (1) areas unfit geologically for either origin or accumulation of oil; or in (2) barren areas within oil or gas zones, or in (3) areas in which wells properly drilled and tested would have been producers. Improper drilling and testing prevents, to a large extent, the classification of the causes of all dry holes. If a hole is known to have been properly drilled, the natural causes of failure to produce can usually be determined. The loss to the industry, in dollars and cents, through drilling the dry holes of class 3 would be difficult to estimate.

Table 1 shows a total of 5,814 dry holes was drilled in the United States in two years. At an average cost of $10,000 a hole, which is probably low, the expenditure for them was over $58,000,000. At the 1920 rate of development it is probable that at least $30,000,000 would be spent annually on dry holes.

THE DIVINING ROD.

A system of prospecting that is independent of all of the foregoing limitations for accumulation and is responsible for a number of dry holes, is based on the use of instruments such as the forked stick, electric boxes, oscillating plumb bobs, and the like. It is not surprising that in an industry in which one man's guess is said to be as good as another's, many well-meaning operators should choose such means as a short cut through an otherwise laborious process of prospecting.

Becker[10] suggested that local magnetic disturbances may attend accumulations of hydrocarbons, but the reduction of this relation to a workable basis for finding oil and gas demands much research and the coordination of many factors that are almost intangible.

Ellis[11] has discussed the history and the use of divining rods and similar devices, and O. E. Meinzer in an introductory note to Ellis's paper says: "To all inquirers the United States Geological Survey, therefore, gives the advice not to spend any money for the services of any 'water witch' or for the use or purchase of any machine or instrument devised for locating underground water or other minerals."

SOLVING THE PROBLEM OF ACCUMULATION.

A synopsis of structural conditions for all oil fields can not be made in the limits of this report. Each field necessarily is a problem first for the areal geologist and then for the driller and development engineer, who will use the evidence of drilling in well-to-well correlations. Later the geologist can take the results of the accumulated

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[10] Becker, G. F., Relations between local magnetic disturbances and the genesis of petroleum: U. S. Geol. Survey Bull. 401, 1909, 24 pp.

[11] Ellis, Arthur J., The divining rod: U. S. Geol. Survey Water Supply Paper 416, 1917, 59 pp.

observations and attempt a solution of the broader problems of formational sequence and structure.

Rocks and minerals studied in outcrops may be penetrated in drilling. Some of these, such as brea, petroleum, gas, and coal in a broad sense are definite indicators of the possible presence of oil-bearing formations, and others, such as "sulphur" gas and marsh gas, are not.

OIL-FIELD ROCKS AND MINERALS.

FORMATIONS PENETRATED IN DRILLING.

In a prospect area no one can predict the relative value, as a guide to future development, of the various strata successively penetrated in drilling. Other strata than those containing oil or gas are important. A stratum regarded as of no consequence at the time of drilling may later have value as a marker, for example, or be a suitable impervious stratum in which to shut off water. As an increasing number of wells are drilled in an area, certain strata will begin to assume prominence and the names of some of them may occur in the logs of nearly every well. The oil operator should be able to recognize the significance of these formations. He should know in what kinds of rocks he may expect to find oil and gas and how he should proceed to test and develop them. Oil-field rocks and minerals may be divided according to their predominant uses into four general classes, reservoir rocks, barrier rocks, marker rocks, and indicator rocks.

DISTRIBUTION OF PRINCIPAL RESERVOIR ROCKS.

Reservoir rocks are all porous, fractured, cavernous, or creviced formations that may be reservoirs for fluid, and all economically barren porous formations that are a possible door to waste.[12] In any complete plan of development the true nature of all such formations must be determined.

Oil and gas are usually found in sedimentary rocks, limestone, sandstone, or shale, which differ greatly in mineralogic composition. Igneous rocks, except in the Thrall[13] oil field of Texas and possibly the serpentines of Cuba,[14] seldom contain oil in productive quantities, but are frequently penetrated by prospect holes started in sedimentary beds. Twelve wells in Kansas were drilled into granite[15] to depths of 103 feet to 1,195 feet before abandonment.

[12] McMurray, W. F., and Lewis, J. O., Underground wastes in oil and gas fields an methods of prevention: Tech. Paper 130, Bureau of Mines, 1916, p. 12

[13] Udden, J. A., and Bybee, H. P., The Thrall oil field: University of Texas Bull. 6 1916, p. 51.

[14] DeGolyer, E., The geology of Cuban petroleum deposits: Bull. Am. Assoc. Petroleu Geol., vol. 2, 1918, p. 138.

[15] Moore, R. C., and Haynes, W. P., Oil and gas resources of Kansas: Geol. Survey Kansas Bull. 3, 1917, pp. 140–170; Taylor, Charles H., The granites of Kansas: Bu S. W. Assoc. Petroleum Geol., vol. 1, 1917, pp. 111–126.

An occurrence of petroleum in granite is discussed by Trumbull,[16] who shows that the oil seepages on Copper Mountain, Wyo., originate in fault fractures in granite where the oil, migrating from sedimentary beds, has become entrapped.

In Ventura County,[17] California, a few 5 or 6 barrel wells have been drilled into close-textured crystalline schist. This schist is underlain by granite, but is overlain, at a distance of a few hundred feet, by petroliferous Tertiary rocks, from which the oil in the schist has probably migrated.

According to Clarke,[18] the average proportion of different rocks in the earth's crust is: Shale, 4 per cent; sandstone, 0.75 per cent; limestone, 0.25 per cent; and igneous rock, 95 per cent. Of course, such a classification combines all of the many intergradations of sedimentary rocks. Average limestone is 76.1 calcium carbonate and contains some clay and sand; average shale contains some calcium carbonate.

In this country oil and gas have been found in at least 23 States and in Alaska. Table 2 gives the geologic age, lithology of reservoir rocks, and nature of the hydrocarbon content for the States in which petroleum occurs; also, a reference covering these features for each State.

TABLE 2.—*Geologic age and lithology of reservoir rocks and nature of hydrocarbon content, by States.*

State.	Geologic age.	Reservoir rocks.	Kind of petroleum.	Reference.
Alabama	Carboniferous	Sandstone and limestone.	Mostly gas, oil, asphalt-base.	Smith, E. A., and McCalley, Henry, Index to mineral resources of Alabama: Alabama Geol. Survey Bull. 9, 1904, p. 70.
Alaska	Jurassic to Tertiary.	Sand, sandstone, and shale.	Paraffin-base	Martin, G. C., Petroleum fields of the Pacific coast of Alaska: U. S. Geol. Survey Bull. 250, 1905, 64 pp.
Arkansas	Carboniferous	Sand in limestone.	Asphalt-base; no production.	Miser, H. D., and Perdue, A. H., Asphalt deposits and oil conditions in southwestern Arkansas: U. S. Geol. Survey Bull. 691, 1919, pp. 271–292.
California	Cretaceous and Tertiary.	Loose sand and shale.	Asphalt-base; small amount of paraffin-base.	Pack, R. W., and English, W. A., Geology and oil prospects of Waltham, Priest, Bitterwater, and Peachtree Valleys, California: U. S. Geol. Survey Bull. 581, 1915, pp. 119–160; and other Survey publications on California oil fields.

[16] Trumbull, L. W., Prospective oil fields: State Geol. Survey of Wyoming Bull. 5, 1913, p. 9.
[17] Smith, George Otis, Classification of public lands: U. S. Geol. Survey Bull. 537, p. 112.
[18] Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 491, 1911, p. 9.

TABLE 2.—*Geologic age and lithology of reservoir rocks and nature of hydrocarbon content, by States*—Continued.

State.	Geologic age.	Reservoir rocks.	Kind of petroleum.	Reference.
Colorado	Cretaceous	Sandstone and shale.	Paraffin-base	Washburn, C. W., Development in the Boulder oil field, Colorado, pp. 514–516; The Florence oil field, Colorado, U. S. Geol. Survey Bull. 381. 1910, pp. 517–554.
Illinois	Silurian, Devonian, Carboniferous.	Sandstone and limestone.	do	Blatchley, R. S., Oil and gas in Bond, Macoupin, and Montgomery Counties, Illinois: Illinois State Geol. Survey Bull. 28. 1914. 51 pp.
Indiana	Ordovician, Silurian, Devonian, Carboniferous.	Sandstone and limestone.	Paraffin-base; small amount of asphalt-base.	Blatchley, W. S., The petroleum industry in Indiana, pp. 461–478; Kinney, B. A., Report of the State supervisor of natural gas for the year 1907, pp. 587–604: Indiana Dept. Geol. and Nat. Resources, 32d Annual Report, 1907.
Kansas	Carboniferous	Sandstone in shale.	Paraffin- and asphalt-base.	Haworth, E., Bennett, J., Cady, H. P., McFarland, D. F., and Bushong, F. W., Special report on oil and gas: Geol. Survey of Kansas, vol. 9, 1908, pp. 5–317.
Kentucky	Ordovician, Carboniferous.	Limestone	Paraffin-base	Munn, M. J., Reconnaissance of oil and gas fields in Wayne and McCreary Counties, Kentucky: U. S. Geol. Survey Bull. 579, 1914, 105 pp.
Louisiana	Cretaceous to Quarternary.	Sand, sandstone, shale, limestone, and dolomite.	Asphalt-base; paraffin-base.	Harris, G. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, 1910, 192 pp.
Michigan	Silurian	Sandy limestone.	Paraffin-base	Smith, R. A., The occurrence of oil and gas in Michigan: Michigan Geol. and Biol. Survey Publication 14, Geol. Series II, 1912, 281 pp.
Missouri	Carboniferous	Sandstone in shale.	Paraffin-base; no production.	Wilson, M. E., Oil and gas possibilities in the Belton area: Missouri Bureau of Geol. and Mines, 1918, 39 pp.
Montana	Cretaceous	Sand	Paraffin-base	Hancock, E. T., Geology and oil and gas prospects of the Lake Basin field, Mont., pp. 101–147; Stebinger, Eugene, Oil and gas geology of the Birch Creek-Sun River area, northwestern Montana, pp. 149–184; Bowen, C. F., Anticlines in a part of the Musselshell Valley, Musselshell, Meagher, and Sweetgrass Counties, Mont., pp. 185–209: U. S. Geol. Survey Bull. 691, 1919.
New Mexico	Carboniferous	Sandstone	do	Richardson, D. B., Petroleum near Dayton, N. Mex.: U. S. Geol. Survey Bull. 541, 1914, pp. 135–140.
New York	Upper Devonian.	do	do	Bacon, R. F., and Hamor, W. A., The American petroleum industry, vol. 1, 1916, p. 83.

TABLE 2.—*Geologic age and lithology of reservoir rocks and nature of hydrocarbon content, by States*—Continued.

State.	Geologic age.	Reservoir rocks.	Kind of petroleum.	Reference.
Ohio	Ordovician, Silurian, Devonian, Carboniferous.	Sandstone in shale, limestone.	....do	Stout, Wilber, Geology of southern Ohio: Geol. Survey of Ohio, 4th ser., Bull. 20, 1916, pp. 665–667.
Oklahoma	Carboniferous	Sandstone and limestone.	Paraffin-base and asphalt-base.	Shannon, C. W., Petroleum and natural gas in Oklahoma: Okla. Geol. Survey Bull. 19, Part I, 1915, 134 pp.
Pennsylvania	Devonian, Carboniferous.	Sandstone, some limy sandstone.	Paraffin-base	Munn, M. J., Claysville, Pa.: U. S. Geol. Survey Folio 180, 1912, p. 2.
Tennessee	Carboniferous	Limestone	....do	Glenn, L. C., The Glennary oil field: Tenn. State Geol. Survey, vol. 8, 1918, pp. 210–219.
Texas	Carboniferous, Cretaceous, Tertiary.	Sand, sandstone, limestone, serpentine, sandy shale, and sandy limestone.	Paraffin-base and asphalt-base.	Udden, J. A., Baker, C. L., and Boese, Emil, Review of the geology of Texas: Univ. of Texas Bull. 44, 1916, pp. 128–135.
Utah	Carboniferous	Sandstone	Paraffin-base	Woodruff, E. G., Geology of the San Juan field, Utah: U. S. Geol. Survey Bull. 471, 1912, pp. 76–104.
Washington	Cretaceous (?), Tertiary.	Sand, sandstone, and shale.	Paraffin-base; no production.	Lupton, C. T., Oil and gas in the western part of Olympic Peninsula, Washington: U. S. Geol. Survey Bull. 581, 1915, pp. 23–81.
West Virginia	Devonian, Carboniferous.	Sandstone, some limy sandstone.	Paraffin-base	White, I. C., Oil and gas well records: West Va. Geol. Survey, vol. 1, a, 1904, pp. 508–509.
Wyoming	Carboniferous, Cretaceous, and Tertiary.	Sand, sandstone, and shale.	Asphalt-base; paraffin-base.	Jamison, C. E., The Douglas oil field, Converse County, and the Muddy Creek oil field, Carbon County, Wyo.: Wyo. Geol. Survey Bull., ser. 3B, 1913, 50 pp.; Trumbull, L. W., Light oil fields of Wyoming: Wyo. Geol. Survey Bull. 12, 1916, pp. 123–130.

LIMESTONE, DOLOMITE, AND CHALK RESERVOIRS.

The main constituent of limestone is calcium carbonate. Most limestones are more or less impure, containing some clay or sand. As a reservoir rock, limestone usually holds the oil in crevices or small cavities or in porous sandy parts. Many oil men believe that production from limestone reservoirs declines rapidly.

Beds of gypsum are sometimes mistaken for limestone. Suspected limestone cuttings may be easily tested by dropping a few of the cuttings into a small glass container of dilute hydrochloric (muriatic) acid. Limestone and dolomite will effervesce in the acid.

Dolomite is a variety of limestone containing magnesium, and the term "dolomite" is sometimes loosely used by geologists as equivalent to magnesian limestone. Dolomitic limestones as well as dolomite occur in crystalline masses.

Oolitic limestone, which consists of small round grains that in drill cuttings frequently resemble sand, is occasionally an oil and gas reservoir. Chalk represents a marine ooze consisting of the skeletal material and shells of minute organisms deposited on the ocean bottom.

Most of the oil in Wayne County, Ky.,[19] is found in a cherty geode-bearing limestone called by drillers the Beaver Creek "sand." Drillers' records show that this limestone differs considerably in hardness. At many wells oil will rise in the hole after the drill enters the "sand," but usually shooting with nitroglycerin is necessary in order to get a satisfactory production.

The famous gusher wells of the Spindletop and the Batson salt domes, Texas,[20] tapped a porous crystalline limestone which apparently does not extend beyond the limits of either pool. Cavernous limestone is the reservoir for oil in many of the saline domes of Louisiana and Texas. At Bryan Heights, Tex., oil is found in crystalline limestone and in one well the drill was reported as dropping in rock crevices between 598 and 611 feet. Much of the limestone of the Gulf coast is dolomitic and so highly porous or cavernous that there is often loss of fluid and no returns to the surface in drilling with rotary tools.

The Trenton limestone[21], comprising alternate beds of shale and crystalline limestone with an average total thickness of 125 feet, is the most important oil-bearing rock in western Ohio.

The Wheeler sand[22] of the Cushing field, Oklahoma, changes from an impure to a sandy limestone.

In the Glenmary oil field, Tennessee,[23] the oil comes from fissures in the St. Louis limestone. The fissuring is not uniform; one hole may be drilled into an unusually open set of fissures, whereas the next hole will strike limestone entirely without fissures. In the Caddo oil field of northern Louisiana, oil of light gravity and gas are found in the Anona Chalk, a reservoir composed of chalky layers with many fossil fragments.

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[19] Munn, M. J., Oil and gas fields in Wayne and McCreary Counties, Kentucky: U. S. Geol. Survey Bull. 579, 1914, 105 pp.

[20] Harris, G. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, 1910, p. 24.

[21] Stout, Wilber, Geology of southern Ohio: Geol. Survey of Ohio, 4th series, 1916, p. 666.

[22] Aurin, Fritz, Correlation of the oil sands in Oklahoma: Oklahoma Geol. Survey Circ. 7, 1917, p. 7.

[23] Glenn, L. C., The Glenmary oil field: Tennessee Geol. Survey Bull. 3, vol. 8, 1918, p. 218.

In the Ranger field, Texas, the oil in the Marble Falls formation occurs in a "tight" black limestone. Usually the "lime" must be shot in order to get production. In the Desdemona field, Texas, the oil occurs near the top of the "black lime."

SAND AND SANDSTONE RESERVOIRS.

Sand and sandstone consists of subangular and rounded grains. Cuttings from a sand stratum consist of separate loose grains, whereas those from a sandstone will have fragments composed of adhering grains with fractures crossing the grains. Usually the grains are cemented with silica, oxide of iron, or limy material. In some sandstones the grains are calcareous. Both sandstones and sands are usually porous.

SANDSTONE.

Sandstone is the most common reservoir for oil and gas in the States of New York, Ohio, Pennsylvania, and West Virginia, and is common in many other States. The productive sandstone strata, as well as the beds of coal and other beds economically important, have been given distinctive names, many of which are firmly established over areas of thousands of square miles. Condit [24] notes, however, that "the oil men are far from consistent in their use of several of the names. * * * For example, the term 'Second Cow Run' is applied to almost any sand 100 to 500 feet below the First Cow Run. The same 'sand' may be designated by several names in different localities."

Although the reservoir rocks are called sands, they are really firm, porous sandstones, in many places interbedded with shale or "slate," and sometimes they must be shot with nitroglycerin before they yield oil. Sandstone strata differ widely in texture and hardness. For example, the Big Injun sand, one of the most persistent of Pennsylvania, West Virginia, and Ohio, is described by Stout [25] as being, in Ohio, a sandstone with shaly members and generally producing salt water; in the Claysville quadrangle, Pennsylvania, Munn [26] describes it as 100 to probably 350 feet thick, including in places a shale "break," 10 to 80 feet thick near the middle. This sandstone usually contains one to three lenses of coarse sand and small pebbles, which form the "pay streaks"; however, in some places these lenses furnish large quantities of salt water. In West Virginia, according to White,[27] the Big Injun oil sand of the drillers is a hard and often

[24] Condit, D. Dale, Structure of Berea oil sand in Summerfield quadrangle, Ohio: U. S. Geol. Survey Bull. 621–n, 1916, p. 223.

[25] Stout, Wilber, Geology of southern Ohio: Geol. Survey of Ohio 4th series, 1916, p. 658.

[26] Munn, M. J., Claysville Folio: U. S. Geol. Survey Geol. Atlas 108, 1912, p. 2.

[27] White, I. C., Petroleum and natural gas: West Virginia Geol. Survey, vol. I A, 1904, p. 79.

fine-grained gray sandstone, with usually two, and occasionally three or four open, coarse, and porous layers, in places pebbly, filled with oil, gas, or salt water. Other productive sandstones, such as the Berea, Dunkard, and Upper Salt, in many places comprise alternating layers of sand and shale.

In Oklahoma, oil and gas are produced from the sandstone portions of the Bartlesville "sand," described by Shannon and Trout[28] as the most widely known oil sand in the State. More oil has been produced from this sand than from any other formation in Oklahoma. It is not oil bearing in all its areal extent. According to Beal,[29] the Bartlesville "sand," which yielded the big production in the Cushing field, ranges in thickness from a few inches to about 200 feet (Cushing field) and in porosity from a compact shale to lenses of porous coarse-grained sandstone.

The so-called Ranger or McClesky sand of north Texas, which lies within and about 250 feet below the top of the Marble Falls limestone, consists of small lentils of quartzitic sandstone bedded in shale and limestone.

SAND.

Oil-bearing sands of Upper Cretaceous, Tertiary, and Quaternary age are usually incoherent and often cause much trouble in the drilling and maintenance of wells. Oil fields in Louisiana, Texas, and California furnish examples of sand reservoirs.

With the exception of those in the Sunset field[30] and the Kern River field,[31] the oil and gas reservoirs of California have not been named so commonly as those of nearly all other fields in the United States, probably because the structural conditions are so complex that no single stratum shows wide continuity in any given field. Consequently, productive strata are named by zones. Identified marker formations, however, usually bear some name.

Arnold and Anderson[32] describe a reservoir sand, typical of California fields, in discussing conditions in the West Side Coalinga field. Guthray No. 1, which was the biggest gusher of this part of the field, is said to have ejected enough sand when it came in to cover the derrick floor and the surrounding ground more than 6 feet deep. The oil, water, and gas sands in all California fields are unconsoli-

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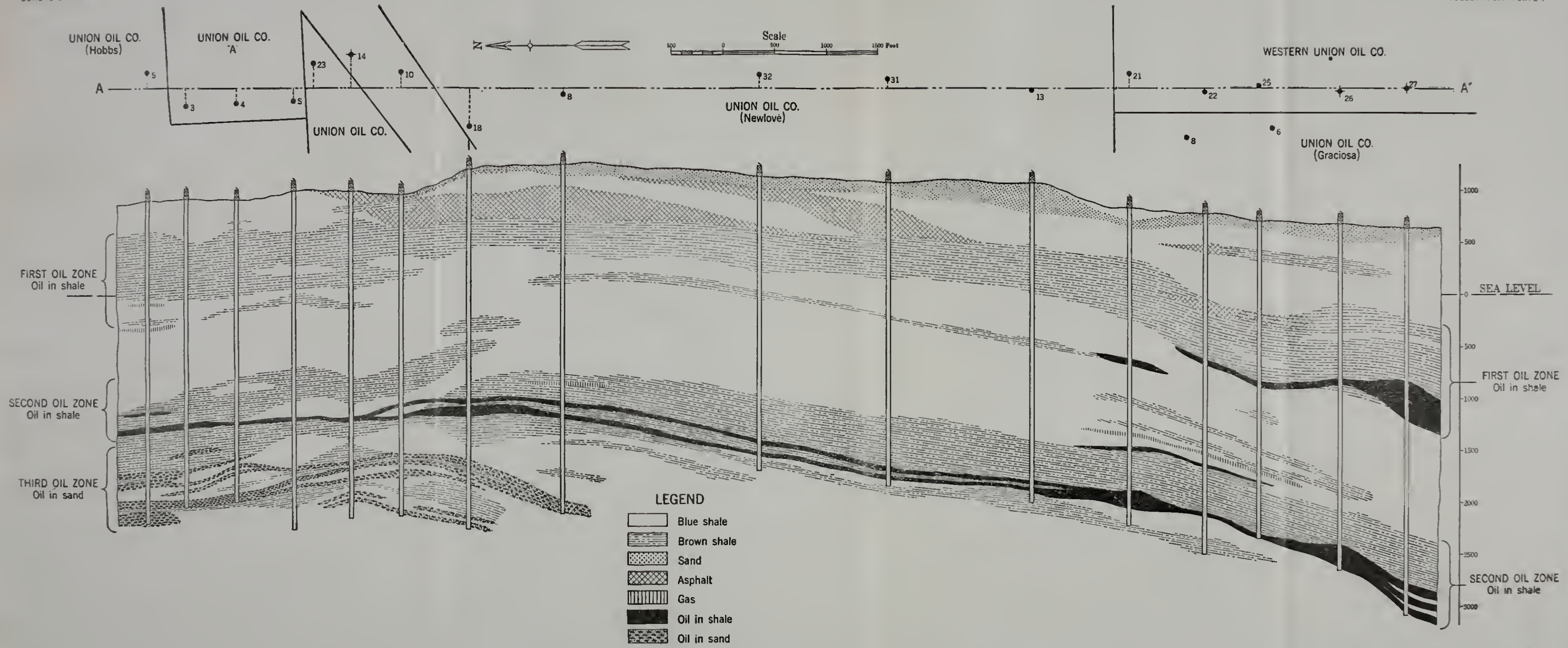
[28] Shannon, C. W., and Trout, L. E., Petroleum and natural gas in Oklahoma: Oklahoma Geol. Survey Bull. 19, part 1, 1915, pp. 35–36.

[29] Beal, Carl H., Cushing oil and gas field, Oklahoma: U. S. Geol. Survey Bull. 658, 64 pp.

[30] Ferguson, R. N., Sunset field, California: California State Mining Bureau Bull. 82, 1917, pp. 234–236.

[31] Ferguson, R. N., Report on cause of damage by water in the southwestern portion of the Kern River oil field, Kern County, Calif.: 5th Ann. Rept., California State Mining Bureau, vol. 5, 1919, pp. 13–15.

[32] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district: U. S. Geol. Survey Bull. 328, 1910, p. 207.



WELL-LOG CROSS SECTION, SANTA MARIA OIL FIELD, CALIFORNIA

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dated. A cross section of wells in the Santa Maria field, California (see Pl. I), shows a combination of Californian conditions with oil and gas in a sand reservoir and also in a shale reservoir.

Oil and gas occur in sand reservoirs in both the "salt dome" and the "stratum" oil fields of the Gulf border of Louisiana and Texas. For example, Harris[33] mentions a well in the Anse La Butte dome, Louisiana, which produced 2,400 to 2,700 barrels of oil daily, including fine sand and about 35 per cent water. Another well penetrated a gas stratum that produced a large amount of gas, blew water and sand out in great quantities and buried the machinery 5 feet deep. In the Bull Bayou field of Louisiana and the Burkburnett field of Texas fine-grained sand is a constant source of trouble in pumping wells.

The operator, drilling either in unconsolidated beds overlying firmer productive strata, as in north Texas or California, or into loose sand reservoirs, as described above, knows that he faces problems entirely different from those met in areas of sandstone, shale, and limestone. These requirements, as applied to prospecting and testing, are discussed under the subject of well-drilling methods.

SHALE RESERVOIRS.

Shale is consolidated mud or clay the water of which has been largely expelled under the influence of pressure. Clarke[34] gives the water content of average shale as 5 per cent. Usually a close-grained shale forms the impervious seal above and below an oil and gas stratum of more porous material, but sandy shale, or a fractured, flinty shale, or a shale composed of absorbent material such as skeletons of diatoms, may be a reservoir for oil and gas. Bituminous shale,[35] showing no free oil, is also common.

Shale is the only reservoir rock of the argillites—clay, shale, and slate. Clay is usually so plastic or contains so much tightly-held water that it makes a better barrier than a reservoir for oil, and slate is so indurated that very little pore space remains for accumulation of petroleum. In the geologic column the argillites change from soft clay in the youngest formations to shale, slate, or some metamorphic rock even harder in the oldest formations.

Diatomaceous shale[36] is economically important as the source of at least some oil. A large amount of oil in the productive fields of

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[33] Harris, G. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, 1910, p. 38.

[34] Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 491, 1911, p. 522.

[35] Winchester, D. E., Oil shale of northwestern Colorado and adjacent areas: U. S. Geol. Survey Bull. 641, 1917, p. 163.

[36] English, Walter A., Geology and oil prospects of the Salinas Valley Parkfield area, California: U. S. Geol. Survey Bull. 691–h, 1918, pp. 219–250.

California [37] is believed to have come from the diatomaceous " mother shales." In many beds diatomaceous shale is white and is commonly called " chalk rock," but it is easily distinguished from chalk in that it is not acted upon by ordinary acids.

The Monterey shale (Tertiary) of California, called " bituminous " by early geologists, contains thick beds of diatomaceous material. In Santa Barbara County, Calif., [38] oil occurs in the soft, porous brown shale of the upper Monterey and also in the fractures and crevices of the flinty, highly silicified shale at the base of the Monterey. A third oil zone, still deeper, finds reservoirs in strata of loose, fine-grained sand. (See Pl. I.) Oil also occurs in brown shale in the North Belridge oil field, Kern County, Calif. Shale oil is found mostly where a fairly compact shale has been fractured by folding and faulting.

In the Florence oil field, Colorado, oil occurs in an irregular zone in the Pierre shale. Washburne [39] says the oil does not follow any bed or series of beds in the shale. The oil zone does not contain any sandstones or other porous beds capable of acting as reservoirs, and the oil lies in joints and fissures. Because of this irregularity, none of the ordinary rules for correlating strata hold in this field, and, what is more important, drilling a well there is more than usually uncertain. The gas struck in drilling a new well may ruin an adjacent well by tapping the source of pressure. Many wells drilled within a few feet of each other have failed to find oil at the same depth.

In the Corsicana field,[40] Texas, the oil " sand " is a highly siliceous, soft gray shale.

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[37] Anderson, Robert, and Pack, R. W., Geology and oil resources of west border of San Joaquin Valley north of Coalinga, Calif.: U. S. Geol. Survey Bull. 603, 1915, pp. 197–198.

[38] Collom, R. E., Bituminous Monterey shales of Santa Maria district: California State Mining Bureau Bull. 73, 1916, chap. v, pp. 205–211.

[39] Washburne, C. C., The Florence oil field, Colorado: U. S. Geol. Survey Bull. 381–d, 1910, pp. 514–523.

[40] Harris, G. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, 1910, p. 31.

IMPERVIOUS BARRIER ROCKS.

Barrier rocks are prominent, relatively impervious formations, such as shale, clay, slate, silicified sandstone, quartzite, or limestone. They are important for two reasons: (1) An impervious stratum is a warning of the possibility of oil, water, or gas, as an oil or gas reservoir is always covered by such a stratum; (2) The casing must be landed in some such formation to shut off water or to prevent migration of oil and gas into porous barren strata. Generally the formations that drill the hardest can be most accurately logged, as they are easier to identify than an underlying porous stratum of unknown content.

One of the fundamental requirements for oil and gas accumulation is a reservoir with an impervious envelope. Clay, shale, slate, compact limestone, quartzite, silicified shale, or chert may form the barriers for the fluid or gas. The term "impervious" is not used in the absolute sense, because unquestionably most of the barrier rocks are not only partly filled with water [41] but are amenable to capillary transfusion of fluid. Just as water entering an oil sand prevents passage of oil into a well, so in many places the water of saturation in a clay or shale assists in preventing the passage of oil from the reservoir.

An impervious parting or "break" is usually considered necessary between an oil or gas stratum and a water stratum, except, of course, the edge water of the anticlinal theory. In stating any serious oil-field water problem one should not say that "the oil and water occur together" until after every possible scientific means has failed to establish the presence of a break between oil and water. Accurate knowledge of impervious strata or breaks within an oil zone is essential for remedial or protective work in a group of wells.

Impervious strata are important in well drilling, as casing is landed or cemented in them to shut off water. Sometimes a suitable stratum in which to shut off water is hard to find. Such a stratum may be a "shell" 1 or 2 feet thick or a body of clay several hundred feet thick. Next to the actual finding of oil or gas, if present, the correct identification of stratigraphically uniform, impervious strata in which to land casing for water shut-off is the most important feature of prospecting and testing interrelated strata.

CLAY, SHALE, AND SLATE.

Clay, shale, and slate differ mainly in hardness. A compact clay is an ideal formation in which to land casing to shut off water.

[41] Johnson, R. H., Water displacement in oil and gas sands: Mining and Metallurgy, No. 157, sec. 7, January, 1920, p. 157.

Clays are more common in beds of Quaternary, Tertiary, or Cretaceous rocks than in older rocks.

Bodies of soft shale or clay are needed in rotary drilling. Rotary mud consists of the finely divided material from shale or clay cuttings, and therefore, where shale or clay is absent, good mud can not be made. When beds of loose, running sand have to be drilled, this lack of mud is serious. The author knows of a "wildcatter" who had to haul mud a long distance from other wells to get enough to "prime" his hole for rotary drilling in an area of firm shale and loose sand.

Clay is sometimes of importance in solving problems of areal geology. For instance, the Beaumont clay, probably the latest member of the Gulf coastal deposits, according to Kennedy,[42] may be said to form the surface of nearly the whole Gulf coast region. The clay beds themselves are irregular; in places they are massive and because of their toughness and tenacity are frequently called "gumbo" by drillers. Throughout the whole of the Beaumont clay area, the only means of obtaining any information relative to structure or thickness is by well logs, and these rarely show the color of the material penetrated or differentiate the beds.

The shallow producing sands of the salt domes at Spindletop and Jennings, Tex., are sealed by overlying clays. Clay is frequently recorded in logs of wells drilled in California. The term "gumbo" occurs often in logs from Louisiana and Texas.

The gradation from clay into shale is indefinite. Frequently a given stratum is logged as clay at one well and as shale at another. Udden suggests that the best practical distinction between clay and shale is to classify as clay only such material as is entirely soft and plastic, and to regard as shale any argillite which comes up in fragments on the bit or in drillings. Light-colored shale is sometimes erroneously called soapstone. True slate, an argillite in which slaty cleavage has been developed by mountain-building forces, is seldom found in drill cuttings.

FLINT, CHERT, QUARTZITE, SILICIFIED SHALE, SILICEOUS LIMESTONE.

The very hard and comparatively thin layers known to drillers as "shell" usually consists of some silicified rock. A large variety of rocks has been formed from siliceous oozes, that may have contained clay, sand, or calcareous matter in varying amounts. Siliceous concretions or layers are common in many limestones.

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[42] Kennedy, William, Coastal salt domes: Bull. S. W. Assoc. Petroleum Geol., vol. 1, 1917, pp. 38–40.

According to Udden[43] flint is a little harder than the steel in a file. It will cut glass and indent some steel. It may have any color, but in drill cuttings is usually gray or grayish white. Flint and chert break into sharply angular fragments like glass.

Acids do not affect quartzitic materials which can, therefore, be readily distinguished from limestone.

Quartzite represents sandstone that has been greatly hardened by pressure or by infiltration of siliceous material. A quartzite will break across the sand grains rather than around them.

These hard substances resist the drill. Usually a percussion bit can combat shells with better success than a rotary bit, which is more easily worn. Shells are easy to log because drilling in them is slow. It frequently happens that the bit breaks through a shell into an oil, gas, or water bearing stratum. Shells form limited markers.

MARKER ROCKS AND MINERALS.

Marker rocks are those reservoir rocks and barrier rocks that because of their persistence and uniformity in texture, content, color, or some other special quality, are easily identifiable as markers or key beds. A bed of fossils or shale or limestone, or of coal or chalk may become a marker. The areal extent of any marker depends on the geologic structure.

The red rock[44] of Coalinga, Calif., is as important a marker for detail work as the Oswego lime[45] of Kansas and Oklahoma. Markers must be easily recognized in drilling.

The use of markers in oil-field practice falls into two general classes. Markers may be used as guides to structure over wide areas. Such markers are the No. 6 coal of Illinois or the Greenbrier limestone of the Appalachian fields. They may be used in any one field for working out such drilling problems as depth to land casing, probable depth to oil, and maximum depth to drill, which will be discussed later under well-drilling methods. Fossil sea shells often serve to distinguish a marker. The No 6, or Herrin, coal and the associated Fusulina-bearing limestone, is one of the most important markers in the oil fields of Illinois. The value of coal as a marker is discussed on p. 37.

The chief oil sands of Illinois lie unconformably below the Pennsylvania series in the Chester group of the Mississippian. The red

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[43] Udden, J. A., Aids to the identification of geologic formations: Univ. of Texas Handbook Series No. 1, 1919, p. 37.

[44] Kirwan, M. J., 1st Ann. Rept. State oil and gas supervisor: California State Mining Bureau Bull. 73, 1915–16, pp. 62–63.

[45] Green, F. C., A contribution to the geology of eastern Osage County: Bull. Amer. Assoc. Petroleum Geol., vol. 2, 1918, p. 119.

shales[46] of the Chester group are important markers for oil drillers in southern and south-central Illinois because they discolor the bailing water. They average about 15 feet in thickness.

In Ohio, Pennsylvania,[47] and West Virginia one of the most easily recognizable markers from which to estimate depths to lower sands is the Greenbrier limestone, or "Big Lime," of the Mauch Chunk formation, Mississippian series. In some places this limestone is parted by shale and is known to the drillers as the Little Lime and the Big Lime. It is supposed to be identical with an oil sand in southeastern Ohio and in the Milton field of Cabell County, W. Va., according to White,[48] but that sand may be a limy part of the Keener sand (top of the Big Injun sand). The shale parting is known to the drillers as the "pencil cave" because its tendency to cave into the well in pencil-shaped fragments during drilling. This limestone has been traced by well records westward from Maryland and its outcrop on Chestnut Ridge and Laurel Ridge, Pa., where it has been correlated with the Greenbrier limestone of Virginia.

The Burgoon sandstone, or Big Injun sand, which underlies the Big Lime, extends throughout southwestern Pennsylvania, West Virginia, and much of eastern Ohio.

A well-defined sand in the Mauch Chunk series underlies nearly all of West Virginia.[49] It was first discovered near Sistersville, Tyler County, W. Va., and named the "Maxton" sand. It lies a short distance below the top of the first "red beds" below the Pottsville conglomerate, whereas the "pencil cave" lies below the Maxton sand and immediately on top of the main Greenbrier limestone. The records of many old wells in Kentucky show that the Mauch Chunk sequence of (1) "red rock," (2) sandstone, and (3) limy shale, was encountered in widely separated places.

The black shale (Albany or Chattanooga shale) of the Devonian is considered a good marker in Allen County, Ky.[50] In Michigan,[51] however, the drillers are likely to confuse the black Antrim shale of the Devonian with the Utica shale of the Ordovician. The latter is easily recognized in drilling, as it is black, bituminous, and of fairly uniform thickness. In Mississippi the Selma chalk is so well defined as to constitute a good marker for working out structure.

In Kansas and Oklahoma, where well records provide data for wide areas, the lateral persistence of beds of the Pennsylvanian age

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[46] Blatchley, Raymond S., Oil and gas in Bond, Macoupin, and Montgomery Counties, Ill.: Illinois State Geol. Survey Bull. 28, 1914 p. 33.

[47] Munn, M. J., Claysville Folio: U. S. Geol. Survey Atlas 108, 1912, p. 3.

[48] White, I. C., Oil and gas: West Virginia Geol. Survey, vol. I (a), 1904, p. 79.

[49] Jillson, Willard R., Mineral and forest resources of Kentucky: Vol. I, series V, No. 2, 1919, pp. 88–125.

[50] Miller, A. M., Geology of Allen County: Department of Geol. and Forestry of Kentucky, ser. 5, vol. 1, 1919, p. 227.

[51] Smith, R. A., The occurrence of oil and gas in Michigan: Michigan Geol. and Biol. Survey Pub. 14, Geol. Series 11, 1912, p. 23.

has enabled the geologist to study broad problems of origin and accumulation. The Pennsylvanian system[52] is composed of many varieties of shale, sandstone, limestone, clay, and coal. Records showing transitions of lithology within certain persistent beds have furnished the basis for many interesting geological theories. Possibly these opportunities for study of the broad geologic problems have enticed engineers in Mid-Continent fields from a detailed study of smaller units of area.

Green[53] believes that the "pink lime" of the drillers, one of the most persistent beds encountered in Osage County, Okla., is continuous with a bed of equal persistence in southeastern Kansas and southwestern Missouri, where it lies about 80 feet below the Fort Scott limestone. It is the first important limestone above the Bartlesville sand and is usually 3 to 15 feet thick. The interval from the "pink lime" to the base of the Oswego, or Fort Scott, increases from 100 feet to over 300 feet from north to south. Several oil sands lie between the Oswego and the "pink lime."

Although Green indicates that the "pink lime" is a reliable marker for drilling into the Bartlesville sand, Berger[54] believes that drillers apply the name to any limestone that they happen to strike below the "Oswego"; he finds in some places as many as six limestones below the Oswego, and in many logs the color of the "pink lime" is recorded as white, so that color is not always a reliable guide in recognizing this marker. Berger believes that what is considered the Bartlesville sand in Osage and Washington Counties is not the same sand throughout; any producing sand that the driller may strike 200 feet to 600 feet below the Fort Scott limestone being called Bartlesville.

From the foregoing statements the reader will see that marker rocks are often noted in well data from several States. They satisfy the two general requirements already mentioned. Some markers, however, are peculiar only to one oil field, as in most of the oil fields of California, where the general geological value of marker rocks or of fossil shells found in drilling is secondary, because the sands are not persistent laterally.

In the Coalinga East Side field, California, are at least two important markers, the "red rock" and the "black shale," which exist only in that area. The "red rock," as shown by the line A′–A in Plate II, furnishes a good datum for correlating well-log cross-sections and estimating depths at which to land casing and the

[52] Moore, Raymond C., Oil and gas resources of Kansas: Kansas Geol. Survey Bull. 3, 1917, p. 86.

[53] Green, F. C., A contribution to the geology of eastern Osage County: Bull. Amer. Assoc. Petroleum Geol., vol. 2, 1918, p. 119.

[54] Berger, Walter, Discussion of paper on A contribution to geology of eastern Osage: Bull. Amer. Assoc. Petroleum Geol., vol. 2, 1918, p. 123.

probable depth to oil. The "black shale" lies just above the oil sand; it gives warning of the proximity of oil and is considered the proper stratum in which to land casing to shut off water. In the Cat Canyon oil field, Santa Barbara County, California, a "heaving" tar sand at variable distances above the oil sands is an excellent marker for correlating strata. In the Santa Maria field, California, the top of the "big brown" shale is the principal marker. In other fields a persistent "shell," a white water sand, a tar sand, a bed of sea shells, or a distinctly colored shale may serve as a marker. The cross section, Plate II, shows the uses of a marker in estimating the depth at which to land casing to exclude water from an oil sand.

A thorough discussion of the value of paleontological markers can not be given here. Fossil sea shells, practically unbroken, are often brought up in well cuttings from considerable depths. A fossil-shell bed of considerable lateral extent may be an excellent guide to the driller and engineer, even though the fossils themselves can not be identified. Blatchley,[55] in discussing the Herrin coal as a marker, says that a thin layer of shale usually overlies the Herrin coal, and over the shale is a very persistent limestone that contains a small fossil (Fusulina) about the size of a large grain of wheat, and fragments of this fossil have been distinguished in drill cuttings. In Illinois bryozoan spines and sponge spicules are also readily recognized in drill cuttings.

Harris[56] gives a detailed account of the use of "sea-shell" evidence in correlating and determining the age of oil sands in the Jennings oil field, Louisiana. Only 13 species could be determined, but the horizontal and vertical distribution of one of these species, *Rangia johnsoni*, was traced. The highest level at which the species occurred in any well was marked on a map of the field. These data showed that the fossil was found only in wells in the eastern part of the field and that the marker thus obtained indicated the presence of two mounds there.

Fragments of fossil-bearing rock are sometimes ejected from a well by the explosion of a heavy shot of nitroglycerin. L. A. Mylius, of the Illinois State Geological Survey, in a letter to the writer, says that a shot of 360 quarts of nitroglycerin at a well in Illinois blew out pieces of Trenton limestone that contained some characteristic Ordovician fossils.

In California fossils are often found in the oil sand produced with the oil; sharks' teeth are found in oil sand of the Coalinga field. Table 3 cites examples of the occurrence of fossil material as shown in the paleontological collection of the fuel-oil department of the Southern Pacific Co., Midway-Sunset field.

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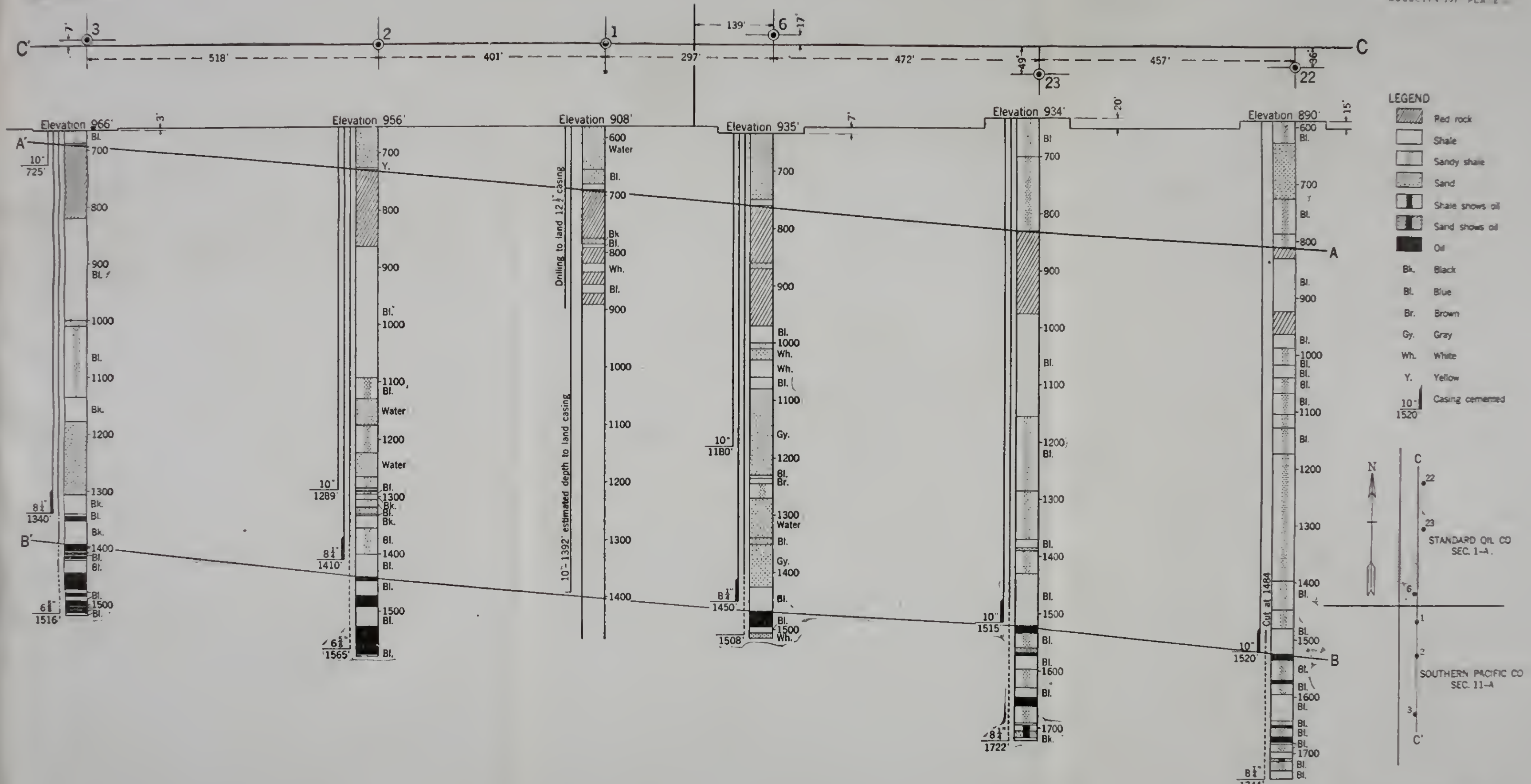
[55] Blatchley, R. S., Geology of Illinois: Illinois Geol. Survey Bull. 22, 1915, p. 28.
[56] Harris, G. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, 1910, pp. 56–59.



WELL-LOG CROSS SECTION, COALINGA OIL FIELD, CALIFORNIA, SHOWING THE USE OF RED ROCK MARKER

TABLE 3.—*Fossil shells from wells penetrating oil and gas formations.*[a]

Company.	Well No.	Location.			Depth and nature of bed.	Name of fauna.
		Sec.	T.	R.		
Southern Pacific Co.	16	31	12	23	Oil sand, 1,580 feet	*Panopea generosa.*
Do	4	5	32	23	Oil below gas sand	*Arca trilineata.*
United Oil Co.	9	6	32	23	Blown out of well from oil sand	Several species.
Southern Pacific Co.	11	25	31	22	Blown out of well from oil sand at 2,800 feet	*Echinarachinus gibbsii.* Pecten, species.
Midway Consolidated Oil Co.	4	4	32	23	Blown out of well from oil sand struck at 3,437 feet	*Echinarachinus excentricus.*
Midway Premier Oil Co.	1	5	32	23	Blown out with gas from unknown depth	Etchegoin, species.
Southern Pacific Co.	25	1	11	24	Blown out of well from oil sand at 1,015 feet	Species not named.
C. C. M. & O. Co.	10	6	32	23	From oil sand at 1,539 feet	Do.
Southern Pacific Co.	4	35	32	23	Fossils blown out of well from gas bed at 2,035 feet	Do.
Standard Oil Co.	1	22	31	23	From oil sand at 2,300 feet	Cryptomya and other genera.

[a] Data through courtesy of E. G. Gaylord, geologist, Southern Pacific Co.

INDICATORS OR SIGNS OF OIL OR GAS.

Indicators are those rocks or minerals that may be or are considered indicators or signs of oil or gas. They may outcrop or be found in drill holes at considerable depth. Indicators include asphaltum, some gases, ozokerite, sulphur, salt, coal, and waters having a certain mineral content.

A number of substances are recognized as indicators of oil or gas either at the surface or in strata penetrated by drilling. Other indicators are found on the surface only. Some substances are considered indicators in small areas. Popular significance is often placed on a particular substance, such as the so-called "paraffin dirt" of the Gulf coast. Many fanciful theories enlist certain natural phenomena as signs of oil or gas. One promoter declared that the lack of vegetation over a large arid area in California is the direct result of diffused emanations of petroleum gas from an immense underground reservoir.

A sign of oil and gas gives no sure indication of where or how to drill. In the words of Lowe,[57] "no sign of oil is so good as a little *oil*, and yet this sign must be taken in connection with structural conditions. * * * Although these signs have their value when present, their absence is not particularly important, and territory can not be condemned because of their absence." Most of the development in the Mid-Continent fields was begun and completed without the promptings of any of the common surface signs of oil or gas.

Any true sign of oil or gas, either on the surface or in strata penetrated in drilling, must necessarily be closely related either physically or chemically to oil or gas. A discussion of these signs, therefore, falls under the following classification of petroleum, natural gas, and the more common associated hydrocarbons, which is an abridged form of a classification of hydrocarbons, by Eldridge.[58] In this discussion some substances with which the hydrocarbons are often confused will also be mentioned.

Classification of hydrocarbons.

- Hydrocarbons
  - Gaseous: Marsh gas. "Natural gas."
  - Bituminous
    - Fluid: Petroleum.
    - Viscous: Mineral tar (asphaltum). Brea.
    - Solid
      - Asphaltite: Gilsonite; uintaite.
      - Coal: Lignite. Subbituminous. Bituminous. Semibituminous. Anthracite.
      - Bituminous shale: Kerogen. Petroliferous.
  - Cereous: Ozokerite.

[57] Lowe, E. N., Oil and gas prospecting in Mississippi: Mississippi State Geol. Survey Bull. 15, 1919, pp. 16–18.

[58] Eldridge, G. H., Origin and distribution of asphalt and bituminous rock deposits in the United States: U. S. Geol. Survey Bull. 213, 1903, pp. 296–297.

GASES.

A good flow of natural gas from a wildcat well is obviously an excellent sign of an accumulation of this particular resource if of nothing else; but the value of natural gas and the necessity of conserving it has not been realized in most fields, because oil has brought more spectacular profits. A prospector for oil usually feels that a large flow of gas is a hindrance to his operations. It would be futile to attempt to set down in figures the amount of gas that was wasted in north Texas alone in the oil development of 1917 to 1920—gas that was wasted in the face of an acute shortage of fuel for domestic and industrial uses. Millions of gallons of gasoline contained in the gas were also wasted. There is probably no other industry that operates at a profit under such enormous initial wastes.

The most common gases that arise from the earth in gas blows and springs and which may be deemed correctly or not as signs of oil or other hydrocarbons, are petroleum gas, marsh gas, hydrogen sulphide gas, carbonic acid gas, and air. Petroleum gas, the natural gas of commerce, is the only reliable indicator of the group. A seepage of natural gas may lead to the discovery of a gas field or a pool of oil and gas. Gas blows are not as easily seen as oil seepages and are, therefore, often overlooked in the search for surface signs. A definite showing of natural gas in a drilling well encourages further prospecting, but small tools have been blown out of a hole by marsh gas, which is not a sign of the proximity of oil.

TAKING A SAMPLE OF GAS.

The best way to ascertain whether or not the gas uncovered in a prospect hole is related to oil and natural gas and is, therefore, an encouraging sign, is by analyzing a sample. The chemist may be able to tell with what other substances the gas is associated in the ground. The presence of ethane (C_2H_6) or gasoline vapors is the only safe indicator of petroleum gas.

For a complete analysis the sample of gas need not be large but it must be pure. A sample can be taken in an 8 or 16 ounce bottle with a rubber-padded cap and a spring to hold the cap in place, such as is used as a container for magnesium citrate.[59] After the bottle is filled the cap or cork should be sealed with paraffin or sealing wax.

There are several simple methods of taking a sample. In one method the bottle is filled with water, held upside down in a bucket or tub of water, and the gas turned into the bottle through a rubber tube or small pipe until the gas, without any air, completely displaces

[59] Burrell, George A., and Seibert, Frank M., The sampling and examination of mine gases and natural gas: Bull. 42, Bureau of Mines, 1913, pp. 6–10.

the water. The solution of such constituents of a gas as carbon dioxide while passing through the water may be prevented by allowing the gas to blow through the water in the bottle for several minutes before the bottle is inverted and displacement begins.

A sample of gas may be taken in a bottle by passing the gas through a tube into the bottle for several minutes until all air has been expelled. If the gas is lighter than air the bottle should be held in an inverted position until corked and sealed, The method of water displacement has the advantage over this method that one can immediately see when the bottle is completely filled with gas.

If the flow of gas is too small for sampling as above, or if the gas has not been piped, a sample may be taken from the place of issue by drawing the gas into a small bellows and then injecting it into a bottle. Water displacement is recommended for this method of sampling.

NATURAL GAS.

Natural gas is designated as "wet," or casing-head, gas and "dry" gas. The distinction is purely arbitrary, and is based largely upon the removable content of gasoline vapor in the gas.

At one time any natural gas containing in 1,000 cubic feet less than 1 gallon of gasoline recoverable by the compression process was termed "dry." Most natural gas carries some gasoline vapor, however, and the use of absorption processes for recovering gasoline[60] is restricting the limits of "dry" gas.

Burrell,[61] in discussing natural gas, says:

> Almost all of the natural gas produced in the United States contains members of the paraffin series of hydrocarbons higher than methane. The ordinary combustion analyses of natural gas show only the two predominating paraffin hydrocarbons, which are ususally methane [or marsh gas] and ethane. * * * The so-called ethane gas, gas containing ethane and the higher hydrocarbons, constitutes most of the natural gas of this country. * * * Some natural gas that contains methane as the only paraffin hydrocarbon is found in Louisiana, in the Caddo fields, at a few places in Oklahoma, in the Murrysville sand in Pennsylvania, and at a few other places. This natural gas is the only kind that does not carry gasoline vapors.

It frequently happens that the natural gas from a new well under high pressure is dry, but as pressure decreases the gas begins to show gasoline. Often a simple absorption test of a doubtful gas will show the presence of gasoline and furnish a clue as to the nature of the gas.

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[60] Burrell, G. A., Biddison, P. M., and Oberfell, G. G., Extraction of gasoline from natural gas by absorption methods: Bull. 120, Bureau of Mines, 1917, p. 15; Dykema, W. P., Recent developments in the absorption process for recovering gasoline from natural gas: Bull. 176, Bureau of Mines, 1919, 90 pp.

[61] Burrell, G. A., Biddison, P. M., and Oberfell, G. G., Extraction of gasoline from natural gas by absorption methods: Bull. 120, Bureau of Mines, 1919, p. 9.

In prospecting for oil, the theory that gas comes from oil is not reliable without corroborating evidence. Fields yielding no oil produce gas in large volume. The Monroe gas field of Louisiana, the largest gas field in the United States, has produced no oil, although the gasoline content of the gas is 100 gallons to a million cubic feet. In other fields gas is found in a reservoir separate from the oil. Frequently, as in parts of the Midway field, California, the gas occurs at different stratigraphic depths over a given area, and efforts to correlate these gas sands in well cross sections are fruitless. Again, a sand may yield oil and gas in one part of a field and give gas only in another part. However, a gas well may lead to further prospecting and the development of producing oil wells.

In Indiana[62] the Emory Oil Co., following the theory that gas comes from oil, drilled in the Petersburg pool in Pike County near an old gas well and got 50 to 75 barrels of oil daily from several wells. In Davies County a gas well drilled to a depth of 380 feet led to the belief that there was an anticline in that vicinity, and as a result several oil wells were brought in at depths of about 725 feet.

The main constituent of natural gas is methane. Natural gas is usually analyzed[63] for the constituents shown in Table 4, and its specific gravity determined.

TABLE 4.—*Analysis of a dry gas and a wet gas.*[a]

	Methane or marsh gas, CH_4.	Ethane, C_2H_6.	Carbon dioxide, CO_2.	Nitrogen, N.	Oxygen, O.	Illuminants.	Helium, He.	Specific gravity.
Dry gas......	92.05	3.15	0.60	3.80	0.20	0.20	....	58.08
Wet gas.....	76.1	12.3	8.2	....	0.3	2.0	....	74.6

[a] Wescott, Henry P., Handbook of natural gas. 1915, p. 102.

MARSH GAS.

Pure marsh gas is all methane (CH_4), but sometimes marsh gas is diluted with nitrogen or other inert gases. Marsh gas is not associated with petroliferous deposits, but is found most often in areas where masses of vegetation have been buried under sediments, in streams, lakes, or marshes, and have decayed with air excluded. It burns as freely as natural gas. As marsh gas has no relation to accumulations of oil, it does not indicate the existence of petroleum at equal or greater depths.

[62] Barrett, Edward, 40th Annual Rept. State geologist of Indiana, 1915, p. 269.

[63] Burrell, G. A., and Seibert, F. M., The sampling and examination of mine gases and natural gas: Bull. 42, Bureau of Mines, 1913, p. 76.

Marsh gas occurs in many places in the great glacial drift sheets and their interrelated deposits of plant remains in the northern United States. Regarding marsh gas in Iowa, Kay and Lees[64] remark that in many places the gas evolved from the decomposition and distillation of these masses of vegetal matter found its way into pockets of sand and gravel buried in the sheets of bowlder clay left by the glaciers.

Gas escapements are so abundant in Terrebonne and adjoining parishes of Louisiana as to lead Wrather[65] to suspect that not all the gas is petroleum gas. He says that deep drilling in the sediments of the Gulf coastal plain and the Mississippi embayment has shown an abundance of deeply buried plant remains, notably tree trunks—some partly carbonized, others partly decomposed. It would seem, therefore, that part of the gas is probably marsh gas arising from this decomposing vegetal matter.

Marsh gas may have been formed and stored in time long past or it may be forming to-day. Bubbles of marsh gas are frequently seen in ponds and streams. For example, analysis of a sample of a large escapement of gas[66] that appeared on a sand bar formed by an eddy in West River at the mouth of Dead River, Miss., suggested "vegetable decomposition as the source of the gas and that it had no relation to deep-seated or petroleum gas." The analysis and a comparison with a "dry" petroleum gas follows:

Analysis of marsh gas and of "dry" natural gas.

	Marsh gas.	Dry petroleum gas.
	Per cent.	*Per cent.*
Carbon dioxide (CO_2)	4.3	0.6
Oxygen (O_2)	1.12	0.2
Carbon monoxide (CO)	0.00	0.00
Methane (CH_4)	88.4	92.05
Nitrogen (N_2)	6.1	3.80
Ethane (C_2H_6)	0.0	3.15

SULPHURETED HYDROGEN.

Smith[67] describes hydrogen sulphide, H_2S, gas as "a colorless gas with a characteristic odor, * * * very poisonous, one part in two hundred being fatal to mammals. The gas burns in air, forming steam and sulphur dioxide." Wrather[68] says that hydrogen sul-

[64] Kay, George F., and Lees, James H., Iowa Geol. Survey Administrative Report, vol. 23, 1914, p. 31.

[65] Wrather, W. E., Discussion of An interpretation of the so-called paraffin dirt of the Gulf coast fields: Bull. Am. Inst. Min. Eng., Bull. 139, July, 1918, p. 1148.

[66] Lowe, E. N., Oil and gas prospecting in Mississippi: Mississippi Geol. Survey Bull. 15, 1919, pp. 60–61.

[67] Smith, Alexander, Introduction to inorganic chemistry. 1918, pp. 415–416.

[68] Wrather, W. E., work cited.

phide gas is commonly, if not universally, present where oil is associated with salt domes. The sulphur gases may have their origin at higher levels than the oil and gas; at any rate, in these areas the presence of hydrogen sulphide gas may be said to be one of the indicators of a salt dome rather than of the presence of oil and gas.

Frequently in the salt domes where "sulphur gas" seepages occur, crystalline sulphur is found in cracks and crevices. Salt, gypsum, pyrite, sulphur water, and native sulphur are usually present in areas or wells where hydrogen sulphide gas is prominent. Hydrogen sulphide gas usually occurs mixed in varying proportions with other gases and because of its odor an impression as to the quantity of this gas present may be erroneous.

In the Casmalia oil field, California, there is much hydrogen sulphide gas; the heavy oil, which has an asphaltic base, is intimately associated with hot salt water and carries about 2.0 per cent sulphur. In the same field a prospect hole struck a stratum yielding 90,000 cubic feet daily of gas high in hydrogen sulphide; the drillers were overcome and narrowly escaped death.

The gas in the oil rock of the Spindle Top field, Texas, is poisonous. Enormous flows of this gas have come from many salt-dome wells. A flow of 6,000,000 cubic feet daily came from 7 wells in the Bryan Heights dome, Texas.

CARBONIC ACID GAS.

Carbonic acid gas, sometimes called damp or choke damp, is heavier than air. It escapes from the ground in many places, bubbles up in some mineral springs and may show as bubbles in the rotary ditch or the bailed fluid. It will not burn nor support combustion, and will put out a candle flame in a confined space. It is in no way related to the occurrence of hydrocarbons.

AIR.

Bubbles of air rising to the surface of a spring or pond are sometimes thought to be natural gas. All ground water contains air which may escape as bubbles in consequence of higher temperature or lower pressure.

PARAFFIN DIRT.

The so-called paraffin, or sour dirt, of the Gulf coast country is a yellow, waxy substance resembling paraffin or beeswax. It is popularly deemed an unfailing indication of the proximity of an oil and gas reservoir, and is supposed to be the result of natural gas emanations.

The New Iberia dome, Louisiana,[69] "was discovered primarily through the interest aroused in 'paraffin dirt' by a paper on 'Indications of oil in the Gulf coast country,'" which was written by Lee Hager, under the name of W. C. Moore. Paraffin dirt is frequently found in salt-dome oil fields. The term "paraffin"[70] is probably a misnomer as applied to this substance, and many question the supposed intimate relationship with petroleum.

AMMONIA.

Ammonia can be detected, by its strong odor, in the sandy blue shale of the oil sand of the Cat Canyon oil field, Santa Barbara County, Calif.

Udden[71] notes that ammonia fumes, recognizable by odor, are present in many shales, clays, and limestones, but may not appear until a fragment of the rock is heated.

As pointed out by Rogers[72] and amplified by Mills,[73] compounds such as ammonium sulphate are reduced directly by contact with constituents of petroleum and natural gas. Consequently the presence of ammonia in a formation penetrated by the drill may, in a way, be an indicator of the presence of oil or gas.

OIL, TAR, AND ASPHALTUM.

In the field, no definite line can be drawn between the three substances—oil, tar, and asphaltum. Petroleum oils will grade by degrees into tar, and tar grades into asphaltum. Oil-well logs and drillers use the names principally to indicate relative viscosities.[74] They may have no proper relation to the similar trade names for refinery products. Such names as fuel crude, refining crude, and asphaltum crude are the outgrowth of trade and refinery requirements.

The petroleum refiner classifies oils as "paraffin-base" and "asphalt-base" crudes. Paraffin-base crudes are those that in refining yield solid hydrocarbons of the pariffin series ($C_nH_{2n}H_{2n+2}$), and carry practically no asphalt. Asphalt-base crudes are high in asphalt and carry little or no paraffin. The crude petroleum in some

[69] Deussen, Alexander, Review of developments in the Gulf coast country in 1917: Bull. Am. Assoc. Petroleum Geol., vol. 2, 1918, pp. 36–37.

[70] Wrather, W. E., Discussion of An interpretation of the so-called paraffin dirt of the Gulf coast fields: Am. Inst. Min. Eng., Bull. 139, July, 1918, p. 1148.

[71] Udden, J. A., Handbook of aids and identification of geological formations: Univ. of Texas Handbook series No. 1, 1919, p. 68.

[72] Rogers, G. S., Chemical relations of oil-field waters in San Joaquin Valley, California: U. S. Geol. Survey Bull. 653, 1917, p. 93.

[73] Mills, R. van A., and Wells, Roger C., The evaporation and concentration of waters associated with petroleum and natural gas: U. S. Geol. Survey Bull. 693, 1919, pp. 70–71.

[74] Bacon, R. F., and Hamor, W. A., The American petroleum industry, vol. I, 1916, pp. 110–114.

ROTARY DITCH WITH OIL SHOWING ON MUD STREAM.

fields is a mixture of the two classes. An oil high in paraffin has been produced by a few wells from strata below the main asphalt-base production of the East Side Coalinga field in California. Under certain conditions, paraffin-base oils (saturated hydrocarbons) may be broken down by the action of gypsum or gypsum-bearing waters into asphaltic oils (unsaturated hydrocarbons).[75]

In a drilling well petroleum may be found in any quantity, from a whirling iridescent film on the water in the ditch, as indicated in Plate III, to a sudden and perhaps unexpected gusher flow, but all showings of oil are not necessarily signs of oil. Grease from tool joints can be easily be mistaken for a sign of oil, and holes in the ground have been "salted" with oil. Failure to find oil is not conclusive proof of its nonexistence unless the presumably favorable reservoir has been thoroughly tested.

Asphaltum or tar usually shows in the cuttings of the ditch as small fragments or balls. Because of its high viscosity, it can not be successfully pumped unless considerable heat is present underground. The production from parts of the Casmalia fields, California, that in the early days of prospecting was logged as tar, has a gravity of 8.5° to 11.5° B. A bailer can not be run down through the oil after it has stood in the well, and sometimes a string of tools is spudded through the cold oil with difficulty. Fortunately, the temperature of the oil zone is at least 146° F., and not only is the oil readily pumped, but some of the wells have come in flowing.

Strata containing asphaltum or tar are found in the higher levels of many wells during drilling and may be a sign of oil and gas at greater depth.

Oil, tar, or asphaltum may show in seepages from eroded reservoir rocks or may rise to the surface through fault crevices. The extent or the abundance of the seepage does not indicate the amount of oil or gas that may be expected from the reservoir, if one exists. Surficial remnants of a reservoir may show asphaltum and tar. A seepage of asphaltic oil may leave, by evaporation and weathering, enough asphaltum to seal tightly a considerable reservoir of oil down the slope part of the stratum. In Plate I (p. 14) the first oil zone is an example of such a reservoir. In most productive fields drilling based on such signs has uncovered a deeper uneroded reservoir that became later the chief source of production.

Oil or gas may show in a shallow water well, in a spring, or on the surface of a lake or ocean from seepage below. Sulphur water, tar, and gas sometimes flow from the same "tar spring." Where these seepages are submarine, as in the Gulf of Mexico and along the Pacific coast, the residues that rise to the surface are washed ashore. In

[75] Trumbull, L. W., Petroleum in granite: State Geologist of Wyoming, Bull. 1, 1916, p. 15.

the Gulf coast, these residues, which differ in color and other physical characteristics, are called sea wax.

CHLOROFORM TEST.

An oil formation penetrated in drilling may not show any visible oil either in the ditch or in cuttings. Consequently an operator is likely to take considerable pains to make sure that none of the porous formations being penetrated by the drill carry oil. At many wells, tests with chloroform, which will show the presence of small quantities of oil, are made with every 5-foot sample of cuttings.

Drill cuttings or crushed rock from an outcrop may be tested with chloroform by placing a tablespoonful of a fairly dry sample in a small bottle or beaker, adding enough chloroform to saturate and cover the sample, and thoroughly stirring and shaking the mixture. Any hydrocarbons such as petroleum, tar, asphaltum, or gilsonite, if present, will discolor the fluid brown, the intensity depending on the amount of hydrocarbon present.

The chloroform test indicates that a rock is petroliferous, but does not indicate the productive value; for ascertaining that, mechanical tests are necessary. The chloroform test may be used in determining stratigraphic relations, from well to well, of petroliferous but non-productive beds; such knowledge is especially useful as a guide in determining uniform depths for shutting off water. Carbon tetrachloride may be used instead of chloroform.

TAKING A SAMPLE OF OIL.

The size of an oil sample is governed by the determination desired from it. Where there is doubt as to whether the oil showing in the ditch is crude oil or lubricating oil from tool joints, an effort should be made to get a sample large enough for analysis by a chemist. Crude oil is likely to give an acid reaction, turning blue litmus paper red, but this test is not conclusive unless it is definitely known that the lubricants are not acid. The litmus test can be made by shaking equal parts of the oil and warm water in a tube and then placing blue litmus paper in the water.

The data usually required for a field test of crude oil are the Baumé gravity, the temperature, and the water content; these can be determined with simple equipment in the field. The sulphur content and the viscosity of the oil are also of value, but are more difficult to determine. A pint sample of oil is enough for gravity, temperature, and water tests.

IRON OXIDE AND MANGANESE OXIDE.

A scum or film of iron compounds on the surface of a puddle of water will show rainbow colors, and is often mistaken for an oil showing. These films of iron compounds break apart into irregular figures when stirred with the finger or a stick, but an oil film will string out along the water without breaking. Oil has a slight odor and will stain a rag; iron films will not. Iron scum is especially common in old unused wells, around bogs, and in springs. Lowe[76] is authority for the statement that "iridescent iron films or burning marsh gas or both have led to drilling most of the wells that have been put down for oil in Mississippi, and needless to say the drilling resulted in failure. Although the State geological survey has examined a great many so-called 'oil signs' in Mississippi, we have never seen a real oil escape."

Black oxide of manganese sometimes colors the cementing material between grains of sand in an outcrop or appears as a coating over the faces of fractured clay, shale, or sandstone. It resembles a carbonlike residue, but yields neither smoke nor odor when heated in a flame, nor does it burn. All of the common hydrocarbons give off smoke when burned and have an odor like oil. Neither manganese nor iron oxide is in any way connected with the occurrence of oil.

GILSONITE.

Gilsonite is a blackish, brittle substance resembling bituminous coal. Richardson[77] classifies it as the "purest native bitumen which we know, the best varieties containing 99.5 per cent bitumen, and with but traces of matter not of a bituminous nature."

Gilsonite is almost entirely soluble in either carbon tetrachloride or carbon disulphide. It is found in Colorado, Utah, and California, and usually occurs as a filling in fissures and cavities, as does vein material. Cavities filled with gilsonite, asphalt, and related hydrocarbons are considered by Clark[78] to be indicators of the possible presence of oil in parts of Utah. Gilsonite occurs in cracks and crevices in the lower part of the petroliferous Monterey shales of Santa Barbara County, Calif. In Foxen Canyon, near the Cat Canyon oil field, is an old, caved-in shaft showing crevices containing gilsonite. As an indicator for oil and gas gilsonite ranks with oil, tar, and asphaltum seepages, but offers no clue to the position or depth of the oil.

COAL.

Coal originated from vegetation that grew in swampy or marshy places. Under heat and pressure after burial the vegetable remains

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[76] Lowe, E. N., Oil and gas prospecting in Mississippi: Miss. State Geol. Survey, Bull. 15, 1919, pp. 16–17.

[77] Richardson, Clifford, The modern asphalt pavement, 1914, pp. 208–210.

[78] Clark, F. R., The Farnham anticline, Carbon County, Utah: U. S. Geol. Survey Bull. 711–A, 1919, pp. 9–10.

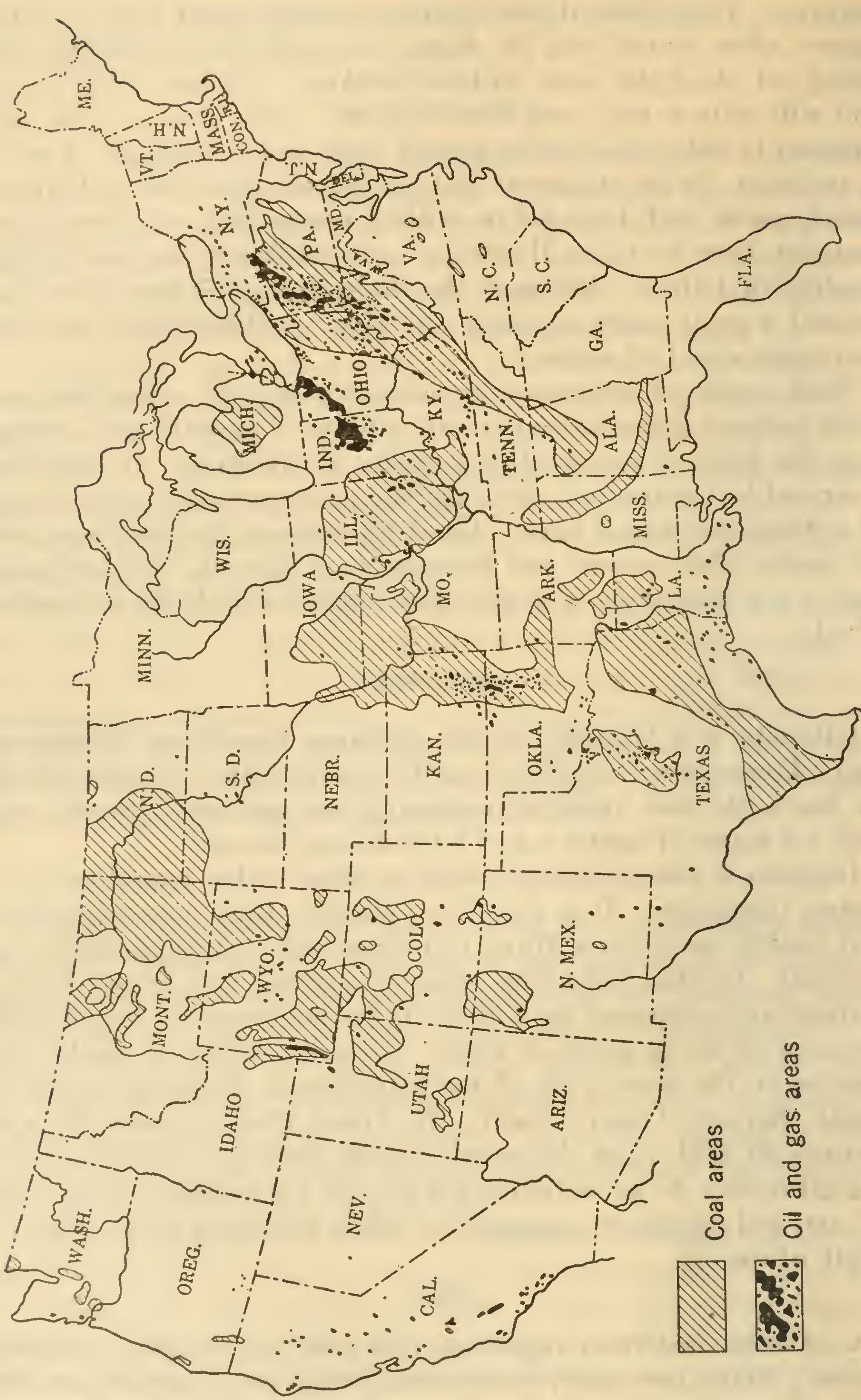

FIGURE 1.—Oil and gas and coal areas of United States.

change from peat to lignite, soft coal, anthracite, and finally to some graphitic minerals.

Coal[79] occurs in commercial quantities in 27 States, as shown in Figure 1, and in Alaska. The coal-bearing formations of the United States range in age from Carboniferous to Tertiary.

Three facts must be considered concerning the relationship of coal and oil:

1. The proximity of beds of coal to reservoirs of oil and gas; hence the possible value of beds of coal as indicators to favorable and unfavorable areas in which to drill for oil.

2. Because of their persistence and easily recognized character, coal beds are valuable markers for both detail and general correlation, as has been shown under "Marker rocks and minerals" (p. 19).

3. Careful logging of all coal strata in drilling is doubly necessary so that neither the oil field nor the coal bed will be damaged by the development of the other.

COAL AS AN INDICATOR OF OIL AND GAS.

The map in Figure 1 (p. 34) shows the areal intimacy between known coal deposits and oil and gas pools in the United States, which may be superficially explained as a coincidence of geologic segregation. Coal can occur together with oil or gas, especially the latter, only under certain limited conditions in sedimentary rocks. In some coal areas different beds of coal may grade successively from lignite to anthracite. The rocks as well as the coal in the anthracite part of the area have been subjected to pressure and heat, and most of the gases attendant upon transition[80] from vegetal matter through lignite and other stages to anthracite have been driven off. The residual coal contains a certain percentage of what is called fixed carbon.[81]

Using the fixed-carbon content of coals in various areas as a basis, White[82] shows that in those formations and regions of the United States in which the coals are but a little altered by dynamic influence—that is, where they have a low fixed-carbon ratio—the oils are heavy and of low grade. On the other hand, in regions of more advanced alteration, where the coal has a higher fixed-carbon ratio, the oils are correspondingly light and of higher grade. The highest degree of alteration of the residues usually occurs in the fields where the oils are highest grade.

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[79] Hayes, C. W., Coal fields of the United States: U. S. Geol. Survey Bull. 213, pp. 257–269.

[80] Clarke, Frank W., The data of geochemistry: U. S. Geol. Survey Bull. 491, 1911, p. 705.

[81] Fieldner, A. C., Smith, H. I., Fay, A. H., and Sanford, Samuel, Analyses of mine and car samples of coal collected in the fiscal years 1911 to 1913: Bull. 85, Bureau of Mines, 1914, pp. 12–13.

[82] White, David, Some relations in origin between coal and petroleum: Jour. Washington Acad. Sci., vol. 5, 1915, p. 203.

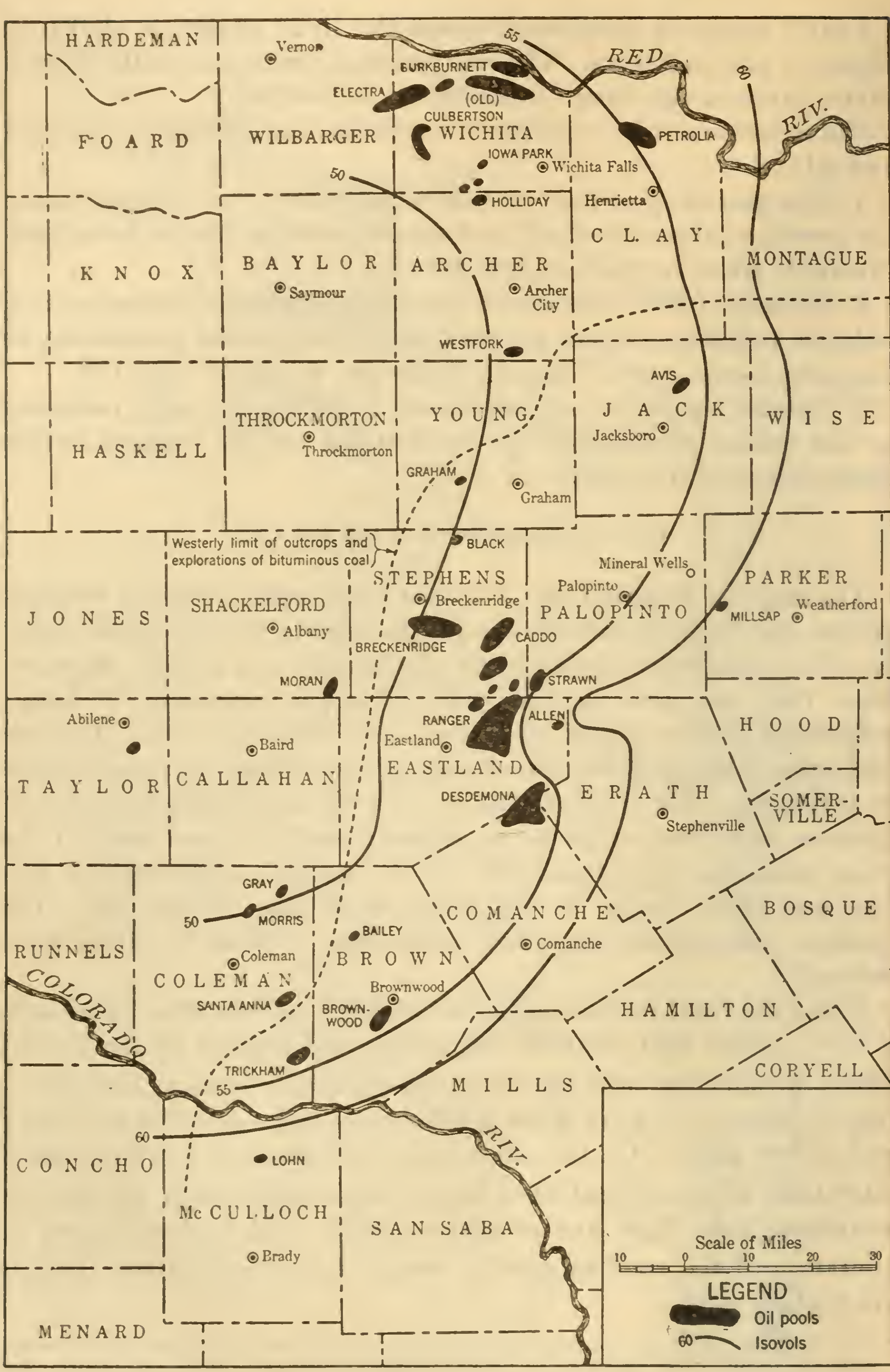

FIGURE 2.—Carbon ratios in north Texas.

White maintains that in regions where the progressive devolatilization of the organic deposits in any formation has passed a certain point, marked in most regions by 65 to 70 per cent of fixed carbon (pure-coal basis) in the associated or overlying coals, commercial oil pools are not present in that formation, nor in any other formations normally underlying it, but commercial gas pools may occur in a broader zone of higher carbonization.

By drawing lines through points of equal fixed-carbon content in a coal field, a system of lines resembling contours will be developed, which have been termed "isovols," as shown in Figure 2. The isovols show both the extent and alteration of the coals and no oil can be expected beyond the limits of isovols that show more than 65 per cent fixed carbon; or, in the words of White, "according to the conclusions here given as to oil-field limits we appear to have at hand a basis on which to exclude large areas of sedimentary strata from the provinces in which we may, with any hope of success, undertake the costly search for oil with the drill." Furthermore, the appearance in a prospect well of cuttings of carbonaceous material showing a high fixed-carbon ratio should, in the absence of encouraging signs to the contrary, constitute a reliable warning against deeper drilling.

Fuller[83] in his paper on the relation of oil to carbon ratios of coals in north Texas says that geologists are still overlooking the bearing of carbon ratios on the presence or absence of oil in prospect areas. He estimates that in the north Texas field alone not less than 25 wells, and possibly more, costing an average of $40,000 each or a total of more than a million dollars, were sunk during the year 1919 where the carbon ratios are known to be prohibitive.

The accompanying sketch of the oil fields of north Texas showing isovols of fixed-carbon ratio, Figure 2, is adapted from Fuller's paper. The westerly limits of outcrop and explorations for bituminous coal are shown on the map. Very little production is found east of the 60 per cent isovol. The use of carbon ratios in this area does not apply to Cretaceous beds overlying the Pennsylvanian. Carbon ratios, as a guide to development of oil strata, will be most reliable for rocks of the same age as those that are suspected to contain oil.

With ordinary care cuttings of coal beds can be easily obtained while drilling. An analysis of such cuttings, if no more definite information is available, should be a useful guide in prospecting for oil and gas.

COAL AS A MARKER.

A detailed description of the utility of coal beds as markers and guides in the determination of oil-field stratigraphy is too long to give here. Many other coal areas, which contain just as good examples of markers as those cited, are not mentioned.

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[83] Fuller, Myron L., Relation of oil to carbon ratios of Pennsylvania coals in north Texas: Econ. Geol., vol. 14, November, 1919, pp. 536–542.

In southwestern Pennsylvania, according to Munn,[84] the Pittsburgh coal is in the best known, most valuable, and most persistent coal bed. It usually has a total thickness, including clay and shale partings, of 8 to 14 feet. Because it is readily recognized in drilling, it has come to be used by the drillers as a key horizon throughout the area in which it occurs.

The Pittsburgh coal of West Virginia is characterized by White[85] as the great key rock of the Monongalia, Marion, Harrison, Doddridge, Wetzel, and Marshall County oil and gas fields. The bed is 10 feet thick, including roof coals.

In the Staunton gas pool,[86] Macoupin County, Ill., a stratum called the "No. 6 coal" is used as a marker. The Herrin coal, or No. 6 coal, lies about 225 feet above a producing-gas sand. It is also used as a marker for general geological correlation in the Carlyle[87] oil field and surrounding territory in Clinton, Washington, St. Clair, Monroe, and Madison Counties, Ill. Kay[88] says that although several coal beds are usually penetrated by the drill, only the No. 6 is uniform in thickness and general characteristics over a considerable area. This bed is on the average about 6½ feet thick. Black shale possibly represents the coal beds in some places.

OIL AND GAS WELLS THROUGH WORKABLE COAL BEDS.

In certain fields where oil and gas wells pass through workable coal beds, correct measurements of the position of the well and the depths at which various coal strata are passed must be determined. The importance of logging all coal-bearing formations correctly is obvious. The thin or deep unworkable coal beds of to-day may be the workable beds of the future.[89] In working a coal mine each well must be surrounded by a pillar of coal, which must be large enough to protect the oil or gas well and to prevent leakage of gas, oil, or water into the mine. Pillars in Pennsylvania and West Virginia vary from 40 feet in diameter or 40 feet square to 200 feet in diameter or 200 feet square, the well being at the center of the circle or square. Figure 3 shows a plan of mine workings with gas wells surrounded by pillars of coal.

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[84] Munn, M. J., Claysville Folio: U. S. Geol. Survey Geol. Atlas 108, 1912, p. 5.

[85] White, I. C., Oil and gas: West Virginia Geol. Survey, vol. I, 1904, p. 76.

[86] Kay, F. H., Petroleum in Illinois in 1914 and 1915: Illinois Geol. Survey Bull. 33, 1916, p. 80.

[87] Shaw, E. W., The Carlyle oil field and surrounding territory: Illinois Geol. Survey, extract, Bull. 20, 1912, pp. 1–37.

[88] Kay, Fred H., The Carlinville oil and gas field: Illinois Geol. Survey, extract, Bull. 20, 1912, p. 42.

[89] Fisher, Casius A., Depth and minimum thickness of coal beds as limiting factors in valuation of coal lands: U. S. Geol. Survey Bull. 424, 1910, pp. 48–75.

OZOKERITE.

Ozokerite is a hydrocarbon with the same chemical properties as paraffin. It differs from the latter in that ozokerite is found native and has the "doughy" consistence of beeswax. It is usually associated with petroleum. Ozokerite (meaning odorous wax) is, according to Gregorius,[90] also known as mineral wax, mineral fat, mountain tallow, rock tallow, and fossil wax, and has other names. The deposition of ozokerite, in cracks and fissures in the rocks, from petroleum takes places in "exactly the same way as is observable any day in the pipe lines from petroleum wells."

In Texas the Thrall[91] oil-field production yielded quantities of a yellow wax, identified as ozokerite, that clogged tubing in wells and stopped the flow of oil. Wells making salt water were free from ozokerite. Many tons of wax were produced and used for fuel, road material, and covering for surface pipes.

In Utah, the presence of ozokerite, as well as gilsonite and asphaltum, is considered to be a sign of oil. The only known deposits of ozokerite[92] of commercial value are those of Utah and of Galicia.

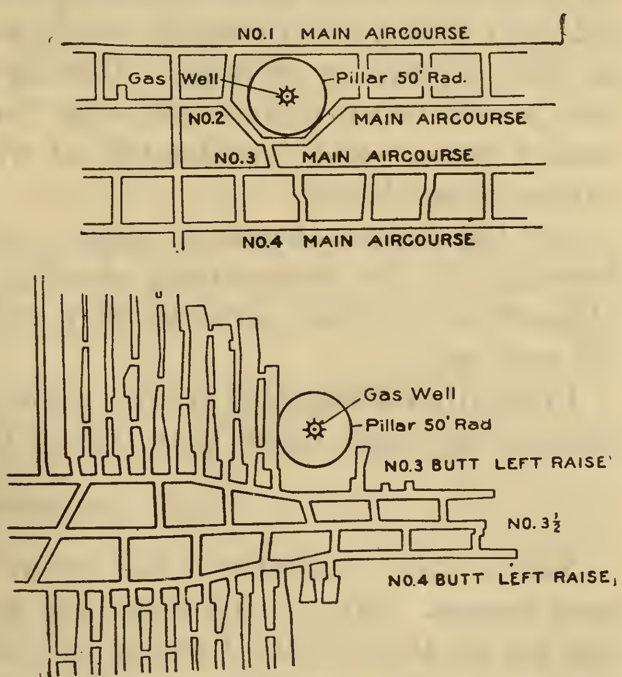

FIGURE 3.—Gas wells, surrounded by pillars of coal, through workable coal beds.

BITUMINOUS SHALES.

According to the organic theory of the origin of oil, petroleum is assumed to be the product of the alteration of certain types of organic materials buried in the strata of the earth's crust. Various kinds of animal and vegetal material were laid down as organic oozes, slimes, or muds. Because of their inherent chemical properties, certain kinds of these materials later became some form of coal and others were converted, with their mud matrix, into bituminous shales.

Bituminous shales yield petroleum when the organic matter in them is decomposed by destructive distillation. Prior to distillation, only traces of oil, perhaps as high as 6 per cent in some shales,

[90] Gregorius, Rudolf, Mineral waxes, 1908, pp. 2–53.
[91] Schoch, E. P., Ozokerite from the Thrall oil field: Univ. of Texas Bull. 66, 1916, p. 79.
[92] Bardwell, Carlos, Chemical properties of Utah hydrocarbons: Trans. Utah Acad. Sci., vol. 1, 1918, pp. 79–80.

can be extracted from the shale by treating it with solvents such as benzine, chloroform, or carbon tetrachloride.

It is doubtful if kerogen shales, such as those of Colorado, Utah, and Nevada, are in any way related to the occurrence of crude petroleum. They can not consistently be considered any more of a sign of oil and gas than coal. As already discussed, the value of coal as an indicator is based on the determination, by means of the carbon ratios of coal, of areas favorable for the existence of pools of petroleum. The carbon-ratio[93] principle has not yet been demonstrated as applicable to bituminous shales.

Oil soaked or petroliferous shales, such as those found in the Santa Maria and Casmalia fields of California, are the result of migration of petroleum from some adjoining reservoir. In prospecting for oil, such shales, at an outcrop, would have the same indicator value as brea deposits or seepages. Cutting of such shales from a drill hole would be an encouraging sign for further drilling. The oil-soaked shales yield considerable oil when treated with benzine or carbon tetrachloride.

For the driller, therefore, unless cuttings of shales suspected of bearing oil give considerable showings of oil when treated with chloroform or other solvents, they will not be favorable signs of oil and gas.

Primarily the so-called organic shales come within the scope of the regional geologist rather than that of the driller and his associates.

SALT AND GYPSUM.

Salt is widely distributed and occurs in many places in enormous rock masses. Salt-bearing strata are commonly penetrated in drilling for oil through the Permian red beds of Oklahoma and northwestern and western Texas. Salt is mined from these beds in west central Kansas. Masses of salt form the cores of the saline domes of the Gulf coast fields of Texas and Louisiana.

The saline formation in southeastern Michigan[94] contains beds of gypsum and salt alternating with dolomite, shale, and marls. In the San Joaquin Valley oil fields in California[95] all the Tertiary formations are extremely gypsiferous and local seams of gypsum are present in the Cretaceous rocks as well. The Cave Creek formation is the chief gypsum-bearing[96] division of the Permian red beds in Kansas.

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[93] Fuller, M. L., Relation of oil to carbon ratios of Pennsylvania coals in north Texas: Econ. Geol., vol. 14, 1919, pp. 536–542.

[94] Smith, R. A., The occurrence of oil and gas in Michigan: Michigan Geol. and Biol. Survey Pub. 14, geol. series 11, 1912, p. 25.

[95] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, California: U. S. Geol. Survey Bull. 398, 1910, p. 49.

[96] Moore, R. C., Oil and gas resources of Kansas: Geol. Survey of Kansas Bull. 3, 1917, p. 120.

Nowhere can the development of salt in a drilling well be considered as an indicator of the existence of petroleum, except in the salines of Louisiana and Texas, where salt domes or plugs form the cores about which oil has accumulated. Salt is an indicator of a favorable structural condition, but not a sign of oil.

Much discussion [97] has taken place as to the probable origin of the salt and gypsum in the salt domes of the Gulf coast fields. Dumble [98] believes that the domes comprise an intrusive mass of salt, gypsum, or anhydrite coming up through the sedimentary beds, which are broken and tilted. He says that the association of gypsum, salt, and anhydrite suggests their derivation from sea water by evaporation and that their deposition must have taken place prior to the beginning of Upper Cretaceous sedimentation.

Salt-dome structures have not yet been found [99] east of the Mississippi, in Mississippi, Alabama, or Florida. Common salt, of course, is found in solution in deep-seated waters in almost every oil field.

SULPHUR.

Petroleum is rarely free from sulphur,[1] but the quantity present is usually very small. Hewett [2] reports a petroleum spring within 100 yards of the largest sulphur deposit on the west bank of Sweetwater Creek, Park County, Wyo., and although this intimate occurrence of sulphur and petroleum seems significant, he believes that the sulphur originates in deep-seated igneous rocks and that the petroleum comes from sedimentary overlying strata. The sulphur deposits of Sulphur Mountain, Ventura County, Calif., are apparently from gas blows.

Sulphur occurs in coal and frequently with gypsum, which is the most frequent of the common sulphates, as pyrite is of the sulphides. In sedimentary rocks, the association of limestone, salt, gypsum, sulphur, and hydrogen sulphide seems to be somewhat general.

Sulphur is abundant in the saline-dome areas of Louisiana and Texas. Incrustations of sulphur in the soil, according to Harris,[3] were doubtless the controlling indication leading to the sinking of the Lucas well (for sulphur) in the Spindletop field of Texas. He

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[97] Matteson, W. G., Principles and problems of oil prospecting in the Gulf coast country: Am. Inst. Min. Eng. Bull. 139, July, 1918, p. 1145.

[98] Dumble, E. T., Origin of the Texas domes: Bull. Am. Inst. Min. Eng., October, 1918, p. 1629.

[99] Lowe, E. N., Oil and gas prospecting in Mississippi: Mississippi State Geol. Survey Bull. 15, 1919, pp. 16–17.

[1] Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 491, 1911, p. 552, 686–687.

[2] Hewett, D. F., Sulphur deposits in Park County, Wyo.: U. S. Geol. Survey Bull. 540 1914, pp. 479–480.

[3] Harris, G. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, 1910, p. 24.

reports that the "sulphur" dome of west central Calcasieu Parish, La., seems to be a saline dome with an unusually large amount of crystalline sulphur in the porous beds of limestone and gypsum. Rogers[4] says that contact of sulphate waters with petroleum produces, among other things, hydrogen sulphide, and that considerable quantities of hydrogen sulphide are probably reduced by oxidation to sulphur. Commercial deposits of sulphur that contain hydrocarbon material have been found near the south end of the Sunset field, California. Small deposits of disseminated sulphur are found elsewhere along the western edge of the Sunset-Midway field, and Rogers thinks that these accumulations have probably been derived from sulphate by the reducing action of hydrocarbons.

In so far as the above hypothesis of reactions between sulphates and hydrocarbons is applicable, sulphur may be considered to be an indirect indicator of oil and gas.

PYRITE.

The brass-yellow mineral, a combination of iron and sulphur (FeS_2), often known as fool's gold, is common in many rocks.[5] Bands or balls of pyrite are found in most coal beds. In the clay, shale, slate, sandstone, and limestone of oil fields pyrite is abundant. It is also one of the minerals easily identified in some very resistant "shells." Sulphur water—that is, water containing hydrogen sulphide in solution—is associated with some pyrite. Heavy hydrocarbons react with pyrite, just as free sulphur does, forming hydrogen sulphide and a lower sulphide of iron.

Pyrite is not a sign of oil or gas.

FOSSIL SEA SHELLS.

The value of paleontological evidence in determining markers has already been discussed. In popular opinion, the presence of fossil sea shells in rocks is a sign of oil or gas, probably because engineers and geologists when examining lands for oil nearly always inquire of the residents if they know of any fossil-shell outcrops. Except that they indicate the presence of sedimentary strata, which is necessary for oil accumulation, fossils are not an indicator.

WATER.

In prospecting for oil and gas, the chemical composition of the waters found in drilling may furnish important clues to the proximity

[4] Rogers, G. Sherburne, Geochemical relation of the oil, gas, and water of Sunset-Midway oil field, California: U. S. Geol. Survey Prof. Paper 117, part 2, 1919, pp. 28–29.

[5] Holbrook, E. A., and Nelson, Wilbur A., Coal pyrite resources of Tennessee: Tennessee State Geol. Survey, Vol. IX, No. 1, 1919, pp. 60–61.

of oil and gas. Thus, analyses from the Appalachian[6] fields show that waters associated with oil and gas are characteristically lacking in sulphates, and that sulphates exist in waters of deep-seated nonpetroliferous rocks that in many places lie outside of oil and gas fields. These facts have influenced the search for oil and gas in California. For example, the Standard Oil Co. of California in drilling the Domingene prospect well, north of the Coalinga field, Fresno County,[7] struck water high in sulphates, which indicated that further prospecting was probably useless.

Chloride or carbonate waters in certain areas also have a definite bearing on the presence or absence of oil or gas. So-called sulphur waters which may be of organic or inorganic origin are no direct guide for oil or gas, except where a sulphur water stratum may become a "marker" for correlation. Sulphur water and "sour water," so common in the salt domes of the Gulf coast, are only indirectly an indicator of the possible presence of oil. Wherever they occur, and sulphur water commonly occurs near oil seepages, they are merely evidence of a group of interrelated conditions, such as those already discussed where salt, gypsum, sulphur, and limestone occur together. If a salt dome is a reliable indicator of an oil field, then these other substances, such as sulphur water, may be considered secondary indicators of oil and gas.

In some localities the waters show distinct characteristics, as in certain Californian fields,[8] or in the Midway field where a water lying between oil-bearing strata is extremely alkaline, with more salt than sea water and a high content of iodine. Bromides and iodides of soda are peculiar to waters lying above the oil in districts north of the Lost Hills field, California.

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[6] Mills, R. van A., and Wells, Roger C., Evaporation and concentration of waters associated with petroleum and natural gas: U. S. Geol. Survey Bull. 693, 1919, pp. 98–99.

[7] Starke, E. A., chemical engineer, Berkeley, Calif. Personal communication.

[8] Starke, E. A., Personal communication.

PART II.—DRILLING METHODS AND RECORDS.

WELL-DRILLING METHODS.

IMPORTANCE OF DRILLING.

The author does not agree with recent writers[1] on oil and gas production, that the drilling of wells "is not worthy of the disproportionate attention it has received as compared with that given to the vital need of developing better methods of locating and extracting." As a matter of fact, few operators give enough attention to the manner in which their wells are drilled. The drilling of the first few wells in any area is the initial step toward determining whether or not those wells and others subsequently drilled will be profitable investments. Unless wells are drilled so as to reveal all the productive possibilities of an area, refinements of theories of location and recovery will be of little avail. The location of future wells is determined by the results of prospect wells. The percentage of recovery[2] or extraction depends intimately on the method and efficiency of drilling.

CONTRACT DRILLING.

Many operators turn the drilling of their wells over to contractors, which is advantageous in some ways but is liable to have drawbacks. The operator is relieved of the need of permanently employing men who have a knowledge of drilling, and the chances of "losing a hole" or of other accidents incidental to drilling are assumed by the contractor; unless the contractor goes bankrupt, the producer is sure of getting a hole drilled. But the contractor's chief object when drilling under contract is to make hole rapidly, and, consequently, few drilling contracts have adequate provision for delays necessary to test formations.

When the responsibility of drilling a hole is thus delegated the contractor obviously has a more vital interest in the method of drilling

[1] Johnson, R. H., and Huntley, L. G., Principles of oil and gas production, 1916, 371 pp.

[2] Lewis, J. O., Methods for increasing the recovery from oil sands: Bull. 148, Bureau of Mines, 1917, pp. 25–26.

than the operator. In many fields the drilling technique, including casing, has been developed from methods most suitable to the contractor. In some Mid-Continent fields, contractors land many strings of casing in order to exclude successive waters as they appear in the hole. This is not done for prospecting purposes, but simply to hasten drilling. Holes are drilled "dry," as water in the hole retards drilling. After the wells are completed the larger casings are stripped from the well, and water temporarily excluded in drilling is allowed to move down the hole to the shoe of the largest casing left in the hole. Often this latter casing is landed with no thought of leaving it in condition to exclude water; in fact, unless there is native water back of the casing at the time of drilling, there is no opportunity to determine whether or not the casing will exclude water. In such practice, the string of casing left in the hole is really an oil string and is there for the sole purpose of holding back caving formations which interfere with production. Some wells could be drilled continuously, although slowly, to the landing depth of the longest water string without using intermediate sizes of casing. This procedure will be discussed later under the subject of temporary water shut-offs in prospecting (p. 136).

The contractor should not attempt to cement a string of casing in order to shut off water, as a conclusion to his drilling job. This work should be done carefully by a cement specialist. If there is any phase of oil-well work that requires specialization and care it is that of cementing casing to shut off water. Specialization seems to be necessary in developing an oil field, as in other enterprises. The oil producer employs an engineer to spot his well, a contractor to drill it, a casing crew to pull casing, a cement man to make a water shut-off, and a well shooter to sidetrack lost tools or bring in production, and maintains permanently on his farm or lease a crew versed mainly in producing, tanking, and transporting oil and gas. If, therefore, the producer is to rely on specialists for all work preliminary to producing oil, he should make certain that each man's part of the work is carried out in such a manner that the completed well will yield to him the greatest possible return on the investment.

THE DRILLING CONTRACT.

Drilling contracts should be so drawn that adequate provision is made therein for properly testing formations and shutting off water. The ultimate object of the job, and not the convenience of the contractor, should determine the nature of the contract. This may mean a higher drilling cost per foot and additional expense for necessary delays, but such added outlay will insure greater security and returns when the well is producing.

In much development work only oral contracts are made. The laws of supply and demand largely control the terms of drilling contracts. Oil operators of northern Texas were able to approximate the terms of a normal drilling contract in the spring of 1920, whereas during the rush development in 1918 the contractor dictated the terms and drilled the hole largely as he saw fit.

The attached contract form for drilling a well with rotary tools combines the practices of several of the largest operating companies in California. The terms of the contract have been developed under normal conditions and are probably more explicit than those of the usual drilling contract. They show, however, that experienced oil operators and contractors both appreciate the necessity of a definite contract when the expenditure of from $50,000 to $100,000 is involved. Those sections of the contract that bear on prospecting and testing are quoted in full. Only the headings of sections irrelevant to the subject at hand are given.

CONTRACT FOR DRILLING WITH ROTARY TOOLS.

THIS AGREEMENT, made and entered into this ____________ day of ________________, 192 , by and between ________________________, a corporation organized and existing under and by virtue of the laws of the State of California, hereinafter designated as "Oil Company," party of the first part, and ________________________ also a corporation organized and existing under the laws of said State, hereinafter designated as "Contractor," party of the second part:

WITNESSETH:

That whereas the Oil Company is desirous of having a well drilled for oil on that certain real property hereinafter described and the Contractor is desirous of drilling said well:

NOW THEREFORE, in consideration of the covenants and agreements hereinafter contained on the part of the respective parties hereto to be performed the parties hereto do hereby agree as follows, to-wit:

1st. Location of well.

2nd. Designation of well.

The well shall be known as ____________________.

3rd. Method of drilling.

The well shall be drilled by the Contractor by the rotary method, and all work shall be done in a first-class, workmanlike manner, and shall be subject to the approval of the Oil Company.

4th. Right of entry.

5th. Fixtures and materials to be furnished by the oil company.

6th. Material, appliances and labor to be furnished by the contractor.

7th. Commencement of work—Landing casing—Testing depth of well.

The Contractor agrees to begin drilling within ______ days after the execution of this agreement and to drill a hole to the depth of ______ feet from the surface, unless stopped at a shallower depth by the Oil Company, as hereinafter provided, and to set in said hole, with or without cementing, a string of 12½-inch casing, the intention being to shut off all water above the oil-bearing strata with this 12½-inch string of casing, if possible.

In case the Oil Company desires to cement the 12½-inch string the Contractor agrees to supply good circulation around this string after it is in the hole, said circulation being what is required for cementing by the Perkins process, or for pumping in cement through tubing, and to maintain said circulation for the length of time necessary to properly cement the well. The Contractor also agrees to lower casing to bottom when the cement is in place and when directed to do so by the Oil Company.

If the 12½-inch casing is cemented, the Contractor agrees to discontinue operations for a period of twenty days, unless otherwise directed by the Oil Company. In case the water is not shut off by the 12½-inch casing above referred to Contractor agrees to drill as far below the ______ inch shoe as the Oil Company may direct and set a string of 10-inch or other suitable size casing to be furnished by the Oil Company with or without cementing and again test as above for shutting off top water.

The Contractor agrees to test each casing by bailing to such a depth and in such a manner as the Oil Company may direct to ascertain if top water is shut off by it, and to drill ahead of each shoe 20 feet before this test is made, if required so to do by the Oil Company.

The Contractor further agrees that in the event it is found desirable to land a string of casing at a shallower depth than has at such time been drilled by the Contractor, to bridge the hole from the bottom up to such point as the Oil Company may elect and set a string of casing of a size to be designated by the Oil Company at such point as the Oil Company may elect and in such manner as hereinafter provided and, in consideration of the same, the Contractor is to be paid for the hole originally drilled and to be released upon completion of such work, from any further work under the contract.

The Contractor agrees to land said 12½-inch casing in such good condition and so straight that a string of 10-inch casing may be easily passed through it; and it further agrees to put the full string of 10-inch casing through said 12½-inch casing. The Oil Company agrees to furnish the men to put the 10-inch casing through the total depth of the 12½-inch casing.

The Contractor further agrees that any and all strings of casing shall be set with or without cementing at the option of the Oil Company, and that the method of cementing shall be designated by the Oil Company.

The Contractor agrees to effectually seal all water and gas bearing strata with fresh, heavy mud under high pressure, and to do such sealing to the satisfaction of the Superintendent of the Oil Company.

8th. Measurement of hole—Log—Access to derrick, information, etc.

The hole shall be measured from the natural surface of the ground beneath the derrick, and shall be measured by drill stem and checked by casing, and the Contractor agrees that the Oil Company may at any time check its measurements by independent measurements. If any question shall arise as to whether the hole, as cased, is straight, the depth shall be determined by the length of the next smaller size casing which can be run into it.

The Contractor agrees to keep an accurate log of the formation drilled through, and to report it to the Oil Company each day.

The Contractor further agrees to allow authorized agents of the Oil Company access to the derrick at all times, and to give them all desired information about the work, and the Oil Company agrees to give the Contractor the benefit of any knowledge it may have of surrounding wells and formations.

It is further agreed between the parties hereto that the depth hereinbefore mentioned is approximate only, and that drilling is to be stopped and casing landed at points designated by the Oil Company as changes in formation may make it advisable.

9th. In case of failure to reach depth, etc.

In case the Contractor fails to reach the depth as designated in the seventh paragraph hereof, or to set the strings of casing as therein specified, or to shut off the water above the oil sands, and in case such failure causes a loss in any way, or of any kind to the Oil Company, the Contractor hereby agrees that no money or compensation whatsoever shall be due or payable to or by the Oil Company for work performed on said well, and the Contractor further undertakes and agrees and binds itself in case of any such failure to repay to the Oil Company on demand any moneys that shall have been paid to it by the Oil Company on account of or under this agreement, and also to reimburse the Oil Company on demand for the cost of any material or appliances furnished by the Oil Company that may have been damaged or lost in the drilling of said well, and also to pay the Oil Company on demand for all water and fuel furnished by the Oil Company to operate the rotary rig.

The intent of this agreement is that the Contractor shall drill said well to the depth designated by the Oil Company and shall turn it over to the Oil Company with all strings of casing properly set at the proper depths and opened to their full diameter for the full length with the water shut off above the oil sands, and that otherwise the Contractor shall receive no compensation and there shall be no liability of any kind on the part of the Oil Company to the Contractor, and the Oil Company shall suffer no loss and shall be made whole for all outlays and expense of every kind incurred by it in the premises.

It is understood and agreed that the depths mentioned hereinbefore are approximate only, and that drilling is to be stopped and the casing landed at points designated by the Oil Company, as changes in formation may make advisable.

10th. TERMINATION OF THIS AGREEMENT.

11th. COMPENSATION.

12th. TERMS OF PAYMENT.

13th. THE OIL COMPANY AND ITS LAND TO BE FREE FROM CLAIMS OF THIRD PERSONS.

14th. COMPENSATION INSURANCE.

15th. BOND FOR FAITHFUL PERFORMANCE.

16th. APPOINTMENT OF REFEREES IN CASE OF DISPUTES.

Should any dispute arise between the Oil Company and the Contractor as to the true intent and meaning of any part of this agreement or concerning any matter or thing in connection with the work to be done hereunder, the point in dispute shall be referred to and decided by two competent persons, one to be selected by the Oil Company and the other by the Contractor, and in case they can not agree these two shall select an umpire, and the decision of any two of the three so selected shall be binding on both parties hereto.

17th. WORK NOT TO BE SUBLET.

The Contractor agrees not to assign this agreement or to subcontract for or sublet the whole or any part of the work to be done by it hereunder without the written consent of the Oil Company first obtained.

IN WITNESS WHEREOF, the parties hereto have caused their respective corporate names to be hereto subscribed and their respective corporate seals to be hereunto affixed by their respective officers thereunto duly authorized, the day and year first hereinabove written in duplicate.

By ------------------------------
And------------------------------
Secretary.

By ------------------------------
President.
And------ ------------------------
Secretary.

CONTRACT PROVISIONS FOR LOG.

In the preceding contract form the mechanical and financial phases of drilling are covered in detail. The requirements for tests to determine whether water is shut off should be noted. As regards the log and formation record, few contracts are much more explicit than those given herein, which say: "Contractor agrees to keep accurate log of the formation drilled through and report it to the company each day."

This stipulation has much the tone of an afterthought and the driller's thoroughness in complying with this part of the contract will depend entirely on the desires of the company. Naturally, if the company is not enough interested to have the well watched each day, the contractor will not press the drillers very hard for a formation record. If the wording of a contract were any gage of the probable fulfillment of its terms, the section on the log should be worded somewhat as follows:

Contractor agrees to assist the company in every reasonable way in determining the true nature, depth, and content of all formations penetrated in drilling by keeping for the company an accurate record of said depth and changes of formation and advising the company at any time during progress of drilling of any signs or indications of oil, gas, or water, so that the company, if it desires, may make adequate tests of such indications.

At one time one of the largest operating companies of California considered writing the following requirements into contracts in order to prevent carelessness in logging and measurement of hole:

1. The hole shall be measured at stated intervals of time or at specified depths in the presence of an agent of the company.
2. The total length of drill stem shall be checked at stated intervals.
3. Casing shall be measured as it is made up and going into the hole.

These requirements were not written into the contract given, because a satisfactory understanding existed between contractors and company in conference. The foregoing will be discussed in more detail under "Log of oil and gas well" (p. 70).

COMPANY OBSERVER FOR CONTRACT DRILLING.

As already stated, time is the controlling factor in a drilling contract, and the contractor is tempted to slide over precautions such as having the joints of casing screwed home, taking careful measurements of the hole, and other slow-moving or incidental mechanical details that are a necessary adjunct to a good job. Some companies, therefore, employ a competent driller to be present in the derrick during critical stages in the drilling of a hole by contract.

The following set of regulations was issued by a large operating company of California to drilling foremen in several fields:

The following regulations are to apply to the drilling of wells and setting of casing with rotaries and when rotaries are operated by contractors:

The drilling rig is to be so equipped that the calf wheels and bull wheels can be operated.

The hole is to be drilled to the depth required and the last 5 feet is to be drilled with a rotary bit the same size as the inside diameter of the casing to be set.

Where contractors are employed, a competent employee of the company (generally a driller) must be present and see (1) the drill stem measured as it is pulled out after having drilled the small hole, (2) the casing measured as it is placed in the hole, and (3) see that all joints of such casing are properly lubricated and screwed together.

In cases where pipe may not be cemented, it is not always necessary to establish circulation before landing casing on bottom. Where casings are cemented, circulation of the mud must be established and maintained until the cement has been pumped behind the casing and the casing is ready to be lowered to the bottom of the hole. While the casing is being lowered its approach to the top of the 5 feet of small hole will be indicated by the labor of the pumps and a rise in pressure. Under no circumstances should the casing be lowered into the small part of the hole until the cement has been pumped back of the casing. It should then be lowered permanently, and should not be pulled out of the small hole after having been set on bottom.

The measurement of the drill stem in "stands" as it is pulled and set back in the derrick is, at all times, to be used as the official measurement, such measurement, for the purpose of setting casing, to be taken from the bottom of the hole to the derrick floor. "Paid hole" to contractors is to be measured from the "grass roots" to the bottom of the hole drilled. When the pumps indicate that the casing is at the top of the 5 feet of small hole the casing measurement shall be checked immediately against the drill-stem measurements. (When possible an adding machine should be used.)

All casings, after having been set on bottom and properly landed, must be given enough stretch and then suspended. Under no circumstances are such casings to be disturbed for 15 days. Proper lengths of joints should be used at the top of hole to permit the taking down of drill stem after the casing has been suspended. As a general rule, it is more satisfactory to suspend the casing on a spider temporarily and at the end of 15 days permanently anchor it at the top of the hole.

In cementing rotary holes, the Perkins method, or a method equally good, must be employed.

The storekeeper in delivering each separate string of casing to be used in wells drilled with the rotary, must furnish the superintendent with a statement giving the exact storehouse measurement and the number of joints delivered. A typewritten form, facsimile of which is hereto attached (p. 52) must be used. The employee who witnesses the measurements must note upon the statement the exact well-casing measurements, the number of joints, and the exact drill-stem measurements, together with the size of the bit used in drilling the small hole. He shall sign the statement and turn it over to the superintendent.

The employee or employees witnessing the setting of the casing, and other operations specified above, must be present continuously from the start to the finish.

Superintendents and foremen are, under no circumstances, to rely upon any information coming from the contractor in relation to the drilling, etc., and must at all times satisfy themselves of conditions as they may exist.

STATEMENT OF CASING USED.

_______________________________, 190 .

Measurement of casing. Sec. ____, T. ____, R. ____, Well ________.

Size of casing ________.

Total measurement of casing by storehouse__________________________ feet.
Number of joints counted by storehouse______________________________ joints.
Measurement of casing from floor to bottom of hole where landed____ feet.
Measurement of casing used____ feet.
Number of joints used____ joints.
Drill stem from floor to bottom of hole____________________________ feet.

(Signed) ____________________________

CLASSIFICATION OF WELL-DRILLING METHODS.

Modern drilling methods[3] may be grouped into three general classes, namely, percussion, hydraulic, and abrasion, according to the method of digging the hole and conveying cuttings to the surface.

Discussion of the percussion method is limited here to the cable-tool system in which formations are broken and hole is made by the pounding of a heavy bit. The design of rig and equipment varies from Star rig to standard, the choice being governed mainly by the depth of hole to be drilled.

The rotary mud-flush system is the principal hydraulic method now used. The formations are bored with a fish-tail, disk, or roller bit, and carried away in the mud stream. Cores are frequently taken in drilling oil wells with rotary tools in Texas, Louisiana, and California. More effective methods of taking formation samples with rotary equipment deserve the attention of operators.

The abrasion principle is employed for three types of drills, which vary chiefly in the abrasive used and which are known as the diamond, calyx, and chilled-shot drills. The possibilities of the diamond drill for prospecting oil-bearing strata are discussed on page 121.

Some of the important modern drilling methods include the use of certain features of both cable-tool and rotary drilling. The circulator method, for example, is an application of the mud-flush principle of rotary practice to cable-tool drilling. This method has been largely supplanted by the combination method which combines the requirements of derrick and rig equipment for rotary and cable-tool drilling so that a shift can be made easily from rotary to cable tools, or the reverse, according to the strata drilled.

CABLE TOOLS.

Approximately 100,000 of the 109,000 wells estimated as completed in the United States during 1914–1918 were drilled with cable

[3] Bowman, Isaiah, Well-drilling methods: U. S. Geol. Survey Water-Supply Paper 257, 1911, pp. 32–33.

tools, which are used in all Eastern fields, the Mid-Continent field, Rocky Mountain fields, parts of Texas and Louisiana, and for all pioneer work in California. Cable tools are especially adapted to prospecting.

The three deepest wells in the United States,[4] two of these the deepest in the world, were drilled with cable tools. These are the Lake well, 8 miles southeast of Fairmont, W. Va., depth, 7,579 feet; the Goff well, 8 miles northeast of Clarksburg, W. Va., depth, 7,386 feet; and the Geary well, 20 miles southeast of Pittsburgh, Pa., depth, 7,248 feet.

In cable-tool drilling the hole is spudded for the first 100 to 300 feet and continued by one of the following three methods: Dry hole, drilling water, or mud fluid. In some areas, however, the entire well has been drilled by spudding. A number of wells in the Lost Hills field, California, were spudded to an average completed depth of 1,000 feet.

DRY-HOLE METHOD WITH CABLE TOOLS.

In the eastern fields, the Mid-Continent, the Rocky Mountain, and some Texas fields, wells are drilled by the dry-hole method, in which only enough water to mix cuttings is run to the bottom of the hole, and drilling can be done with considerable open hole. In some fields water can be run into the hole from the surface; in others, however, it is necessary to dump water on the bottom with a bailer, because water running down the sides of open hole causes the formation to cave. Other conditions being equal, cable tools have the greatest percussive power with open hole.

Hemp cable is used to best advantage in dry-hole drilling. In Illinois fields the drillers splice a hundred feet or so of manila line on the end of a wire rope. This is called a snapper. Hemp cable puts less strain on the derrick when spudding and makes hole faster.

In drilling with dry hole, a water sand is detected as soon as entered and a string of casing can be landed to exclude the water from the hole, thus enabling the operator to continue drilling dry. Such conditions are ideal for prospecting and for testing formations. Samples of all exposed formations, excepting cuttings from a gas stratum when the well is "blowing off," can be taken frequently by bailing. Fluid has a better chance to enter the hole from any exposed oil or water sand.

The "dry-hole" method has been used to a limited extent in California, where it has been revived after almost complete abandonment in the early days of drilling. The first two wells drilled in the Coalinga East Side field—sec. 8, T. 19 N., R. 15 E.—and the dis-

[4] Press Bulletin, U. S. Geol. Survey, August, 1919.

covery well in the Lost Hills field, California, were drilled dry. Beds of loose sand prevented the general use of this method. Bell[5] cites some of the advantages of dry drilling in the Casmalia field, Santa Barbara County, Calif.

DRILLING-WATER METHOD WITH CABLE TOOLS.

Since 1898,[6] cable-tool practice in California has been to drill with the hole either partly or completely filled with drilling water, which is necessary in order to hold back loose, caving, or heaving formations by hydrostatic pressure, and to facilitate the lowering of casing as drilling progresses. Casing must be lowered in the hole so that the drilling jars are always inside the casing. The pressure exerted at any depth is about 43 pounds a square inch for each 100 feet of fluid above that depth. The content of oil, gas, and water sands is hard to detect when the hole is full of drilling water, which must be bailed out in order to test for native fluids.

When drilling water is used, the tools are buoyed up and do not strike as strong a blow as in a dry hole. Drillers often use more drilling water than is necessary, because it washes off the line and tools when they are pulled out. As in dry-hole drilling, samples of formation are frequently bailed off bottom. Contamination of these samples by material that works down behind the casing from loose formations above may be avoided by maintaining a fluid level inside the casing higher than that of any water stratum back of the casing.

MUD-FLUID METHOD WITH CABLE TOOLS.

The mud-fluid method of drilling with cable tools, which was used in California in 1909, and later in the Cushing field, Oklahoma,[7] instead of the dry-hole method, is a variation of the Californian practice of carrying a hole full of drilling water. When a well is being drilled through a high-pressure gas sand, there are least two advantages in the use of mud fluid over clear drilling water; foot for foot of hydrostatic head, mud fluid will put a greater back pressure on a gas sand; drilling water has a tendency to wash and expose formations, whereas a high column of mud fluid, exerting pressure on a gas sand, drives mud into the sand and clogs it. When mud fluid is used, drilling can proceed with gas under control, cuttings can

[5] Bell, H. W., California State Mining Bureau Bull. 84, 1917–18, pp. 364–365.

[6] Lewers, Charles R., and Booth, Henley, C., Defendant's statement of facts proven: U. S. of America *v.* Southern Pacific Co. et al., 46 civil A–16, A–24, A–25, A–26, A–28, p. 246, 1918.

[7] Heggem, A. G., and Pollard, J. A., Drilling wells in Oklahoma by the mud-laden fluid method: Tech. Paper 68, Bureau of Mines, 1914, pp. 5–6.

frequently be bailed off bottom,[8] and casing may be lowered as the well is drilled, or drilling may be carried on with considerable open hole, depending upon whether formations stand up or not.

When mud fluid is used with cable tools a better sample of the rock from a gas stratum can be obtained than when cuttings are all being blown away, as in the dry-hole method. The action of mud in a well is discussed further on page 58.

An objection to the use of mud fluid in cable-tool drilling is that the clay used for mudding must be practically free from sand, because sand may settle around the tools and stick them. Fluid free of sand can not always be obtained where formations containing sand predominate. The usual specifications in Oklahoma stipulate that the mud fluid shall be " free from sand and grit." This is for two reasons. One is that the fine limestone cuttings of Oklahoma, if present in the mud fluid, will quickly settle around a string of tools and freeze them; the other is that sand and grit in the mud fluid left back of a string of casing will settle out of the fluid and hasten the settling of the mud.

ROTARY TOOLS.

The rotary method of oil-well drilling was first used successfully in 1901 in sinking wells through loose sandy formations in the Spindletop field near Beaumont, Tex. It is now used extensively in Louisiana, Texas, and southern Oklahoma, and in California where extra heavy equipment had to be used. Marked improvements in rotary tools have been made during the past twenty years, and in many respects the rotary principle is the ideal one for drilling oil wells. Probably with further improvements in machinery and practice, and a larger number of trained drillers, rotary rigs will be more generally used.

The ease and speed with which a rotary drills, as well as the semiautomatic removal of cuttings, have been the chief causes of carelessness and lack of accuracy by drillers in logging the formations penetrated. The rotary is undoubtedly a hole maker, but something more than a hole is needed to make either an oil well or an oil property. Advocates of the rotary system should realize the great need for simple methods of getting an accurate formational record, especially of depths and the content of thin formations. Until contractors and drillers can convince careful operators that the rotary can make a true formation record, as well as dig holes, this otherwise valuable tool will not be as generally used as it deserves. In the discussion that follows the criticisms made are intended only to emphasize those phases of rotary drilling that need remedying. Sug-

[8] Pollard, J. A., and Heggem, A. G., Mud-laden fluid applied to well drilling: Tech. Paper 66, Bureau of Mines, 1914, p. 13.

gestions will be offered with the intention of making the rotary a more reliable tool for prospecting.

DEEP-WELL DRILLING WITH ROTARY.

The deepest rotary-drilled holes recorded are in California. The Standard Oil Co. drilled a test well, Packard No. 11, in Kern County, to a depth of 6,240 feet. A well was drilled in the Kettleman Hills, Kings County, to 6,602 feet. Rotary tools were used from the surface to 3,500 feet, cable tools from 3,500 to 4,070 feet, and rotary tools from 4,070 to 6,602 feet. It is common practice to drill holes with rotary tools in California to depths greater than 4,000 feet. The Producers Oil Co., in the Humble pool, Texas, drilled a hole with rotary to 5,410 feet. The drill entered rock salt at 2,342 feet, and was still in salt when drilling stopped. The depth of salt drilled was, therefore, 3,068 feet. Three other deep test wells drilled in Texas, all with rotary machinery, are those of S. M. Swenson & Sons, at Spur, Dickens County, 4,489 feet; C. C. Codman et al., near Vidor, Orange County, 4,640 feet; and Gulf Production Co., at Spindletop, 4,270 feet. A great deal of the Spur[9-10] test well was drilled with core barrel, and reliable results were therefore obtained.

In drilling with the rotary, mud fluid is continuously circulated through the drill pipe to the bit working on the bottom, and returns to the surface outside the drill pipe. Thus the mud fluid serves the double purpose of carrying away cuttings and of "walling up" the hole. No casing is necessary except perhaps a short conductor pipe, at the surface while drilling is in progress, for the mud plastered to the walls of the hole by the rotation of the drill stem and the hydrostatic pressure of the fluid serves the purpose of casing.

In recent years, especially in California, the rotary method has been largely used by operators or contractors who engage to land two or three thousand feet of casing of a certain diameter to shut off water. One of the chief advantages of rotary drilling is that long strings of casing can be carried through loose formations with a minimum use of conductor casings.

CONDITIONS SUITABLE FOR ROTARY DRILLING.

Where underground conditions are known, the rotary can be used to advantage, if the territory is suitable, in drilling through the nonessential strata overlying productive oil and gas zones. If markers or key beds have persistent characteristics identifiable in rotary cutting, the hole can be carried to such markers. The hole should be prospected ahead from the lowest marker with cable tools or frequent core-barrel samples should be taken with rotary. (See

[9-10] Udden, J. A., The deep boring at Spur: University of Texas Bull. 363, 1914, p. 21.

Plate II, p. 22.) This procedure will assist in finding suitable formation in which to land casing to shut off water. The top of the oil zone can also be determined, and there will be less trouble in getting the well to produce.

Stratigraphic uniformity (see Plates II, p. 22, and V, p. 156) in depths of water shut off is one of the first prerequisites of successful protection of oil strata from infiltrating water.[11] Unless there is considerable vertical leeway in some suitable formation, such a desired result may not be attained. It will be hazardous to drill with rotary through zones carrying water and oil in different strata unless, of course, the method of relying upon rotary mud alone to seal these strata behind a single string of casing is adopted. In areas where nonproductive strata lie unconformably above oil and gas bearing formations, the geologist can entertain little hope of working out the conditions of deposition and structure from the data of rotary logs.

Some of the above difficulties are illustrated by Deussen's[12] description of conditions in the Humble oil field, Texas. In drilling to the deep sand at Humble it is customary to set 10-inch casing from the surface to 200 or 300 feet. Thereafter no more casing is set until about 2,600 feet, depending more or less upon the depths of the oil sand in the locality being tested. From the surface to this depth 6-inch casing is set in gumbo, excluding such water, gas, or oil as may be in the sands above the casing point. Attempt is made to set 6-inch casing as close as possible to the top of the oil in order to exclude water. The nature of the formations being drilled is difficult to detect when there is 1,500 to 2,000 feet of open rotary hole. To avoid passing through the oil sand and shutting it off behind a string of casing, the foreman prefers to set casing some distance above where he expects oil. Such procedure often lets water into the oil sand from a depth below the foot of the 6-inch casing.

The diameters and depths of holes and the casing used in these rotary-drilled wells are relatively much less than those used in Californian practice. Rotary equipment used in Texas and Louisiana is much lighter than that used in California, and holes are usually finished with 6-inch or smaller casing. In many wells it would be advantageous to start with a larger-sized hole, even when finishing with 6-inch casing, in order to facilitate a proper segregation of fluid-bearing strata for testing or for protection.

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[11] McLaughlin, R. P., Ann. Repts. State oil and gas supervisor: California State Mining Bureau Bull. 73, 1917; 82 and 84, 1918. Ambrose, A. W., Underground conditions in oil fields: Bull. 195, Bureau of Mines, 1921, p. 259.

[12] Deussen, Alexander, The Humble (Texas) oil field: Bull. S. W. Assoc. Petrol. Geol., vol. 1, 1917, pp. 71–72.

MUD FLUID.

In order to understand better the advantages and disadvantages of the mud-flush system with rotary drilling, a knowledge of the nature and purposes of mud fluid is necessary. Mud fluid plasters the walls of the hole, in lieu of casing, and carries the cuttings to the surface.

Although walling up a hole with mud may be desirable for the immediate requirements of drilling, the after effects are not always the best. Mud fluid should not be used promiscuously. As the depth of the hole increases, the hydrostatic pressures of fluids in the hole increase, and, as Pollard [13] says:

> That is a serious proposition in a well. We are dealing with pressures of 1,000 to 1.500 pounds to the square inch. What will that do under those conditions in the ground? Many drillers and operators are of the opinion that mud fluid simply walls up the face of a well. I have read from supposedly noted petroleum engineers that the walling up of a well consists of putting mud fluid into a well, and the drillings in returning to the surface are plastered upon the side of the well with the mud fluid, caused by the wabbling of the drill stem, no mention being made of the penetrating effect that becomes dangerous and is sometimes detrimental, inasmuch as it will load up an oil or gas sand in a manner that will spoil the production of wells adjacent to the well that is being tested.

Also, in a new well a productive oil sand may be mudded off and no one be aware of it.

The distance that mud fluid will penetrate formations depends upon certain factors, summarized as follows: (*a*) Porosity of formation, (*b*) consistence of mud fluid, (*c*) effective pressure of a column of fluid on any porous formation, (*d*) amount and content of fluid in formation and rock pressure exerted, (*e*) the reduction of pressure and oil content of a sand brought about by pumping adjoining wells, and (*f*) diameter of hole mudded.

POROSITY OF FORMATIONS.

Different rocks or beds differ in their capacity to absorb mud fluid under pressure. Shale will not take as much mud as sand, and a shell absorbs much less. The filtering reaction of various formations to mud fluid would give an irregular-shaped core of mudded strata, diminishing in density away from the bore hole, as shown in Figure 4.

In rotary drilling, the hole frequently "loses circulation," that is, the fluid stream is diverted underground through some porous or creviced stratum instead of returning through its regular channel to the surface. Sawdust, manure, or chopped bull rope must sometimes be added to the mud fluid to assist in clogging the pores and estab-

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[13] Pollard, John A., 3rd Ann. Rept. State oil and gas supervisor: California State Mining Bureau Bull. 84, 1918, pp. 81–84.

lishing the necessary filter. Hydraulic lime mixed with the mud will cause the fluid to thicken and thus will expedite clogging.

Mud has been known to travel long distances in sand. Kirwan,[14] in discussing abandonment operations of the American Petroleum Co. at well No. 8, Coalinga field, California, gives some significant data. Observations such as the following are usually overlooked in the inspection of mudding operations:

Evidence that the mud fluid traveled away from the well when the fluid was *thin* is had from the fact that muddy water on the fifth day appeared in succession in the production of wells Nos. 7, 6, and 5, being more pronounced in the nearest one, No. 7, distant 332 feet, and least in No. 5, distant 1,000 feet.

This dissipation over a large area was overcome by thickening the mud fluid and forcing it into the sand under pump pressure.

Nolan[15] cites an abandonment job in the East Side Coalinga field, where over 40 tons of mud under a pressure of less than 200 pounds was pumped into a 30-foot sand and three days afterwards appeared in a well 400 feet away.

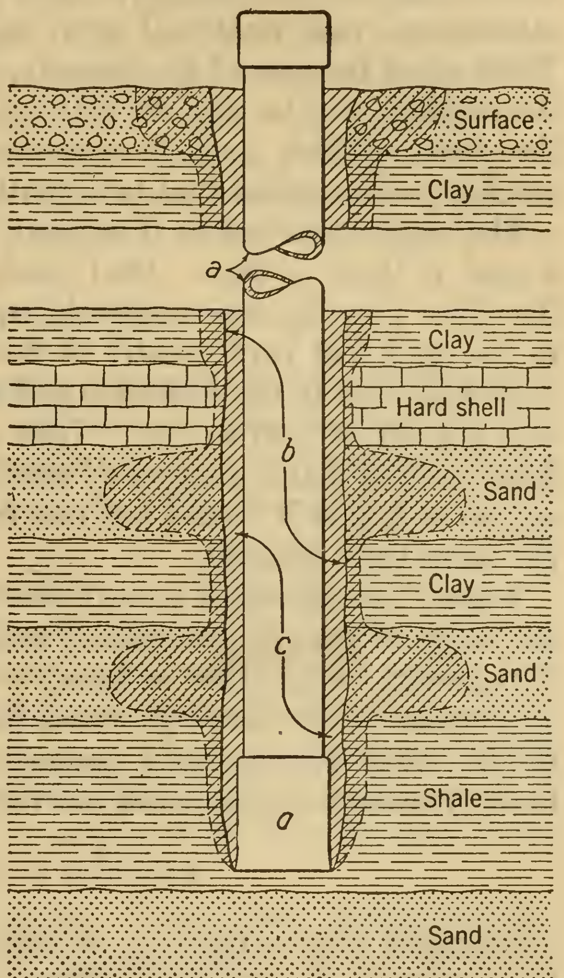

FIGURE 4.—Penetration of mud fluid in different formations.

The purposes of mud fluid should not be confused. This discussion is confined to the action of mud fluid in penetrating porous formations and not to the hydrostatic value of a column of mud fluid back of a string of casing in preventing the migration of fluids, for which a nonsettling fluid is desired. A fact frequently overlooked is that mud rapidly settles out of a salt-water mixture no matter how finely divided it may be.

Where mud fluid is used for sealing formations, the necessity of having the fluid free from sand and grit is not apparent. Small particles in the fluid may often facilitate the clogging action of the filter.

[14] Kirwan, M. J., Mud fluid in abandonment of well No. 8, American Petroleum Company, sec. 19, T. 20 S., R. 15 E., Coalinga: California State Mining Bureau Bull. 82, 1918, pp. 339–341.

[15] Nolan, E. D., Use of mud fluid: California State Mining Bureau Bull. 84, 1918, p. 80.

CONSISTENCE OF MUD FLUID.

In rotary drilling different conditions may cause the driller to change from time to time the thickness or consistence of the mud. In thin mud used as a conveyor of cuttings, the heavier particles tend to lag back as they move from the bit and up the hole. On the other hand, thin mud will drop the cuttings quickly in the ditch. Thick mud, because of its viscosity, will carry heavier particles, but the cuttings will be slow to settle out of the mud as it runs through the ditch. Thick mud is necessary to prevent caves and to fill quickly porous strata that take drilling fluid.

The subject can not be dismissed, however, by simply saying that a mud is thick or thin. Mud fluids of equal specific gravities and therefore bearing approximately equal quantities of solid material in the fluid will vary greatly in fluidity. Tough[16] reports that the mud fluid used in the Eldorado and Augusta fields, Kansas, has a specific gravity of 1.40 to 1.60. Tests of mud fluids from Californian fields showed that a mixture of mud having a specific gravity of 1.41 was so stiff that it would not run from an inverted glass and could not have been pumped.

Nolan,[17] in discussing uses of mud fluid in the Coalinga field, gives the range of specific gravities of muds used as 1.05 to 1.10, a mud of 1.10 gravity being about as heavy as can be used for drilling. Blue clay muds of the above gravities have viscosities ranging from 2.3 to 3.5. Mud from red clay (serpentinous material) seems to have a lower viscosity for the same gravity.

PRESSURES OF MUD FLUID.

Provided free circulation is maintained, the pressures produced by a column of mud fluid opposite any porous formation will be equal to the hydrostatic head of that depth of fluid from the surface. For pure water this head would be, roughly, 43 pounds a square inch for each 100 feet of depth. For mud fluid the above factor should be multiplied by the specific gravity of the mud fluid. The fact that the mud-fluid stream is in free motion and the mud pumps register little or no pressure has no bearing on the hydrostatic head of the mud fluid column. On the other hand, a pressure of 200 pounds at the pump is the equivalent of increasing the hydrostatic head of the mud fluid by almost 500 feet, provided the circulation is closed. For the fluid in motion, however, the pump pressure mentioned will be partly offset in overcoming frictional and viscosity resistances.

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[16] Tough, F. B., Methods of shutting off water in oil and gas wells: Bull. 163, Bureau of Mines, 1918, pp. 75–76.

[17] Nolan, E. D., Demonstrated value of mud fluid in protecting oil sands: California State Mining Bureau Bull. 84, 1919, p. 79.

A partly exhausted oil, water, or gas sand is supposed to take more mud than a freshly tapped sand. Nevertheless, a veneer of a few inches of mud over the face of an exposed oil or gas stratum, held in place by a column of mud fluid, will resist the entry of high-pressure oil, gas, or water. In "killing" a gas sand the operator should guard against pumping mud which has been filled with bubbles of gas back into the hole. The occluded gas will greatly decrease the weight of the mud and, proportionately, its hydrostatic value.

In mudding operations, as in the abandonment jobs already mentioned, pumping in neighboring wells must usually be stopped in order to build up a pressure to prevent the fluid traveling farther than is desired.

DIAMETER OF HOLE MUDDED.

In considering the action of mud in a porous stratum, the diameter of the hole is important. The total area exposed as the face of a filter to mudding action can be computed from the thickness of the formation and the diameter of the hole. For example: A sand 50 feet thick is mudded through a 12-inch hole; the area of the exposed face of the stratum to each vertical foot of thickness is 3.14 square feet; that is, mud fluid is applied to the interior of a cylindrical sand filter having an area of 50 times 3.14 square feet, or 157.1 square feet. However, if the sand (same thickness, 50 feet) is mudded through a 6-inch hole, the face of the filter through which mud must be applied will be 78.5 square feet. The area of outlet into the sand to be filled with mud through a 6-inch hole is only half the area exposed in the 12-inch hole.

Comparative data may be obtained by reducing thicknesses and diameters to the common term of "exposed area." This is shown in Table 5.

TABLE 5.—*Exposed filter area for holes of various diameters and depths.*

Well No.	Thickness of sand.	Diameter of hole.	Exposed area.
	Feet.	*Inches.*	*Square feet.*
1	50	12	157.1
2	70	8	146.3
3	25	6	39.3
4	50	6	78.5

CONCLUSIONS.

The foregoing discussion shows that mud fluid indiscriminately used may cause more harm than good. In prospecting and testing, therefore, the thickness of the mud used should be carefully watched.

In oil-well drilling nearly all steps of the work are controlled by inference, and results must be judged similarly. In the mud-flush system the quantity and burden of the returning fluid are the sole indicators of the course of travel of mud in the hole. The mud can be seen only when it leaves the sump and when it returns. The operator should be able to feel, with fair assurance, that the mud fluid in rotary drilling is acting solely as a conveyor for cuttings and a substitute for casing.

COMPARISON OF ROTARY AND CABLE TOOLS.

The first cost of tools and other equipment is greater for rotary than for cable drilling. Daily labor costs are also higher. With rotary tools, on the other hand, more hole a day can be made in loose formations and less casing is needed to complete the well. Heavy gas pressures are controlled more easily with rotary than with cable-tool drilling, except, of course, when mud fluid is used with the latter. Cable tools have the advantage over rotary of showing more faithfully the depth, character, and content of the formations penetrated, and of drilling a straighter hole. Other advantages and disadvantages are controlled by local conditions; for example, in "dry-hole" cable territory the rotary will use more water than cable tools, but in some fields in California the hole will take so much water in cable-tool drilling as to cause the operator to install rotary in order to clog porous formations with mud and thereby save water.

An inspection of 841 jobs in California to shut off water with either rotary or cable tools [18] gave the following information recorded in Table 6:

(1) Ten-inch casing is the predominating favorite for water strings landed with rotary tools. In fact there were more 10-inch water strings (177) landed with rotary than with any other single size of casing with either rotary or cable tools.

(2) With respect to diameters, which control the maximum size of bit to be used in further drilling, 10 inches is the exact mean of the largest and smallest diameters in common use, namely, 15½-inch and 4½-inch.

(3) The number of 12½-inch, 10-inch, and 8¼-inch water strings landed with cable tools is almost evenly distributed among the three sizes, the totals being 129, 145, and 143, respectively.

[18] Collom, R. E., Comparison of methods of excluding water from oil wells in California: California State Mining Bureau Bull. 84, 1918, p. 126.

TABLE 6.—*Segregation of wells according to depths, diameters of casing and tools used for one year's work of shutting off water in oil fields of California.*

[NOTE.—Numbers in black-face type represent the favored tool, cable, or rotary for each diameter of casing in each depth group.]

Depth of wells.	Number of wells according to diameter of casing.																		
	15½ inches.		12½ inches.		11⅝ inches.		11 inches.		10 inches.		9⅝ inches.		8¼ inches.		6¼ inches.		4½ inches.		Total.
	Rotary.	Cable.	Rotary.	Cable.	Rotary.	Cable.	Rotary.	Cable.	Rotary.	Cable.	Rotary.	Cable.	Rotary.	Cable.	Rotary.	Cable.	Rotary.	Cable.	
Feet.																			
100 to 1,000	......	......	......	**a 18f**	......	**11f**	......	......	......	**16f**	......	**5f**	......	**11f**	......	**3f**	......	**1f**	65f
	b 3c	**4c**	40c	**53c**	1c	**7c**	......	......	4c	**55c**	......	**1c**[1]	......	**13c**	......	......	......	......	181c
1,001 to 2,000	......	**1f**	......	**7f**	......	......	......	......	1f	**6f**	......	......	......	**1f**	......	......	......	......	16f
	......	......	31c	**51c**	......	......	**2c**	......	54c	**50c**	......	**1c**	7c	**25c**	......	**2c**	......	......	223c
2,001 to 3,000	......	......	......	......	......	......	**17f**	......	**4f**	1f	......	......	1f	1f	......	......	......	......	24f
	......	......	**10c**	......	......	......	**13c**	......	**95c**	16c	......	......	23c	**48c**	......	**12c**	......	**2c**	219c
3,000	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
	......	......	......	......	......	......	**1c**	......	**19c**	1c	......	......	10c	**44c**	2c	**33c**	......	**3c**	113c
Rotary total	......	......	......	......	......	......	17f	......	5f	......	......	......	1f	......	......	......	......	......	23f
	3c	......	81c	......	1c	......	16c	......	172c	......	......	......	40c	......	2c	33c	......	......	315c
Cable total	......	1f	......	25f	......	11f	......	......	......	23f	......	5f	......	13f	......	3f	......	1f	82f
	......	4c	......	104c	......	7c	......	......	......	122c	......	2c	......	130c	......	47c	......	5c	421c
Total rotary and cable	1f		25f		11f		17f		28f		5f		14f		3f		1f		105f
	7c		185c		8c		16c		294c		2c		170c		49c		5c		736c

a "f" is formation shut off.

b "c" is cement shut off.

Cable-tool drilling is better than rotary for prospecting and testing known beds for the following reasons: The principle of rotary drilling is to "wall up" formations with mud, which leads, at least, to concealing the content of formations, whereas the cable tool bares all formations and, especially in dry-hole drilling, leaves them open to testing; moreover, at certain stages of cable-tool drilling the content of formations can be tested by bailing, without landing a string of casing or otherwise seriously interrupting drilling.

The rotary driller is required to recognize changes of formation by the action of mud pump, rotary table, and speed of drilling. Progress in depth is marked on the drill pipe, and in order to examine cuttings, time must be allowed, varying with depth, for the cuttings to be brought to the surface. Frequently drilling must be suspended and mud circulated until cuttings arrive in the ditch. The time required for formation samples to be conveyed to the surface in the circulating mud increases directly with the depth of hole and inversely with the thickness of mud and the speed of circulation. These factors often require readjustment of depths in the driller's final log to compensate for the change in the depth of the drill pipe between the time the behavior of the drill or pump indicated a change in the formation and the time a change of cuttings appeared in the mud at the surface. Such readjustments lead to errors.

In a field drilled with rotary tools any driller can detect such formations as hard rock, hard "shell," sand (hard or soft), shale, and gumbo, by the way the engine runs, the action of the rotary table, and the "tune" of the mud pump. Actual loss in drilling time and, therefore, in footage of hole, is required to make accurate observations in thin formations, regardless of their nature. For example, a test was made in a rotary hole, 3,310 feet deep, in the Santa Maria field, California, by the United Western Consolidated. The formations drilled were all shale which insured a fairly uniform diameter of hole. Two quarts of red paint were put into the drill pipe at the surface and it required 2 hours and 33 minutes for the paint to make the round trip. The paint showed a distinct color on the surface of the mud stream along the edges of the rotary ditch. The pump had an 11-inch stroke and 6¼-inch liners, and the combined strokes a minute were 80. The hole was 12½ inches in diameter, and the drill pipe 6 inches, nominal. One hour and 57 minutes of this time, almost 2 hours, was required for the paint to travel from the bit to the surface. (See p. 104.) At a well of such depth, the operator will not be inclined to shut down frequently to take samples of each change of formation.

The cable-tool driller must also note changes in formation by the behavior of the drill, but to a lesser degree. With each system of drilling the driller is guided in his conclusions by the behavior of the drill and by inspection of cuttings, marks, and material on the bit. Generally more hole is drilled by rotary without removing the tools than by cable tool; as a result rotary-drill logs show fewer formation changes and seemingly thicker beds.

Table 7 shows the number of times there were changes in their thicknesses in three rotary holes as compared with one cable-tool hole. The data were taken between equal stratigraphic depths.

TABLE 7.—*Identification of formations and their thicknesses in three rotary holes as compared with one cable-tool hole.*

Formation.	Three rotary holes.		One cable-tool hole.	
	Number of times logged.	Average thickness.	Number of times logged.	Average thickness.
		Feet.		*Feet.*
Surface sand	3	80	1	475
Yellow clay and sand	1	185	....	....
Yellow clay	3	45	....	....
Blue clay	14	49	9	25
Sand and bowlders	25	51	....	....
Yellow clay and bowlders	5	87	....	....
Blue clay and bowlders	32	94	....	....
Clay	1	55	3	14
Sticky blue clay	1	30	....	....
Blue shale	4	26	8	35
Sand and gravel	1	70	....	....
Hard sand	8	15	....	....
Sand	1	5	5	14
Shell	10	2.5	13	6
Water sand	1	11	3	20
Sandy blue shale	2	25	5	21
Sandy blue shale, oil	1	9	....	....
Sticky shale	1	10	....	....
Brown shale	....	....	3	13
Gray sand	....	....	3	42
Brown shale, show oil	....	....	2	9
Gray sand, show oil	....	....	1	25
Tar sand	....	....	1	40
Blue clay, little gas	....	....	1	10
Brown sandy shale	....	....	2	10
Adobe	....	....	1	5
White sand	....	....	3	40
Shale	....	....	8	21
Oil shale	....	....	1	12
Total	114	....	73	....
Average per hole	36	57	73	25

The data in Table 7 were taken from logs of wells chosen at random in a certain area in the Midway field, California. In the three rotary holes changes of formation were noted on an average of 36 times a hole as against 73 times in a single cable-tool hole, all to an equal stratigraphic depth. The 475 feet of surface sand in the cable-tool log probably offsets material logged as surface sand, yellow clay and sand, yellow clay, and yellow clay and bowlders in the logs of the rotary holes. Except for this lumping of surface strata in the cable-tool log, the formations recorded are generally much thicker in the rotary logs, averaging 57 feet as against 25 feet in the cable-tool hole.

This comparison seems to indicate that formational changes are noted with greater exactness in cable-tool drilling, which has an important bearing on the certainty with which a driller works in landing casing to shut off water. The fact that changes of formation were noted only 36 times in a rotary hole as compared with 73 times in the cable-tool hole is evidence, at least, that a number of strata were either overlooked with the rotary drill, or else two or three changes of formation were reported under one name.

A rotary driller may log a 60-foot stratum of shale. The actual condition may be, for example, 45 feet of shale, 10 feet of sand, and 5 feet of shale. Three changes of formation have been logged as one. He lands casing, to shut off water, 50 feet below top of shale, as logged, and the shoe of the casing is set in the middle of a sand stratum and water is not shut off.

In comparing methods of excluding water from oil wells in California [19] the author studied 814 drilling jobs in order to determine how the method of drilling influenced the operation of shutting off water. Table 8 compares success and failure in shutting off water in Californian fields by casings landed with rotary or with cable tools. No similar data are available in any other fields of the United States.

TABLE 8.—*Comparison of success and failure of water shut-off by casings landed with rotary and with cable tools.*

Fields and tools.	Number of jobs.			Percentage of failure.
	Success.	Failure.	Total.	
1. Midway:				
Rotary	87	13	100	13.0
Cable	76	8	84	9.5
Totals	163	21	184	11.0

[19] Collom, R. E., work cited, pp. 113–115.

TABLE 8.—*Comparison of success and failure of water shut-off by casings landed with rotary and with cable tools*—Continued.

Fields and tools.	Number of jobs			Percentage of failure.
	Success.	Failure.	Total.	
2. Coyote Hills:				
Rotary	11	4	15	25.7
Cable	11	[a] 5	16	31.2
Totals	22	9	31	29.1
3. Montebello:				
Rotary	18	[b] 10	28	35.7
Cable	11	[b] 6	17	35.3
Totals	29	16	45	35.5
4. Sunset:				
Rotary	19	[c] 19	38	50.0
Cable	30	4	34	11.8
Totals	49	23	72	31.9
5. Coalinga:				
Rotary	73	[d] 14	87	16.1
Cable	54	2	56	3.6
Totals	127	16	143	11.2
6. Lost Hills, Belridge, and McKittrick:				
Rotary	32	[e] 7	39	18.0
Cable	67	14	81	17.3
Totals	99	21	120	17.5
7. Whittier, Puente, Olinda, Brea Canyon, Newhall, Ventura County, Santa Maria, Casmalia, Cat Canyon, Arroyo Grande, Kern River:				
Cable	185	34	219	15.5
8. All fields:				
Rotary	240	67	307	21.8
Cable	434	73	507	14.4
Totals	674	140	814	17.2

[a] Five cable recementing jobs not included.
[b] Four cable and five rorary recementing jobs not included.
[c] Five rotary recementing jobs not included.
[d] Two rotary recementing jobs not included.
[e] One rotary recementing job not included.

The first six fields listed in Table 6 are those in which there was enough use of both methods to warrant a comparison. Ten fields—including Ventura County in group 7—in which most of the work was done with cable tools, show that the proportion of failures in landing water strings with cable tools is 15.5 per cent. The proportion of failures with cable tools for all fields in the State as shown in group 8 is 14.4 per cent, whereas failures with rotary tools for all fields is 21.8 per cent. The difference is 7.4 per cent.

This seeming disadvantage in the rotary method is due mainly to operations in the Coalinga, Sunset, and Midway fields, the failures with rotary and with cable for Coalinga and Sunset fields being in the ratio of four to one. A study of the stratigraphy of Coalinga field (see Pl. II, p. 22) and Sunset field shows many changes of thin formations.

In the Montebello field, the newest field in California at the time these data were gathered (July 31, 1917, to June 30, 1918), the proportions of failures for both kinds of tools, rotary, 35.7 per cent, and cable, 35.3 per cent, are double the average for both methods for all fields, 17.2 per cent. This is undoubtedly due to the uncertainties and hazards of drilling in undeveloped territory.

Until a number of wells have been drilled, formations have been carefully prospected and tested, and experience has indicated the stratigraphic position of suitable formations in which to land casing for water shut-off, the hazard is greater than under known conditions for drilling. In developed fields, especially where early development was done with cable tools, the operator's engineer [20] can forecast with considerable accuracy by the use of cross sections, peg models, subsurface contours, and other data derived from well logs, the depth at which a desirable stratum for shutting off water should be entered by the drill.

The responsibility of the driller and the engineer in such operations is equal. The driller furnishes the engineer with data on formations and depths and with these, supplemented by data from other wells, the engineer guides the driller in further operations.

The results mentioned show that in the important matter of correctly finding suitable formation in thin strata to shut off water, rotary failures are undoubtedly due to discrepancies in measuring depths in rotary holes with drill pipe, or to inaccurate logging of the depths of formation changes, or to the impossibility of bailing the hole, during drilling, to identify oil or water bearing strata. The foregoing comparison of rotary with cable-tool drilling has been given in considerable detail because shutting off water is one of the most important steps in drilling an oil well.

[20] Ambrose, A. W., Underground conditions in oil fields: Bull. 195, Bureau of Mines, 1920, p. 67.

Figure 5 shows stratigraphically equal parts of graphic logs of two wells drilled in a California field, one with cable and the other with rotary tools, and illustrates some of the comparisons made

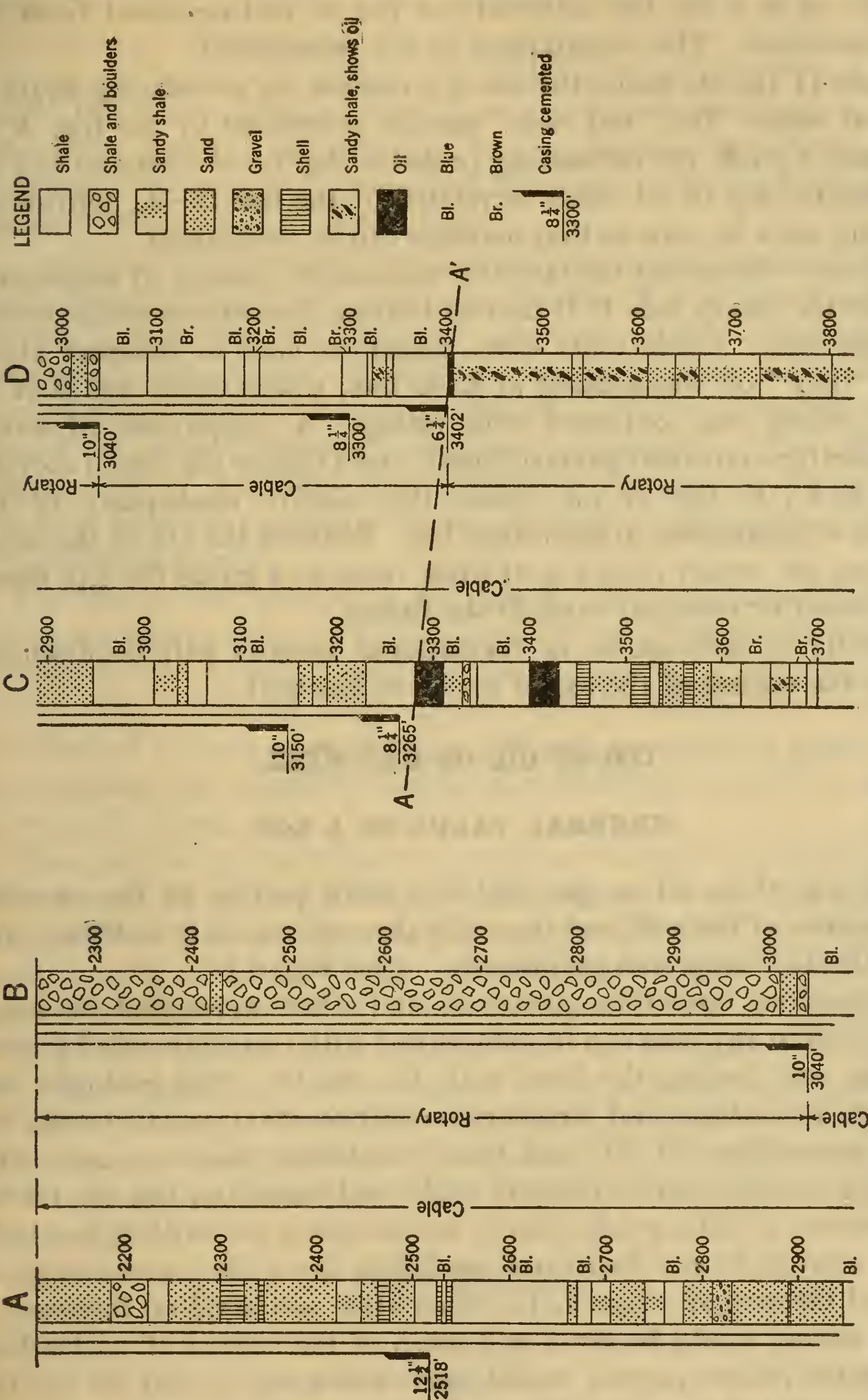

FIGURE 5.—Graphic logs of two wells, in a California field, well A–C drilled with cable tools and well B–D chiefly with rotary tools.

above. The rocks penetrated are alternating beds of sand, shale, gravel, conglomerate, and thin layers of silicified sandstone. The "shale and bowlder" bed, probably conglomerate, at depths of 2,187 to 2,225 feet, in the cable-tool log, A, is a formational marker and is important for correlation. It would be impossible to correlate this stratum, or any other stratum, with formations shown in the rotary log, B, as in a log the artificial can not be distinguished from the real bowlders. This comparison is not exceptional.

Plate II (p. 22) shows the use of a marker for correlating strata in several wells. The "red rock" marker correlated by the line A′–A becomes a guide for estimating probable depths of strata to and including the top of oil sands correlated by the line B′–B. Obviously, drilling must be done so that markers can be recognized.

Figure 5 shows that the operator realized the danger of attempting to drill the rotary hole B-D into oil-bearing formations without more definite data. Cable tools were, therefore, used to prospect ahead until "pay" oil was entered at 3,402 feet, where water was shut off and drilling was continued with rotary. A comparison of stratigraphically equivalent parts of logs C and D below the line of correlation A–A′, to top of oil, shows the relative inadequacy of the record of formations in the rotary log. Without the aid of the cable-tool log, the rotary record is of little value as a guide for any necessary repair or remedial work in the future.

Details of deficiencies in formational records will be discussed under the subject of the log of an oil or gas well.

LOG OF OIL OR GAS WELL.

GENERAL VALUE OF A LOG.

The log of an oil or gas well is a word picture of the physical appearance of the well and the rocks through which it is drilled, and may also be interpreted graphically. (See Fig. 5.)

Prospectors, operators, geologists, and others agree that the existence of oil in any area can be determined with certainty only by prospecting and testing the land with the drill.[21] The geologist can indicate formations and structural conditions that are favorable for the accumulation of oil, and those conditions that are not. His training enables him to identify rocks and structure, but the record of previous drilling guides him in his decisions, for drilling has indicated what rocks and structural conditions favor the accumulation of oil, and theories of origin and accumulation are based on this record. Much money would be saved and much of the hazard of wildcatting eliminated if the operator would learn where not to drill for oil, but it is doubtful if records will ever be so complete that the geologist

[21] Lewers, Charles R., and Booth, Henley C., work cited, pp. 246–254.

can select a new area and say with certainty "drill here and you will get oil."

The foregoing discussion emphasizes the general value of complete records of drilling. The operator's immediate need is for a complete and accurate record or log of his oil or gas well, especially if it is a wildcat or prospect well drilled for the information it can give. Oil is the ultimate object, but to predetermine at what depths oil will be found is difficult and often impossible. In the log of the first well all possible information that will guide the operator in future drilling should be assembled.

Present drilling methods being considered, a prospect well should be drilled with cable tools wherever possible. The prospect well may become a producer, but its main value lies in the information on formations penetrated. Without a record of these no intelligent campaign of development can be adopted, and the more accurate the record the greater the return from the investment. This statement applies equally if drilling proves that the formations contain no oil, for such conclusive proof removes uncertainty and prevents the loss of additional money.

The map of any producing field shows many abandoned wells for which no logs or other records are available. Because the wells are abandoned the territory seems to be unproductive. Possibly some of the wells were drilled only a few hundred feet deep, or water was not shut off in them or some other difficulty prevented a proper test; nevertheless, the stigma of being nonoil-bearing is hard to remove from such an area.

One operator has said that it is necessary to drill one well to prove the presence of oil and that a second well must be drilled to get it. The question of whether or not a second well shall be drilled depends largely on the information gained from the first. This excepts speculators and stockjobbers, who drill not to get production but merely to prove the presence of oil or gas. Oil constitutes such proof, but they usually have no desire to produce, protect, nor conserve the oil. Naturally the information sought by such speculators is a fragmentary part of that which is essential. Often the disregard for all incidental information in drilling defeats the purpose of getting proof of oil.

TOUR REPORTS.

In some fields the log of a well, as it appears in final form, is assembled from a series of tour reports. A tour, pronounced "tower" by the driller and frequently misspelled "tower," is a working shift of 12 hours, except in California and Gulf coast fields, where it is 8 hours. Reports prepared by the driller on each tour set forth the amount of hole drilled, the nature of formations penetrated, any signs or evidence of oil, gas, or water, and depths at which they were noted, causes of delays, and amount of casings placed in the hole.

Tour reports are a recent innovation with many companies. The custom was to keep a log book at the well. This document, much thumbed and oil besmeared, was formerly noteworthy for its brevity as to formation and casing records. Its main use seemed to be as a chronicle of human events. In it were recorded the doings of the well crew and occasional bits of contemporaneous oil-field wit. However, such records were better than none at all, and often after the fragments had been carefully pieced together they have given valuable information.

Realization of the necessity of detailed and complete logs has followed the adoption of engineering methods. A number of operators now issue instructions to drilling crews for guidance in the preparation of complete tour reports, but even then a drilling foreman not in sympathy with engineering requirements will soon instill a spirit of carelessness among the crew. The following is a blank form of tour report used by the Texas Pacific Coal & Oil Co., Ranger, Tex.:

DRILLER'S TOUR REPORT.

FARM ________________________ WELL NO. ______

DATE ________________________ 19__, 7— M.

FORMATION.

DEPTH AT BEGINNING OF TOUR ________________________ FEET.

MADE DURING TOUR ________________________ FEET.

DEPTH AT END OF TOUR ________________________ FEET

________ FEET OF ____________ FROM ________ FT. TO ________ FT.

________ " ____________ " ________ " ________ "

________ TOTAL FEET MADE DURING TOUR.

WATER.

GOT WATER AT ____________ FEET

NO. OF BAILERS ______________

IF HOLE FULL, STATE FLUID LEVEL

FROM SURFACE ____________ FEET

FRESH OR SALT ________________

UNDERREAMING.

FROM ____________________ FEET

TO ____________________ FEET

FROM ____________________ FEET

TO ____________________ FEET

CASING.

SIZE________________________	AT BEGINNING OF TOUR____________FT.________IN.
WEIGHT______________________	PUT IN DURING TOUR ________FT.________IN.
MAKE________________________	AT END OF TOUR____________FT.________IN.

HOURS DRILLING ________ HOURS IDLE ________ REASON ________

REMARKS: ____

____

____

____

____

DRILLER.

THE DRILLERS' LOG BOOK.

The "Drillers' Log Book," used by the Interstate Oil Co., Maricopa, Calif., is a fair sample of a form for gathering complete data. The book provides 45 pages for specified data, and additional pages for notes. It is 5¼ by 8¼ inches in size, bound in blue cloth, and is called the "Blue Book" by the drillers. It is strictly a "lease" or "farm" book and, on completion of the well, is retained in the field office. If further work on the well becomes necessary, the crew call for the Blue Book, which gives the complete record of previous work on the well. From the entries in this book the tour reports and final log are prepared.

The details of the assembled book follow:

Front cover.

Name of Company.

____

DRILLERS' LOG BOOK.

Record of Well No____________________________________

Property ____________________________________

Section____________________ T____________________ R____________________

____

Inside front cover.

INSTRUCTIONS.

Each driller must post up this book before he leaves the derrick at the end of each tour.

Samples must be taken from each formation and never more than 30 feet apart in the same formation or 15 feet apart after oil sand has been reached, and a mark showing depth at which taken must be placed with the sample.

Save all sea shells or fragments thereof.

Give the best information you can. If in any doubt, consult with some one in authority.

Driller must record and caliper inside diameter, also outside diameter, of all tools, casings, casing shoes, and couplings.

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DESCRIPTION OF CONTENTS.

Illustrations of the various headings listed in the index follow. The heading of each section is repeated on each page of the section. For example, the heading "Tool records" and the instructions thereunder are printed completely on each of pages 39 to 44, inclusive.

GENERAL DATA

Property__________________________________Section__________, T_____, R_____

Well No__________________________________Elevation of floor_______________

Rig built by____

Sand line over derrick____________________feet____________inches____________

Drilling line over derrick_________________feet____________inches____________

Date spudded in____

Date well came in flowing____

Date well put on pumping____

Date started abandonment____

Date completed ____

Date abandoned____

Names of drillers	Names of tool dressers

LOG OF WELL

From	To	Thickness	Formations

CASING RECORD

Size________________ Threads per inch____________ Weight______________
Make of casing______________________ Kind of shoe________________________
Shoe i. d_______________ Shoe o. d_______________ Pipe i. d______________
Pipe o. d_______________ Collar o. d______________

Joint number	Feet	Inches	Total	Perforations	Remarks

CASING SUMMARY

State amount, size, position, where cut, and date when casing is removed.

Length		Size	Floor to shoe		Make	Remarks
Feet	Inches		Feet	Inches		

PERFORATIONS

Check joints in remarks column of pipe tally. State name of machine, operator and date.

Date	From	To	Holes			Remarks
			Rows	Size	Centers	

PLUGS AND ADAPTERS

Describe material, length, size, and depth of all plugs, rocks, adapters, etc., put in well.

____
____
____
____

FINAL CASING RECORD

1. State if casing is cemented or not.
2. If cemented state how many sacks of cement used.
3. Kind of cement.

Date	Size	Total	Remarks
....	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....

WATER TESTS

State size of casing being tested, also complete description and results of tests

Who made tests .... Name of driller ....

SHUTTING OFF WATER

Complete description of methods, material used, dates, condition and position of casing, and preparation of well.

.... sacks of .... brand cement
Process............
Top of cement found in pipe............
Depth of casing shoe while setting............
Dates set from............ to ....
Size of casing............
Drilled out to............
Complete description of preparation and methods............
....
Name of driller............
Name of tool dresser............

WATER NOTES

State at what depth and in what formation water is found, how found, kind of water, amount of rise or fall in well when standing or bailed, etc.

TOOL RECORDS

Before running any tool in hole, caliper and complete measurement must be taken. Record inside diameter, outside diameter and length.

Especially record caliper and length of all rope sockets and mandrel necks.

SHOOTING RECORD

Depths of shot, quantity of explosive used, purpose of shot, results.

For any further information on forms for oil-field records, the reader is referred to Bureau of Mines Bulletin 195.[22]

Use of such forms, however, does not insure accurate reports. Some employers have a short-sighted policy of gaging the efficiency of a drilling crew solely by the amount of hole made on tour. A great deal of work is necessary around a drilling rig besides making hole. However, to offset this policy drillers are accustomed to report total depth of hole at any given time shorter than it actually is. This is called saving or "banking" hole and is done by mutual understanding between opposing drillers at the well. The shortage may run as high as one hundred feet. The hole not reported is held in reserve against the time when delays, unavoidable or otherwise, prevent drilling, when part or all of the reserve hole will be reported as drilled on that date. Such practice leads to inaccuracy in reporting and logging formations. Measurements of hole should be checked frequently by a man not working with the drilling crew, and the employer should adopt some more scientific method of gaging work done than by amount of hole made.

A similar practice making for inaccuracy is that of averaging the amount of hole drilled a day between opposing drillers. One driller may dig 25 feet of hole in shale on his tour and the driller opposite him may spend all of his tour drilling through 2 feet of "shell." The formations drilled will probably be reported as shale, 15 feet, and hard rock, 12 feet. This practice is bad, for the resulting log may cause much unnecessary expense in future operations where dependence is placed on the existence of a particular formation at a specific depth.

A log must be taken at its face value. Certain parts of the record, such as water sands, junked tools, etc., are a statement of liabilities.

[22] Ambrose, A. W., Underground conditions in oil fields: Bull. 195, Bureau of Mines, 1920, pp. 201–229.

The reported oil and gas sands, according to their productivity, casing, and successful water shut-offs are part of the record of assets. Falsification of any of these important parts of the record will usually lead to loss of money and will rarely bring gain. Oil wells are monuments to intentionally, or otherwise, concealed errors. All work is done beneath the surface, therefore the opportunity for error and the temptation for successful concealment are equally great. The success of the industry depends to a large extent upon the integrity of the driller. If all mistakes and blunders can not bear the light of day they should at least be buried in some part of the log where they will not be the cause of future trouble.

THE WRITTEN LOG.

In the final log, details of tour reports are condensed. The final formation record shows names, thicknesses, and relative positions of strata and makes proper designations for oil, gas, or water. The log also provides for a separate summary of depths of oil, gas, and water-bearing strata. Depths to markers or key beds can also be summarized. The final log shows the names of men who worked on the well and dates of commencement and completion. The log should also show what kind of tools were used in drilling and the depths between which they were used.

Such a log is not complete unless supplemented by a history giving a record of all important mechanical operations in drilling, especially those of testing formations as a result of which certain conclusions as to the nature and content of strata were drawn. A fair sample of a complete log and history of an oil and gas well follows. The forms are adapted from those of the California State Mining Bureau.[23] The typewritten entries are printed in italics.

Fill this blank in with typewriter. Write on one side of paper only.

LOG OF OIL OR GAS WELL

FIELD ______________________________ COMPANY __________________________

Section ____ Township ________ Range ________ Elevation *895*. Number of well *40*.

In compliance with the provisions of Chapter 718, Statutes of 1915, the information given herewith is a complete and correct record of the present condition of the well and all work done thereon, so far as can be determined from all available records.

Signed ____________________________

Title _________________________

(*President, Secretary or Agent.*)

Date *January 20, 1916.*

The summary on this page is for the ORIGINAL condition of the well.

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[23] McLaughlin, R. P., 1st Ann. Rept. State oil and gas supervisor: California State Mining Bureau Bull. 73, 1917, pp. 14–15.

OIL SANDS. (*Medium grained oil sands.*)

1st sand from *1,542* to *1,550′ 8″*.
2d sand from ______ to ________.
3d sand from ______ to ________.
4th sand from ______ to ________.
5th sand from ______ to ________.
6th sand from ______ to ________.

IMPORTANT WATER SANDS

1st sand from *600* to *855*.
2d sand from *1,365* to *1,373*.
3d sand from *1,383* to *1,393*.
4th sand from *1,722* to *1,728*.

CASING RECORD.

Size of casing	Where landed	Where cut	Weight per foot	Threads per inch	Kind of of shoe	Make of casing	Cemented		
							Yes	No	Number of sacks
12½″	*1,084*	*Not*	*40*	*10*	*Plain*	*Reading*		*No*	
10″	*1,527′ 6″*	*1,200 ft.*	*40*	*10*	"	"	*Yes*		

CEMENTING OR OTHER SHUT-OFF RECORD

Casing, size	Sacks	Time set	Method	Test and result (give water level and bailing results)
10″	*45*	*30 days*	*Pumped through tubing*	*Bailed dry. Stood O. K. 12 hours. Drilled ahead 9 feet and hole tested dry.*

PLUGS AND ADAPTERS (*See history.*)

Heaving plug—Material____________ Length_________Where set___________
Adapters—Material________________ Size_________________________________

TOOLS

Rotary tools were used from__________ ft. to_____________ ft______________
Cable tools were used from___________ ft. to_____________ ft______________

PERFORATIONS

State clearly whether a machine was used or casing was drilled in shop

From	To	Size of holes	Number of rows	Holes per foot	Machine—Shop
ft.	ft.				
ft.	ft.				
ft.	ft.				
ft.	ft.				
ft.	ft.				

Thirty days after completion well produced *no* barrels of oil per day.

The gravity of oil was___degrees Baumé. Water in oil amounted to___per cent.

NAMES OF DRILLERS.	NAMES OF TOOL DRESSERS.
------------------------------	------------------------------
------------------------------	------------------------------
------------------------------	------------------------------
Date drilling started *Mar. 6, 1910.*	Date well was *abandoned, July 8, 1913.*

FORMATIONS PENETRATED BY WELL

DEPTH TO—		Thickness	Name of formation
Top of formation	Bottom of formation		
0	*15*	*15*	*Surface.*
15	*75*	*60*	*Blue shale.*
75	*100*	*25*	*Brown shale.*
100	*120*	*20*	*Blue clay.*
120	*140*	*20*	*Yellow clay.*
140	*170*	*30*	*Blue clay.*
170	*210*	*40*	*TAR SAND.*
210	*295*	*85*	*Blue sandy shale.*
295	*303*	*8*	*Black sandy shale.*
303	*545*	*242*	*Dark blue shale.*
545	*550*	*5*	*WATER SAND and oyster shells (Ostrea titan).*
550	*600*	*50*	*Dark blue sandy shale.*
600	*855*	*255*	*Coarse water sand.*
855	*870*	*15*	*Blue shale.*
870	*1,075*	*205*	*RED ROCK. Marker.*
1,075	*1,078*	*3*	*Blue clay.*
1,078	*1,088*	*10*	*RED ROCK.*
1,088	*1,105*	*17*	*Sandy blue shale.*
1,105	*1,215*	*110*	*Blue shale.*
1,216	*1,260*	*45*	*Coarse sand (trace of oil and gas).*
1,260	*1,293*	*33*	*Hard blue shale.*
1,293	*1,355*	*62*	*Muddy WATER SAND.*
1,355	*1,365*	*10*	*Dark blue shale.*
1,365	*1,373*	*8*	*WATER SAND.*
1,373	*1,383*	*10*	*Dark brown shale.*
1,383	*1,393*	*10*	*WATER SAND.*
1,393	*1,485*	*92*	*Dark blue sandy shale.*
1,485	*1,492*	*7*	*Sand—poor showing of oil.*
1,492	*1,512*	*20*	*Sandy blue shale.*
1,512	*1,519*	*7*	*Sand (showing no oil).*
1,519	*1,542*	*23*	*Dark blue shale.*
1,542	*1,550*	*8*	*Medium grained OIL SAND (very good).*
1,550	*1,685*	*135*	*Sandy blue shale.*
1,685	*1,695*	*10*	*Red clay.*
1,695	*1,722*	*27*	*Dark blue shale.*
1,722	*1,728*	*6*	*WATER SAND (coarse grained).*
1,728	*1,730*	*2*	*Blue shale.*

HISTORY OF OIL OR GAS WELL.

FIELD______________________________ COMPANY_______________________________
Section__________ Township____________ Range________ Number of well *40*.
Signed______________________________
Title__________________________
(*President, Secretary, or Agent.*)

Date: *January 20, 1916.*

It is of the greatest importance to have a complete history of the well. Please state in detail the dates of redrilling, together with the reasons for the work and its results. If there were any changes made in the casing, state fully, and if any casing was "side tracked" or left in the well, give its size and location. If the well has been dynamited, give date, size, position, and number of shots. If plugs or bridges were put in to test for water, state kind of material used, position, and results of pumping or bailing.

The well was drilled with standard tools. It was spudded in March 6, 1910.

The hole was started with 12½-in. bit and this size casing was carried to 1,084 feet. The 10-in. casing was then carried to 1,526 feet, when it was cemented with 45 sacks of Santa Cruz cement pumped in through tubing with packer. The casing was then driven into blue shale 1′6″ and landed at 1,527′6″. Cement stood 30 days, then hole was bailed dry and stood dry 12 hours. Drilled ahead 9 ft. and hole tested dry.

The hole was drilled with 8¼-in. bit to 1,730 ft., but a water sand was entered from 1,722 to 1,728 ft. 6 in.

There were five attempts made to shut off bottom water (see log) but all were failures.

The 8¼-in. casing was pulled out and on April 1, 1913, 95 sacks of cement were dumped in, 1,660–1,535 feet. On ten successive bailing tests an average of 72 ft. of water came in in 14 hours. On April 13, 14 sacks more of cement were dumped in at 1,535 ft. and four bailing tests, similar to above, made no change in the water. On April 20, a casing tester was set in the 10-in. at 1,450 ft. and the casing tested dry. The hole was cleaned out to 1,544 ft. and the 8¼-in. cemented at that depth on April 25 with 14 sacks of cement. Cement set five days and the casing leaked 75 ft. of water in twelve hours. Casing was screwed up 10 in. and tested dry. Cement was drilled out and the hole drilled ahead to 1.580 ft. and bailed dry, and on seven successive tests filled up an average of 256 ft. of water in twelve hours. Water level *before plugging bottom was 450 ft. from the surface.*

The 8¼-in. casing was loosened and all recovered. Put in 15 sacks of cement at 1,539 ft. with dump bailer, then stone and rock to 1,525 ft., topped with 15 sacks Mt. Diablo cement. The 10-in. casing was then ripped at 1,200 ft., and this 1,200 ft, was recovered, leaving (1,200–1,527′6″) 327′6″ of 10-in. casing in the hole. The hole was then abandoned. The casing left in the hole is 1,084 ft. of 12½-in. casing and 327′6″ of 10-in. from 1,200 to 1,527′6″. Top of plug is at 1,525 feet.

THE GRAPHIC LOG.

A graphic log is a drawing to scale showing the formation record and the physical condition of a well. For many uses a graphic log is better than a written log. Formations, casing records, and method of shutting off water are indicated by certain symbols. (See Fig. 5, p. 69.) The development engineer uses the graphic log in preparing well cross sections, peg models, and casing programs. Ambrose[24] proposes standardization of symbols for graphic logs so that the symbols in all drawings can be recognized without reference to a legend.

THE FORMATION RECORD.

A large proportion of the formation records in existence have been made by drillers, and their commonplace identification of rocks has been used by engineers in many fields with satisfactory results. However, the names are not always lithologically correct. Some companies employ geologists who carefully watch and identify all samples brought to the surface; this should be the universal practice at prospect wells.

COMPARATIVE VALUE OF DRILLERS' AND ENGINEERS' OBSERVATIONS.

The following part of the record of a well drilled at Hope, Ark.,[25] shows parallel descriptions of geological formations by geologists and by drillers.

Part of record of well No. 4 of Hope Water & Light Plant, Hope, Ark.

Age and formation.		Depth at which sample was obtained.	Description of samples. (By H. D. Miser. No samples above 565 feet were preserved.)	Driller's record.		
				Material.	Thickness.	Depth.
		Feet.			*Feet.*	*Feet.*
Upper Cretaceous.	Bingen formation.	1,495–1,501	A drab-colored micaceous sandy clay.			
		1,501–1,585	Mixture in about equal amounts of micaceous sandy greenish-gray earth and micaceous calcareous glauconitic sand containing some small kaolinized feldspars here and there. There are a few small crystals of pyrite.	Shale, blue	30	1,530
				Gumbo	10	1,540
				Shale, sandy	45	1,585
Lower Cretaceous.	Trinity formation.	1,585–1,595	Mixture of drab clay with a smaller amount of red clay. Still smaller amounts of pyrite, quartz sand, and a few fragments of shells are present, but these are probably foreign.			
		1,595–1,610	Mixture of red clay, chiefly, with some sandy drab-colored clay and loose glauconitic quartz sand. All but the red clay are probably foreign.	Gumbo, red	20	1,605
		1,610–1,675	Main constituent is red clay; the minor constituents are drab-colored sandy clay, sand, pyrite, and lignitiferous matter. Three specimens of foraminifera were found.	Rock, hard	10	1,615
				Gumbo	35	1,650
				Rock, soft	25	1,675
		1,675–1,700	Fine angular quartz sand makes up most of sample, though there is some red clay and some dark clay. Three specimens of foraminifera found.	Rock, hard	25	1,700

[24] Ambrose, A. W., Underground conditions in oil fields: Bull. 195, Bureau of Mines, 1920, p. 26.

[25] Miser, Hugh D., and Purdue, A. H., Asphalt deposits and oil conditions in southwestern Arkansas: U. S. Geol. Survey Bull. 691–j, 1918, p. 280.

Part of record of well No. 4 of Hope Water & Light Plant, Hope, Ark.—Cont'd.

Age and formation.		Depth at which sample was obtained.	Description of samples. (By H. D. Miser. No samples above 565 feet were preserved.	Driller's record.		
				Material.	Thickness.	Depth.
Lower Cretaceous.	Trinity formation.	*Feet.*			*Feet.*	*Feet.*
		1,700–1,720	Drab-colored, slightly calcareous clay and some pieces of red clay.	Shale, blue	20	1,720
		1,720–1,735	This sample is so mixed that the character of the rock can not be determined. It consists of dark clay, calcareous gray sandstone containing abundant carbonized wood, red clay, pieces of limestone or shells, and much pyrite.	Rock, hard	30	1,750
		1,735–1,750	Sample consists mainly of brown fine quartz sand. Some pieces of sandstone having a calcareous cement are present. Some pyrite was seen. One foraminifer found.			
		1,750–1,758	Red and greenish clay, mainly red.	Gumbo	5	1,755
		1,758–1,780	Brown fine quartz sand with a little pyrite. Few pieces of red clay, and the other rocks are probably foreign. Some pieces of sandstone present.	Shale	25	1,780
		1,780–1,820	Gray fine angular quartz sand.			
		1,820–1,825	Pyrite abundant; one piece of woody matter partly replaced by pyrite; good many comminuted shells, much quartz sand, which makes up half of sample; and both red and dark clay.			
		1,825–1,835	Fine gray sand mixed with some calcite. This may be from a calcareous sandstone. There is one large piece of fossiliferous calcareous sandstone containing fine particles of disseminated pyrite. Some red and drab clay are present.	Rock, hard, white; salt water at 1,920-1,975 feet.	215	1,995
		1,835–1,852	Fine gray quartz sand and some calcite (probably calcareous sandstone). Very few pieces of dark clay present.			

The main advantage of the geologist's description over the driller's classification is that recognition of rocks or "sea shells" will indicate important markers and their stratigraphic position in the general geologic column of an area. This is shown in the log under "Age and formation." The geologist has endeavored to group the strata under the various important marker formations to which they seem to belong.

The value of the data obtained from a drilling well depends on the ability of the drillers. All subsequent studies of underground conditions, from well to well, are based on observations made and recorded by them. Considerable effort has been made to have drillers log results according to the geologist's way of thinking. Instead of all operators in a given field standardizing the commonplace rock-names used at the derrick, the tendency has been to require translation of these expressions into the broader classifications of geology, lithology, or paleontology. The driller can not be expected to take the necessary time to learn the science of geology, although his work necessitates his learning some of the elementary principles. The geologist, on the other hand, should acquaint himself with the mechanical limitations under which the driller works in determining the nature and content of subsurface strata.

However, an overzealous geologist or engineer can carry refinements in rock classification so far that no commonplace segregations of strata appear in the log. Consistency in classification is sometimes of greater importance than having every rock or formation correctly named. New drillers in a partly developed area may give names to formations entirely different from those that older men in the field are accustomed to apply, and identification of the beds by name only becomes difficult. If a formation has been improperly named in a number of logs, continued use of that name is better than the confusion caused by changing to a correct but unfamiliar name. Whoever subsequently attempts to prepare well cross sections, which include such inconsistent logs, is often at sea for a basis of correlation. For example, if the practice in an area has been to call a certain formation "brown shale," a new driller would be inconsistent, although he were perhaps closer to the truth, to call the same formation in another well "dark gray shale," or "firm shale."

The classification of many formations is colorimetric. Marker formations are indicated as "red rock," "black lime," "big blue," etc. With these formations consistency in the color designation is more important for correlation than is lithologic accuracy. On the other hand, a lack of knowledge of different rocks and their geologic significance has often proved costly. The author knows of a well at which drillers logged the various rocks penetrated as green shale, white shale, blue shale, etc. Surface outcrop showed that the hole was started in sedimentary rocks. A geologist, casually examining the cuttings, logged as varicolored shales, found that the drill was below sedimentary rocks and had been working for at least 600 feet in serpentine and related rocks. Generally, except possibly in Cuba, experience has shown that when the drill hits serpentine it is time to quit. The cost of continuous geological observation at this prospect well would have been small compared with the money fruitlessly spent in drilling for oil in impossible rocks.

Harris[26] tells of two drillers who in the spring of 1907 were engaged on a well in the Cedar saline, Winn Parish, La., where at 78 feet they struck rock of the toughest type for drilling which continued practically to 1,000 feet. Work was discontinued at a depth of a little more than 1,200 feet, where the drill encountered "volcanic rock." Specimens sent to Harris showed clearly that the supposed

[26] Harris, J. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, 1910, p. 110.

igneous rocks consisted of gypsum and limestone darkened by hydrocarbons and pyrites, and the so-called "volcanic rock" was a favorable indication for further drilling instead of abandonment.

CONFERENCES OF DRILLERS AND ENGINEERS.

Uniformity of nomenclature for identical strata in any oil field is important and could be obtained by more far-sighted relations between interested parties. Too often the barbed-wire fence separating adjoining properties is regarded as a barrier to friendly intercourse. The fact should not be overlooked, however, that there are no artificial barriers underground in the pool from which all operators are extracting oil. Further, the most inefficient of the operators by his acts largely determines the entire future value of the pool.

In a new field, as soon as a few wells have been drilled, a conference of superintendents, drillers, and engineers should be held to discuss, among other things, the subject of formations penetrated in drilling. The drillers would tell how the rocks respond to the drill and how the cuttings look, and the engineers would make suggestions as to proper nomenclature. Uniformity of names could be determined. Early dealing with the problem would aid greatly in all further development of an area and would also foster a spirit of mutual interest and cooperation.

David White[27], before the American Association of Petroleum Geologists, expressed the above in a more emphatic manner, as follows:

> Now it isn't exactly my personal job to labor with the driller. I wish it were; I would like to try it. Probably I wouldn't do any better than any of you, but I would like to ask you, Is it not possible that after all your failure to get adequate and accurate well criteria may be due to the fact that you are not in cordial contact and sympathy with the driller? The driller is drilling, but he seems to have little interest or incentive to gather the data for which you must depend on him and the intelligent collection of which would make his task so much more interesting to himself. His ability and intelligence are not inferior to yours. Are you doing your best to bring him to a better basis of operation? How many of you are conducting schools? How many of you put aside your high-brow clothes and forego your high-brow language (which is worse than high-brow clothes) and so present the subject of rock characters that he, recognizing them, will take pride in good logs and in gathering the samples to serve as vouchers for his identification? Heaven knows you will never get the material you so badly need; they will never get it for you and they will never try to, unless you interest them in finding the truth and in learning how to apply it.

BASIS OF NAMES OF OIL-FIELD ROCKS.

The predominating physical characteristic of a rock will usually prompt the name used in classification. The designation brown

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[27] White, David, Bull. Amer. Assoc. Petroleum Geol., vol. 3, 1919, p. 79.

shale will be discarded for caving shale. Shale, clay, mud, slate, and limestone are usually denoted by color or hardness, and sand, sandstone, gravel, and other porous material by texture or hardness. The name given any rock depends upon (1) the way the drill works in the rock, (2) what the rock does to the drill, (3) how the cuttings look at the surface either before or after they are dry, and (4) the probable fluid content of the rock.

Classification on the above basis usually is fairly dependable, but there are some exceptions; for example, the graphic log, B, in Figure 5 (page 69), shows 800 feet of an almost unbroken mass of "shale and bowlders." Without further inquiry, any oil-field worker will know that this is the log of a rotary-drilled hole. Rotary bowlders are usually the evidence of a condition, but not of a formation. These bowlders are made artificially out of hard strata or bodies of shale. They represent solely a mechanical interference with drilling, and do not rightly belong in the record of formations, where only the natural material in its stratigraphic sequence should be entered. That so-called bowlders were made of certain material, or followed down the hole from some higher formation, should not appear in the formation record. The cable-tool log in Figure 5, A, shows that within the zone logged as "shale and bowlders" were a number of beds that should have been, but were not, logged individually. It is hard to understand why geologists and engineers, at least, will continue to fill a log, which is supposed to be a geological record, with hundreds of feet of "bowlders."

Sand, shale, and sandy shale are often confused. In Figure 5, D, all the strata in the rotary hole below 3,408 feet are logged as sandy shale, because sand from the sand members penetrated continued to show in the mud when the bit was working in shale.

Also, oil continued to show in the rotary hole below 3,402 feet during most of the drilling. No clear-cut stratification is evident. The cable-tool log shows that strata were probably definitely segregated.

Similar obscurity of record has also been seen in cable-tool logs of wells penetrating through a heavy oil zone of alternating beds of creviced and impervious shale. Apparently the changes from barren strata to oil-bearing strata could not be detected by the way the drill worked. The heavy oil followed the tools and as a result the entire zone was logged as oil-bearing.

CLASSIFICATION OF LOG TERMINOLOGY.

Four guides ot the identification of formation are given on this page. A complete and inclusive classification is hardly possible. One of a number of qualities, such as color, hardness, or porosity, will predominate and determine the name.

The work of Udden and Phillip [28] is an example of what may be done as a preliminary step in the study of subsurface conditions in an oil field. Their results are presented here in considerable detail because the method can be applied to any field. In addition, a number of valuable conclusions are drawn from the classifications.

Udden and Phillip have classified the terms used in the formation records of 37 wells near Petrolia, Tex., and of 10 wells in the Electra field, according to their own interpretation of the exact meaning and have noted the number of times each of the terms has been used and the thickness of each of the several formations. All the wells have a combined depth of 81,153 feet.

Table 9 shows the number of times different rocks expressly named or inferred to be present were reported, the average thickness of strata, the total number of feet reported, and each rock's percentage of the total thickness studied.

TABLE 9.—*Kinds of rocks logged in drilling.*

Kinds of rock.	A Number of times noted.	B Average thickness of strata, feet.	C Total number of feet reported.	D Per cent of total thickness.
Gravel	6	7	45	0.05
Sandstone	350	42	14,866	18.30
Argillites (shale, clay, mud, etc.)	579	92	53,290	65.60
Limestone	33	27	881	1.10
Gypsum	17	28	478	.55
Surface deposits	11	16	181	.20
Mixtures	94	79	7,445	9.30
Gypsum and other minerals	25	13	335	.40
Unidentified rocks	75	48	3,632	4.50
All rocks	1,196	39.4	81,153	100.00

Columns A and B in Table 9 show that the number of times a rock was noted and logged varied directly with the thickness of the stratum. For example, the average thickness of gravel, column B, is shown as 7 feet and was noted 6 times; and the argillites, average thickness 92 feet, were noted 579 times. There are some inconsistencies in this conclusion, but reference to the table confirms the almost self-evident fact that the thinner the bed the greater the chance of it being overlooked in drilling.

[28] Udden, J. A., and Phillip, Drury McN., Underground formations: Univ. of Texas Bull. 246, 1912, p. 62.

SANDSTONES.

Sandstones are logged as "sand," "sand rock," "rock sand," "rock and sand," and "sand shell." Table 10 shows the number of times these various names were used in reporting sandstone.

TABLE 10.—*Drillers' names for sandstone.*

Names used.	Number of times used.	Total thickness reported.
		Feet.
Sand	243	8,842
Sand rock	105	5,706
Rock and sand	1	230
Rock sand	1	60
Sand bowlders	4	19
Sand shell	2	9

SHALES AND CLAYS.

Argillaceous beds make up 70 per cent of all the material logged, and this high proportion caused them to be described by color, texture, and contents, as shown in Table 11:

TABLE 11.—*Drillers' names for argillites.*

Names used.	Number of times used.	Total thickness reported.	Names used.	Number of times used.	Total thickness reported.
		Feet.			*Feet.*
Shale	227	21,141	Shale and bowlders	4	178
Mud	164	16,002	Gumbo and rock	3	120
Gumbo	41	2,724	Shale and rock	2	69
Slate	32	1,622	Clay and bowlders	1	159
Clay	27	3,115	Soapstone	1	70
Mud and bowlders	13	608	Shale and clay	1	36
Gumbo bowlders	8	640	Soapstone and rock	1	30
Mud and rock	7	442	Slate and mud	1	22
Formation	5	1,942	Slate rock	1	19
Caves	5	591	Shale rock	1	3
Shale and mud	5	263	Shale and gumbo	4	418
Talc	5	44			

LIMESTONE.

Only 1 per cent of the reported rock consists of limestone.

TABLE 12.—*Drillers' names for limestone.*

Names used.	Number of times used.	Total thickness reported.
		Feet.
Lime	11	20
Lime shell	7	205
Lime rock	6	80

Drillers probably failed to report some limestones. Table 12 shows names they gave. Some rock termed limestone was probably calcareous sandstone. Gypsum is sometimes reported, as "gypsum" or "gyp rock," for some other rock, such as limestone.

OTHER FORMATIONS LOGGED.

A list of miscellaneous terms for formations that were used is given in Table 13.

TABLE 13.—*Other names given by drillers.*

Names used.	Number of times used.	Total thickness reported.	Names used.	Number of times used.	Total thickness reported.
		Feet.			*Feet.*
Flint rock	18	282	Surface clay	3	53
Quartz	3	39	Soil	3	14
Iron pyrite	2	9	Quicksand	1	10
Bowlders	2	5	Sod	1	1
Surface	3	103			

Table 14 shows that in this particular area most of the sandstones penetrated are less than 30 feet thick, and they become less and less frequent as their thickness increases. Thin clay beds are less frequent than thin sands. The most common thickness for argillites is 100 to 199 feet. No less than 161 beds of argillites measured over 100 feet.

Many sedimentary areas occur in which sandstone beds are much thicker than any shale or clay beds with which they are related. The above comparison, however, fills one of the requirements in oil accumulation, namely, comparatively thin reservoirs of sand interbedded with shale.

TABLE 14.—*Number of times various rock strata were logged according to thickness.*

Names of rocks.	Limits of thickness of beds, feet.													
	1–9	10–19	20–29	30–39	40–49	50–59	60–69	70–79	80–89	90–99	100–199	200–299	300–399	400–790
Sandstone	98	60	44	31	20	20	13	7	5	3	18	6	4	2
Argillites (shale, clay, etc.)	58	76	65	42	31	29	39	22	23	18	95	40	16	10
Limestones	23	9	6	1	1	1	2	1	......	......	......	1	......	......
Mixtures	9	19	14	9	4	5	6	3	3	3	4	6	4	1
Undetermined rock	24	10	11	5	2	3	2	1	2	1	4	1	2	2
All other rocks	21	6	6	3	4	1	1	......	......	......	1	......	......	......
All kinds of rocks	233	180	146	91	62	59	63	34	33	25	122	54	26	15

TABLE 15.—*Number of times terms and phrases denoting physical properties of rocks were used.*

Color.		Contents.		Cohesion.		Stratification.		Texture.	
Blue	200	Oil	63	Hard	88	Mixed	35	Sandy	5
Red	175	Water	41	Soft	15	Broken	19	Fine	2
White	81	Gas	33	Loose	4	Shelly	2	"Putty"	1
Red and blue	46	Salt water	17	Shaly	2	Streaks	2	"Porous fossil"	1
Black	42	Dry	14	Rocky	2	Stratified	1		
Brown	24	Oil and gas	6	Tough	2				
Gray	19	Dead	4	Very hard	2				
Light	9	Oil and water	3	Cavy	1				
Lead colored	8	Salt water and oil	3	Rotten	1				
Blue white	4	Fresh water	2						
Dark gray	1	Dead, little water	1						
Blue and brown	1	Salt	1						
Red and white	1	Oil and salt water	1						
Blue and black	1								
Total	612		189		117		59		9

In Table 15 the number of terms used are few, only a little more than the number of rock names already noted. The simple rock names are about thirty and the simple qualifying words are about forty. Names were given 1,143 rock strata, and properties were indicated for 986 of them.

Less than 1 per cent of the rocks are described by texture; 5 per cent are described in a general way as to stratification; 10 per cent are described with regard to cohesion; 17 per ent are described as to content—oil, water, gas; and 54 per cent are described with regard to color, which shows the importance of a colorimetric classification.

TABLE 16.—*Names used by drillers for the contents of sandstone reservoirs.*

Names used.	Number of times used.	Total thickness logged.	Average thickness.
		Feet.	*Feet.*
Oil	54	921	17
Water	41	2,250	55
Gas	32	526	16
Salt water	17	1,425	84
Dry	14	252	18
Oil and gas	5	51	10
Dead	4	29	7
Oil and water	3	83	28

MEASUREMENT OF DEPTHS OF STRATA.

The foregoing classification of log terminology is based upon at least two assumptions that can not be substantiated by mere inspection of a log. These are that thicknesses of strata were correctly measured, and that all formations penetrated were given the correct commonplace name. Therefore, probably there are some errors in the classification.

In order to appreciate the opportunity for error, the means of measuring depths of strata should be considered. The rotary or cable-tool driller determines the depths to the top and bottom of any stratum mainly by the action of the tools, confirming this by examining samples of cuttings. Both cable and rotary drillers know by the " feel " of the tools when the formation changes. They can also tell to a limited extent what kind of a rock the drill is working in.

The " feel " of formation change is to the driller the most accurate indicator of the exact position of change. The cable-tool driller, when he feels a change, looks up at the screw and notices how much screw he has out; the rotary driller makes his estimate from the length of drill stem that has passed through the table.

The principle involved in identifying rocks and changes by the "feel" of the tools is explained by a driller as follows: "If you are whittling a stick with a jackknife, and you suddenly hit something hard, you know it is a knot." The opinion is based on degree of hardness, but the stick might contain some other hard material besides a knot. Likewise, in the driller's observations the fact that a change has taken place will be reliable, but the nature of the change is subject to error. Several kinds of rocks may have nearly equal hardness, or toughness, or other quality that gives a positive indication, but its reactions to a rotary drill might be the exact reverse of those to a cable drill. A limestone that is soft to cable tools may be hard to a rotary drill.

Therefore in a field where the lithology of the various strata is unknown, it would not be wise to depend upon the "feel" of the tools nor the "tune" of the mud pump for a complete formation record. After the lithology of any given stratum or series of strata has been correctly determined in a field or a part of a field, the engineer's and driller's determinations may be joined for the convenience of both.

Drillers will continue to dig oil wells and record results according to the mechanical reactions involved. With the cooperation of engineers and geologists the formations can be recorded in the commonplace expressions of the derrick and the log be correct. Consistency of nomenclature for samples from the same stratum but from different wells is the primary requisite.

No two drillers have exactly the same system of drilling. The action of a string of cable tools while drilling freely may be compared to the bounding action of a ball at the end of an elastic string. In good drilling the drill line is elastic and is so tight that the tools reach out with a "snap" from the stretch of the line and hit a springing blow instead of dropping by dead weight. However, some drillers let the drill "teeter" up and down with fairly slack line and others may let the bit wallow around on the bottom of a hole. Such careless drilling is the cause of crooked or "flat" holes, or both.

The following account of actual observations of tools working underground illustrates what can be done with drilling tools under proper manipulation: At the Veteran copper mines, Kimberly, Nev., Star rigs were used for drilling holes for ventilation from the surface into underground workings.[29] A drilling site, vertically over a certain drift, was spotted at the surface by engineers. A hole was drilled with cable tools which entered the roof of the

[29] Snyder, W. A., Personal communication to the author, April, 1920.

500-foot level at almost dead center. The drilling was continued to the 1,000-foot level and the bit also entered the roof of this level, although off center. In oil-well practice this would certainly be considered a straight hole.

When the bit entered the 500-foot level and started into the floor of the drift, the driller in charge went into the mine to observe the action of the tools, which were working on a hemp drilling line. The length of line and tools was 500 feet. The drilling stroke was 36 inches. The bit on the upstroke would disappear into the hole in the roof of the drift and on the downstroke would hit the floor of the drift. In other words, for a working stroke of 36 inches, the actual movement of tools, owing to elasticity and stretch of drilling line, was over 8 feet. A line, say, 2,000 feet long would have a still greater working reach.

The statement has been made that in deep wells, depths, as usually measured,[30] are accurate within only 5 or 6 feet because of the stretch in the drilling cable. It is true that when cable tools are working in easily drilled rock the drill, as already explained, will reach out because of the elasticity of the cable and perhaps, after the driller has run out a screw's length of 5 feet of cable, the actual depth of hole drilled will measure 7 or 8 feet, or more. The stretch is an elastic one, however, and does not interfere with fairly accurate measurements. Measurements to bottom of hole are made on the "pick-up" of either drill line or sand line. The pick-up is the jerk that comes in the line just as it is pulled taut in taking weight of tools or bailer which have been resting on bottom. That is, in measuring a hole where the bit has worked freely it would be necessary to let out 2 or 3 feet more of line carrying dead weight only, in order to have the bit touch bottom. In the author's experience, measurements of hole can be made within a few inches of accuracy if care is taken. Naturally, the stretch of a cable in a "dry" hole will differ slightly from that in a hole full of fluid. However, in either case, if the derrick is measured over carefully just before measuring hole, the stretch of cable through the dead weight of tools and cable will be accounted for as the drill line is measured on its way into the hole. A 200-foot section of the line will be weighted just as heavily at the top of the hole, when being measured, as it will in its final position in the hole. Each measured unit of cable has its maximum length and maximum stretch when it is being "measured in."

At a cable-tool hole if the driller does not rate the change of formation from the action of the drill, he will from examining cuttings when the bailer is run. Such procedure, however, gives a

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[30] Shannon, C. W., Petroleum and natural gas in Oklahoma: Oklahoma Geol. Survey Bull. 19, part 2, 1917, p. 86.

variable of 5 feet or more. Suppose, for example, the last bailer sample was blue shale. The tools are run into the hole and immediately drill into a sand. The driller lets out a screw, then pulls the tools and bails; the bailer shows sand. If he assumes that the hole entered sand at the end of the screw, then the top of the sand stratum will be logged as 5 to 7 feet deeper than it actually is. If the driller is watching the tools closely he will probably catch the change close to the right place.

A 5-foot stick fashioned out of a piece of pine board is the unit of measure in an oil derrick and is as much a part of the equipment of the derrick as the "headache" post. Many logs show too that the driller attempts nothing smaller than 5 feet in his measurements of depth of strata. The following formation record is an actual example.

TABLE 17.—*Formation record, showing use of 5-foot unit of measurement.*

From—	To—	Thickness.	Formation.
Feet.	*Feet.*	*Feet.*	
0	210	210	Surface sand.
210	460	250	Yellow clay and sand.
460	590	130	Blue sand.
590	650	60	Blue sand and shale.
650	695	45	Blue sand.
695	720	25	Yellow clay and sand.
720	735	15	Sandy blue shale.
735	750	15	Tar sand.
750	1,095	345	Sandy blue shale.
1,095	1,100	5	Sandy shell.
1,100	1,255	155	Sandy blue shale.
1,255	1,320	45	Blue shale.
1,320	1,325	5	Tar sand.
1,325	1,450	125	Blue shale.
1,450	1,455	5	Shell.
1,455	1,505	50	Blue shale.
1,505	1,520	15	Oil sand.

If 5 feet is the working unit of measurement, then the variable from accuracy is at least 2.5 feet. Inasmuch as the engineer reduces log data to a scale of 100 feet to the inch for cross sections and correlations, 2.5 feet on such a scale is within the limits of accuracy for him, but this is no reason why the driller should not measure more carefully.

In a rotary hole the driller keeps on drilling as long as the bits cut; he does not have to run out a screw of drill line, pull tools, and bail, and in consequence does not note many changes of formation. When he notices a change, the depth to it is measured by the length of drill pipe extending from the bit to the top of the rotary table.

Estimates of lengths of joints or of stands of drill pipe simply produce an "estimated" formation record. The stands of pipe should be measured accurately with steel tape. The bad effect of using estimates for lengths of drill pipe is shown by a certain well that was measured after nine days' drilling, when the depth reported was 1,535 feet. Measurement of hole, by the company, showed the depth to be 1,624 feet. The difference of 89 feet in the two measurements was attributed to the driller using an arbitrary factor of 20 feet for lengths of drill-pipe joints, whereas, as a matter of fact, the stands of drill pipe (four joints to the stand) measured from 82 to 87 feet. It was necessary to distribute the above error through the formation record to that depth.

If the change in formation is noted from the cuttings, the length of time it takes cuttings to reach the surface must be considered, and how much hole has been made since the cuttings from the change were first noticed in the rotary ditch. Whenever the time that the change of formation took place is finally decided, that depth, in a rotary hole, is measured by the length of drill pipe. The requirements and means for measuring rotary holes have already been mentioned in the discussion of drilling contracts. (See p. 47.)

The total depth of a cable-tool hole at any time can be measured by (1) length of drill line, (2) length of sand line, (3) steel tape, and (4) length of casing where casing is landed.

MEASURING HOLE WITH SAND LINE OR DRILL LINE.[31]

1. All measurements of line must be made with steel tapes. Cloth and metallic tapes are subject to great changes in length. Use of a 5-foot stick on a sand or drilling line for distances of more than 200 feet is inaccurate.

2. The unit of measurement shall be either the distance the sand line "measures over" from the floor of the derrick at the casing head along the sand line to the top of the flanges of the sand reel, or the distance the drill line "measures over" from the floor to a point on the bull-wheel shaft 5 feet above the floor.

3. The "distance over" can be determined in the following manner with a bailer and sand line:

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[31] McLaughlin, R. P., 2nd Ann. Rept. State oil and gas supervisor: California State Mining Bureau Bull. 82, 1918, pp. 59–60.

(*a*) Run the bailer into the well a short distance and tie the string on the sand line, level with the surface of the floor, using a straight-edge or steel square to determine the correct position.

(*b*) Tie a strand of rope (target) tightly on the sand line at a position on a level with the top of sand-reel flanges, laying a straight stick on top of the flanges to determine this position.

(*c*) Lower the bailer into the well until the target is within easy reach of the derrick floor. Attach the end of a steel tape to the sand line at the target. Raise the bailer until another target can be fastened at the end of the tape and tie another target. Lower the bailer, detach the tape, hoist the bailer and attach the tape at the second target, hoist the bailer, and set a third target. Repeat the operation until it is possible to measure with the tape to the target first set at the floor. The tape must be shorter than the height of the derrick, so that it will not go over the pulley at the crown block.

When a target is tied to the line, paint should be put on the line above and below the target to show any displacement of the target.

To measure into the well after the unit length or "distance over" is determined, hold the bottom of the bailer dart, when raised, level with the surface of the floor, set a target at the top of the flanges of the reel, lower the bailer until the target is level with the floor, and set a second target at the reel. Correct count of the targets is most easily kept by detaching and keeping each one as it reaches the floor.

MEASURING HOLE WITH STEEL TAPE.

In almost all fields, except in California, common practice is to measure depth of hole with a weighted steel tape. This method is probably inherited from the days of the use of hemp cable, or "rag" line. If nothing interferes with the tape, such measurements should be accurate, but the magnetic drag of a steel tape on casing is frequently so great that it is impossible to tell when the weight reaches the bottom of the hole or to feel the "pick-up" as the strain of the weight comes on the tape in lifting the weight off bottom.

Fuller,[32] in discussing the subject of measuring wells, says that the magnetism of the casing presents an important obstacle to correct measurements. A. C. Lane has found that the cling of the steel line used in lowering thermometers into deep wells is considerable. He says [33] that in the well at Grayling, Mich., a man's full strength was required to start 2,600 feet of steel tape, although the weight of the tape itself was not over 25 pounds.

[32] Fuller, M. L., Magnetic wells: U. S. Geol. Survey Water-Supply Paper 258, 1911, pp. 87–88.

[33] Michigan Academy of Sciences, 4th Rept., 1904, pp. 166–167.

Depths of hole need not be measured directly with a steel tape if the rig is equipped with a steel sand line or drill line. Where casing is in the hole, the sand-line method will be more accurate.

MEASUREMENTS BY LENGTHS OF CASING.

When the casing is in the hole, the depth of hole may be checked against the computed length of casing in the hole. Usually the casing is measured joint by joint before it is screwed together and run down. All measurements should be made with steel tape, as accumulative error may occur through the take-up in screwing casing together; casing should be measured from collar to collar after it is screwed together and is ready to be lowered into the hole.

Occasion may arise when the exact length of a string of casing must be determined after it has been run into a well. For such measuring several tools are available.

Soyster and Dougherty[34] say that in measuring a string of pipe of uncertain length, the shoe is usually found by means of a ripper, underreamer, or latchjack, run on the drill stem, or by means of attachments used on the bailer, or by means of a hook run on a string of tubing. Varying conditions determine which of the methods is most convenient or desirable. Satisfactory results have been secured with each. Whatever the method, the common practice is to make repeated trials until the correct measurement is thoroughly established.

A tool called a "shoe grab" can be made for measuring casings. The special part of the body of the grab is hollow and is usually made of a swage nipple. The small end of the nipple is fitted to a substitute so that the shoe grab can be run on a string of tools. Three upward-pointing pieces of spring steel are riveted to the nipple in such a manner that they will expand to at least the outside diameter of the casing when the tool is run below the shoe of the casing. The springs are made of material that will bend easily.

The principal advantage in the use of this tool over a latchjack is that the collar spaces between two or three joints of casing above the shoe may be located. These distances can be checked against the casing record and leave little doubt as to the depth at which the grab engages the shoe.

The shoe grab has given the depth and thickness of a "shell" in open hole below the shoe when the grab was properly constructed, with a slight inward curve of the tip of the springs. The shell was noted by the feel of increased tension on the drill line while the shoe grab was passing through it.

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[34] Soyster, M. H., and Dougherty, John H., Measuring casing: 5th Ann. Rept. State oil and gas supervisor, California State Mining Bureau, vol. 5, Nov., 1919, pp. 5–10.

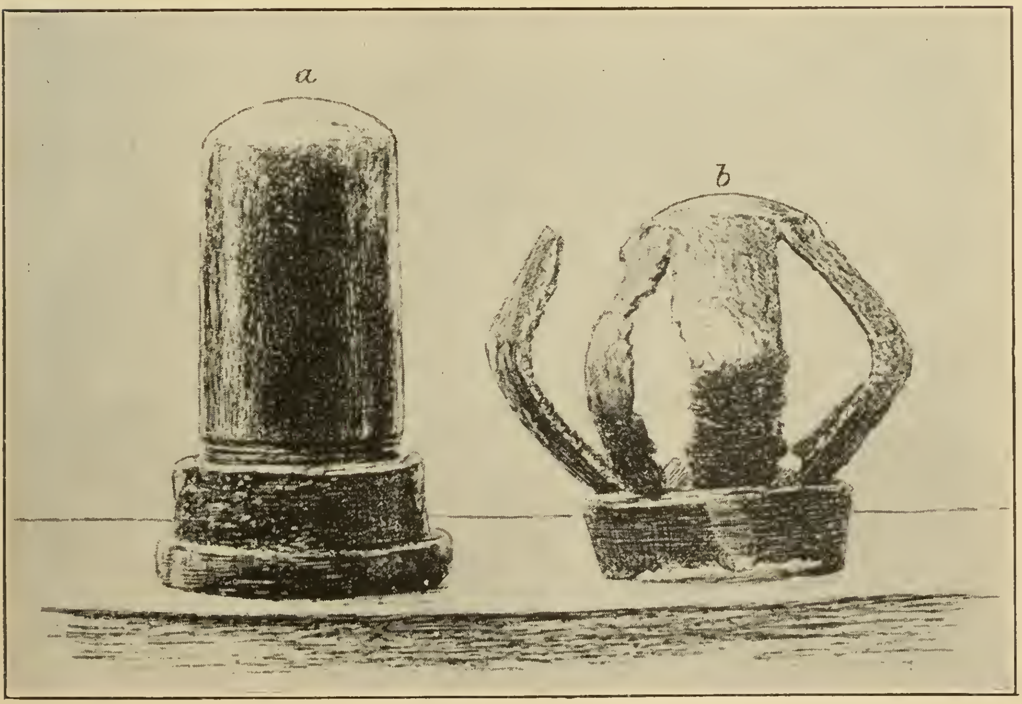
MECHANICAL REACTIONS AS INDICATORS OF KINDS OF ROCKS.

An effort has been made to show in Tables 18 and 19 some of the mechanical reactions that indicate to the driller the kind of rock the bit is cutting. The data that have been gathered from the oil fields of several States show little difference between the reactions of either rotary or cable tools to a sand stratum, whether drilled in California or Louisiana. A representative, instead of a complete, classification is deemed enough because the reactions indicate only the physical nature of the rocks. The effect of hard sand on rotary bits is shown in Plate IV, *A*.

TABLE 18.—*Mechanical reactions of various rocks to cable tools.*

Field and formation.	Mechanical reactions.	Cuttings.	Effect on bit.
Southern Oklahoma:			
Shale	Tools run smoothly and drill easily and fast in dry hole.	Bailer material mostly mud; fragments in mud and occasionally on bit.	Does not wear bit.
Gumbo	Drills roughly; tools jerk walking beam and won't drop.	Bailer material mud; tools come out loaded with gumbo.	Do.
Soft sand	Drills fast and easily; tools plunge.	Sand in bailer; none on bit.	No wear on bit, but markings vertical.
Sandstone	Drills smoothly with occasional "kick back."	Grains of sand and chunks of sandstone in bailer.	Wears bit out of gage.
Limestone	Hard and slow drilling; big "kick back."	Chips and irregular pieces, rock mostly pulverized.	Wears bits, but does not knock them out of gage like sandstone.
Gypsum	Drills smoothly and more easily than crystalline limestone.	Mostly pulverized; occasional flakes.	Does not wear bit excessively.
Ranger field, Texas:			
White limestone	Drills hard but free, with tight line.	White and pulverized.	Cuts bit badly—3 bits per tour.
Shale	Drills fast and easily in dry hole.	Chunks and fragments in bailer and small pieces stuck to bit.	Does not cut bit.
Black limestone	Drills hard, with tight line through oil-saver.	Cuttings fine grained.	Cuts bit a little.
Wyoming field:			
Hard shell	Drills clean with increased motion.	Occasional fragments in bailer.	Does not wear bit fast; cuts it vertically like sand.
Limestone	Do	Cuttings fine grained and heavy.	Does not wear bit badly.
Shale, slate, etc.	Drills fast in dry hole, except when cavy. Slow motion.	Fragments of material in bailer.	Very little wear, but "dubs bit under."
Sandstone	Drills clean and free.	Cuttings show as sand grains and fragments of cemented grains.	Cuts bit badly, vertically.

A. ROTARY BITS BEFORE AND AFTER DRILLING IN HARD SAND.



B. WATER CYLINDER BEFORE AND AFTER INTERNAL EXPLOSION.

TABLE 19.—*Mechanical reactions of various rocks to rotary tools.*

Field and formation.	Action of pump and tools.	Cuttings.	Effect on bit.
Midway Field, California:			
Hard sand	Pump runs with low pressure, sand takes some fluid; tools jump.	Sand shows in ditch with thin mud.	Cuts bit badly (see Pl. IV, *A*); for 1½ hours drilling hard sand.
Loose sand	Pump runs with low pressure; frequently takes mud; necessary to thicken fluid; when bit is stopped and set on bottom sand can be sluiced out with mud stream, causing tools to plunge.	Sand shows in ditch with thin mud.	Does not cut bit much.
Sandy shale	Pump runs with low pressure; digs like sand, but with bit set on bottom can not sluice out any hole below bit.	Fragments in ditch with thin mud; streaked samples on tools.	Cuts bits considerably.
Soft shale	Pump runs with medium pressure.	Small fragments in ditch; soft chunks on bit, with streaks upon breaking.	Cuts bit very little.
Hard shale	Pump runs with more pressure than in sand; tools jump.	Shows in ditch in small flakes and chunks; very little sticks to bit.	Cuts bit badly.
Clay	High pressure on pump; run thin fluid; pump sometimes stalled; machinery runs smoothly with tension on table and chains; necessary to spud tools in order to clean the bit.	Change of color is the only showing of clay formation in the ditch; plenty of clay sticks to the bit.	Does not cut bit.
Shell	Pump runs freely; tools, chains, and tables jump.	Small fragments show in thin mud in ditch.	Cuts bit badly.
Sea shells	Pumps run freely, unless in clay.	Fragments and some perfect specimens show in ditch.	Do not cut bit.
Northern Louisiana fields.			
Hard rock	Pump runs slowly with low pressure.	Cuttings show in ditch in thin mud.	Wears bit badly and to all shapes.
Hard shell			
Hard limestone.			
Sand (hard and soft)	Run without much steam pressure; cuttings easy to handle.	Cuttings show in thin mud in ditch.	Do.
Shale	Run with nearly full head of steam; pumps handle cuttings without spudding but have to work hard.	Fragments show in ditch.	Does not wear bit much.
Gumbo	Run pump with full head of steam; even then continual spudding needed to mix cuttings enough to allow free returns.	Will ball up and shut down pump; no show but color in ditch.	Do.
Chalk	Run pumps with full head of steam; does not ball up; sometimes have to spud.	Small fragments of hard chalk in thin mud.	Does not wear bit badly; hard streaks wear bit.

TABLE 19.—*Mechanical reactions of various rocks to rotary tools*—Continued.

Field and formation.	Action of pump and tools.	Cuttings.	Effect on bit.
Northern Louisiana fields—Con.			
Gypsum........	Does not take much steam pressure; pump can be run slowly; gypsum balls up on point of bit and retards progress, but has no effect on pump.	Shows in flakes or small particles in thin mud; balls up on bit.	Does not wear bit much.
Salt............	Drills slowly; returns not hard to handle; no effect on pump.	Small particles occasionally.	Do.
Southern Oklahoma:			
Shale, various colors.	Tools run smoothly, medium pump pressure; drills fast.	Fragments show in thin mud.	Do.
Sandy shale....	Tools run smoothly, chain "settles down"; drills fast.	Fragments show in mud like shale.	Wears bit more than shales.
Gumbo.........	Tools run in jerks; high pump pressure; hard to drill; driller has to reverse engine and spud tools to clean bit.	No show in ditch other than color; sticks to tools.	Does not cut bit.
Clay............	Tools run smoothly; easy drilling; high pump pressure.	Balls up on bit; no sample in ditch other than color.	Do.
Limestones.....	Tools jump and jerk when cutting; low steam pressure; hard to drill.	Fragments in ditch occasionally.	Smooths bit and knocks it out of gage.

Evidently an inspection of the cuttings of a rock is necessary in order to give the rock the right name. After the engineer has properly identified a rock and the driller has learned what the rock is—for example, a hard shale—although it drills like the limestone of some other field in which he has worked, then the reactions of the drill will suffice for further identification by that driller. At the conference of drillers and engineers, proposed on page 86, representative samples of oil-well formations should be discussed. These should be compared with samples of other formations with which they are liable to be confused. The development engineer of a property should make certain that the drillers on the property can make an accurate sight inspection of the various rocks, also that he in turn is familiar with the driller's code of determination.

SAMPLING AND IDENTIFYING CUTTINGS.

CABLE-TOOL SAMPLES.

When a hole is drilled with cable tools, samples of formations can be obtained in two ways: Samples of such parts of the rock as have not been pulverized by the drill can be brought up in the bailer; or, if the material is sticky, fragments will be found on the bit when it is pulled out.

The contents of the bailer are mostly mud. When the bailer is dumped, a bucketful of the contents is caught for a sample. After much washing and stirring the coarser ingredients of the sample will settle out and from these the nature of the formation is determined. A soft shale or clay will be identified only by such fragments as have escaped pulverizing. A sandy shale is liable to have its shale constituent converted into mud and the bucket sample upon washing will show sand, therefore the formation will probably be called "sand" instead of "sandy shale."

ROTARY TOOL SAMPLES.

A number of methods have been suggested for taking samples of cuttings from rotary tools. The main drawback to most methods is the time involved. Cuttings are conveyed in the mud flowing from the bit into the ditch. If the mud is thin, the coarser particles will settle out in the ditch. Sand will remain in suspension long after the mud has passed through the ditch. Some drillers throw a large thread protector into the head of the ditch and catch samples in it. Any sort of a riffle or baffle in the ditch will hasten the dropping of cuttings from the mud. Some drillers drive a row of large nails spaced about 1 inch apart across the floor board of the circulating trough. Sawed-off nail kegs weighted with a few thread protectors can be used for catching samples. The ditch, bucket, rings, or whatever else is used to catch a formation sample should be cleaned of all other cuttings.

An accurate sample of formation can be obtained by shutting down drilling and circulating all cuttings out of the hole with the bit set on the bottom. When clean mud appears, clean out the ditch. Start drilling, and the first cuttings that appear at the surface will be from the depth at which drilling started. This method requires time, say two hours for each sample taken from below 3,000 feet. Naturally time to take many samples will not be spared.

Samples of certain kinds of formations can be taken just before pulling out by drilling a small amount of hole without circulating. The material will "ball up" on the bit. These samples, of course, are limited to certain materials and can be taken only when tools are being removed. In pulling out, care must be taken not to knock off the sample on the bit and to pick up a new sample from the wall of the hole at some distance from the bottom. The drill pipe should be "backed out" by hand; that is, the engine should not be reversed. The pipe should be measured as each row of "stands" is set in the derrick.

The greatest need in taking rotary samples is some definite means of knowing the exact depths from which the samples come. It has already been shown in comparing rotary and cable tools (p. 62) that certain tests, such as introducing paint or dye into the mud stream, will indicate the length of time of travel of the stream from the pumps down the hole and back to the ditch.

A series of paint or dye tracers in the mud stream can be utilized for accurate sampling, as follows: Note the exact depth of hole and mark it on the drill pipe. Place 2 quarts or more of paint or dye in the drill pipe at the surface and start the drill pump. Note the time and number of strokes of the pump a minute, also the actual length of stroke, and make a careful estimate of the efficiency of pump delivery. A pump displacement table will give the length of time it takes the paint to reach the bit. When this time has expired, the depth drilled should be noted. The tracer is now mixing with cuttings and the depth from which they are starting to rise in the mud stream is known. When the paint returns, take a sample of the cuttings. These cuttings come from the depth already noted.

The total time for displacement in any given depth of hole will be computed for the total diameter of the hole. No allowance is made for the displacement of the solid material of the drill pipe in the hole. This is undoubtedly more than taken care of by the indeterminate variations in diameter of the hole, owing to caves and irregularities of hardness of various strata. The most important factors to know are the length of time it takes the tracer to reach the bit and the depth of the hole at that time. The tracer and cutting may take considerably longer than the computed time to travel from the bit to the surface.

The total time of displacement minus the time required to displace the capacity of the drill pipe gives the time cuttings take to reach the surface. The total time of the round trip for the paint, to and from the bit, is divided in the ratio of the squares of the radii of the drill pipe and of the hole. In the well cited on page 64 the ratio is as $\overline{3}^2$ is to $\overline{6.25}^2$, or as 9 is to 39.06. That is, for a 6-inch drill pipe in a $12\frac{1}{2}$-inch hole, a round trip which requires 2 hours and 33 minutes will be divided into 36 minutes to the bit and 117 minutes—1 hour and 57 minutes—from the bit to the surface. These figures emphasize the advantage of large drill pipe for rapid removal of cuttings.

Table 20 showing capacity of pumps may be used in such determinations.

TABLE 20.—*Capacity of pumps.*

Note: To find the capacity for one revolution, multiply the capacity for a single stroke by 1, 2, 3, or 4, for single, duplex, triplex, or quadruplex, single-acting pumps, and for double-acting pumps, by 2, 4, or 6.

Diameter of cylinder, inches.	Area of circle, square inches.	Capacity of stroke, in gallons, for different length of stroke, in inches.												Diameter of cylinder, inches.
		4	5	6	8	10	12	14	15	16	18	20	24	
1¼	1.23	0.0212	0.0266	0.0319	0.0425	0.0531	0.0637	0.0743	0.0797	0.0848	0.0955	0.1062	0.1274	1¼
1⅜	1.48	.0256	.0321	.0385	.0513	.0642	.077	.089	.0963	.1027	.1156	.1280	.1541	1⅜
1½	1.77	.0306	.0382	.0459	.0612	.0765	.0918	.1071	.1147	.1224	.1377	.1530	.1836	1½
1¾	2.41	.0416	.0521	.0625	.0833	.1041	.1249	.1457	.1562	.1666	.1874	.2082	.2499	1¾
2	3.14	.0544	.068	.0816	.1088	.136	.1632	.1904	.204	.2176	.2448	.2720	.3264	2
2¼	3.98	.0688	.086	.1033	.1377	.1721	.2063	.241	.258	.2754	.3096	.3442	.4128	2¼
2½	4.91	.085	.1062	.1275	.17	.2125	.255	.2975	.3187	.34	.3825	.425	.51	2½
2¾	5.94	.1028	.1285	.1543	.2057	.2571	.3085	.3598	.3855	.4114	.4626	.5142	.617	2¾
3	7.07	.1224	.1530	.1836	.2448	.306	.3672	.4284	.459	.4896	.5508	.612	.7344	3
3¼	8.30	.1436	.1795	.2154	.2872	.5954	.4312	.503	.5385	.5748	.6466	.7182	.8624	3¼
3½	9.62	.1666	.2082	.2499	.3332	.4165	.4998	.5831	.6247	.6664	.7497	.833	.9996	3½
3¾	11.05	.1912	.239	.2868	.3824	.478	.5736	.6692	.687	.7648	.8605	.9561	1.447	3¾
4	12.57	.2176	.272	.3264	.4352	.544	.6528	.7616	.816	.8704	.9792	1.088	1.3056	4
4¼	14.19	.2456	.307	.3684	.4912	.6141	.7368	.8596	.921	.9824	1.105	1.228	1.473	4¼
4½	15.90	.2754	.3442	.4131	.5508	.6885	.8262	.9639	1.0327	1.1016	1.2393	1.377	1.6524	4½
4¾	17.73	.3068	.3835	.4602	.6136	.7671	.9204	1.073	1.15	1.2227	1.380	1.534	1.84	4¾
5	19.64	.34	.425	.51	.68	.85	1.02	1.19	1.275	1.36	1.53	1.7	2.04	5
5¼	21.65	.3748	.4685	.5622	.7496	.9371	1.124	1.311	1.405	1.499	1.686	1.874	2.228	5¼
5½	23.76	.4114	.5142	.6171	.8228	1.0285	1.2342	1.439	1.5427	1.6456	1.8513	2.057	2.4684	5½
5¾	25.97	.4496	.562	.6744	.8992	1.124	1.348	1.573	1.686	1.789	2.022	2.248	2.696	5¾
6	28.27	.4896	.612	.7344	.9792	1.2240	1.4688	1.7136	1.8362	1.9584	2.2032	2.448	2.9376	6
6¼	30.68	.5312	.6640	.7968	1.062	1.328	1.593	1.859	1.992	2.124	2.39	2.656	3.186	6¼
6½	33.18	.5744	.7182	.8610	1.1488	1.4364	1.7955	2.0109	2.1546	2.2082	2.5885	2.8728	3.4473	6½
6¾	35.79	.9196	.7745	.9294	1.239	1.549	1.858	2.168	2.323	2.47	2.788	3.098	3.716	6¾
7	38.49	.6664	.833	.9996	1.3328	1.666	1.9992	2.3324	2.499	2.6656	2.9988	3.332	3.9984	7
7¾	47.17	.8168	1.021	1.225	1.633	2.042	2.45	2.858	3.063	3.266	3.674	4.804	4.9	7¾

Careful observations of the time of travel of mud fluid will assist in other determinations. For example, if a porous stratum starts to take mud when penetrated, the delay of a color signal in showing at the surface in the mud stream will give a time basis for estimating the quantity of fluid the formation is taking.

DATA ON FLOW OF MUD FLUID.

The following notebook form is suggested for recording data on time of flow of the mud-fluid stream:

Notes on tracer for cuttings.

________________________________ Company. Well No. ____________________
(Lease or farm.)

____

Time ________ m. ____________________, 19____
Tracer put in drill pipe and pumps started at________ m.
Depth of hole____________________
Diameter of hole:________ feet of________ in.-hole.
________ feet of________ in.-hole.
________ feet of________ in.-hole.
Diameter of drill pipe______ in.
Measured stroke of pump________ in.
Combined number of strokes a min.________
Size of liners or diameter of plungers________ in.
Computed time for tracer to reach bottom________________________
Length of drill pipe when tracer reached bottom________
Tracer showed at surface at________ m.
(Time.)
Total time for round trip of tracer________________________
Sample taken at________ m. and marked____________________________________
(Formation.)
from________ feet.
(Depth.)

Suman [35] gives additional data on taking samples with rotary tools in the Gulf coast fields. The common size of pump used there is the 10 by 5¾ by 12 inch, and the speed ranges from 55 to 15 strokes a minute. A test of two of these pumps on the derrick floor showed that one pump had a 10-inch stroke and an 11-inch stroke instead of 12. While running at 60 strokes a minute they should deliver 160 gallons a minute. By actual test they delivered 97 gallons and were only 60 per cent efficient.

Another set of pumps running at 45 strokes delivered 75 gallons a minute, whereas they should have delivered 120 gallons, an efficiency of 62 per cent. Suman thinks that 60 per cent represents the average efficiency of this class of pumps when handling drilling mud.

[35] Suman, J. R., Taking samples with rotary: Oil Weekly, July 3, 1920, p. 47.

The diagrams in Figure 6 are calculated from the following formula:

$$N = \frac{D(R^2 - r^2)E}{x^2yz}$$

where N = number of minutes for fluid to be expelled from hole and sample brought up.

D = depth of hole in inches.

R = radius of drilled hole.

r = radius of outside of stem.

E = efficiency of pump (60 per cent used).

x = radius of pump cylinder.

y = stroke of pump.

z = pump impulses a minute (both sides)—twice the number of strokes.

The top diagram shows that cuttings would take 28½ minutes to travel from the bottom of a 3,000-foot hole of 6-inch diameter containing a 3-inch drill stem, the pump running 65 strokes a minute. These diagrams neglect the displacement of the drill collars or tool joints, and are plotted on a fixed efficiency factor of 60 per cent.

Almost all of the "grief stems" or "Kelly joints" in use by the more progressive drillers in the Gulf coast country are marked with a cold chisel every foot of their length. These stems are further marked in Roman numerals from I at the bottom, going to XXVIII at the top. The driller keeps track of the depth to the change in the formations by noting the mark on the grief stem at the time he enters the new formation. This gives an accurate measurement to the top of the new formation, as he has a correct tally of the amount of drill stem in the hole at all times. By making the same notation when the drill leaves the new formation, the driller knows the thickness of the formation and the depth to it. By waiting the proper length of time to collect cuttings from the sample box, he will then have a sample of the formation as well.

After the pumps have worked long enough to bring the cuttings to the surface, several consecutive samples may be taken in kegs or other containers. The cuttings in each keg are then washed with clear water in order to free them from drilling mud. While still wet, the samples are inspected by the driller, and then poured into bottles for future reference. The samples should be kept wet in their natural state so that they can be inspected weeks later for oil and still show any light oil that might be in the sand. In the meantime, any indications of gas will be noted by the frothy nature of the drill mud as it comes from the well and circulates in the ditch.

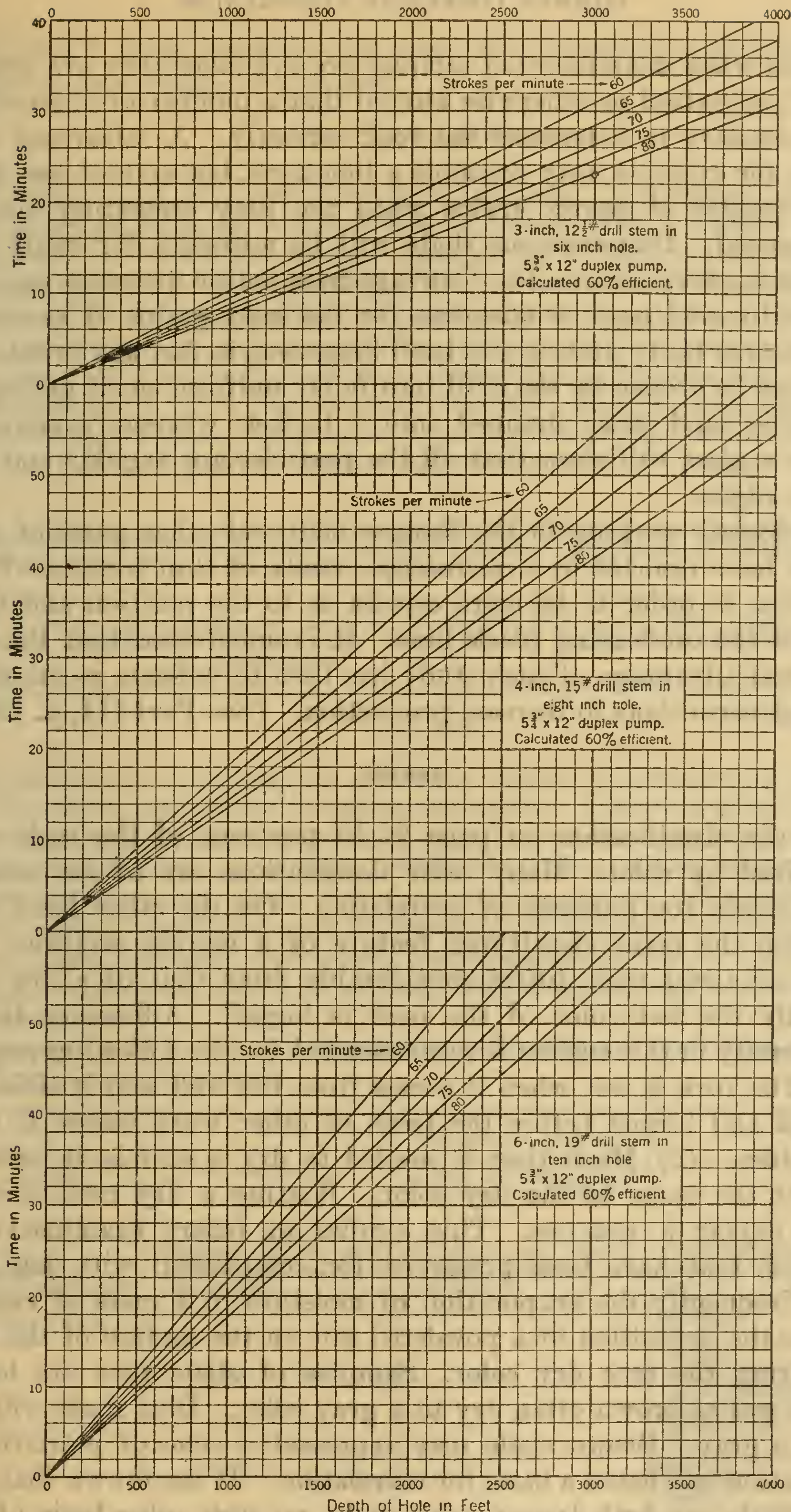


FIGURE 6.—Number of minutes required for cuttings to reach the surface from various depths of hole according to the speed of pumps.

COMMON CONFUSING APPEARANCES.

Even when unadulterated samples are available, they are often so finely pulverized or otherwise altered that a number of observations are necessary to determine the rock correctly. A calcareous sandstone, for example, may resemble a limestone, but an acid test shows the presence of quartz grains when the limy cementing material is removed. Diatomaceous shale will be mistaken for chalk until it fails to effervesce in acid. Cuttings from oolitic limestone until dissolved by acid may be mistaken for the sand grains of sandstone. Cuttings of flinty shale, chert, hard limestone, in fact any brittle rock that can be broken by the drill into fairly uniform small grains will resemble sand when dumped into a bucket, whereas examination under a glass will show that all the particles are angular and have sharp edges.

Geologists working in the Ranger field and other parts of north Texas have resorted to a microscopic study of thin sections of drill cuttings, in order to be more certain as to the position and thickness of the oil-bearing black lime. It is understood that the most practical advantage of such study has been to indicate positions for nitroglycerin shots to increase production. (See Part III, p. 126.)

COLOR.

In the classification on page 92 52 per cent of the rocks were described by color. Many color designations are of no value or significance for purposes of correlation. On the other hand color is often the main identifying feature of a marker stratum. The color of a wet rock differs considerably from that of a dry rock. Usually the wet color of the rock is logged. Adherence to and uniformity in this custom is recommended for the following reasons: (1) The rock is wet when it comes from the well and it should be named and logged before the press of other work causes it to be forgotten. (2) Much time is needed to dry a sample in order to give it the name of the dry color. Wetting a dry rock is easier than drying a wet one. This applies to future examination of samples that have been preserved for comparison with log data. (3) Frequently the evaporation of moisture in a mass of cuttings causes the deposition of a powdered salt on the surface of the rock, obscuring the true dry color. Samples of shale that are logged while wet as brown often dry to a gray color. Blue shale will also dry to gray. Brown shale may represent a zone of petroliferous saturation and hence a basis for correlation. If the brown shale and blue shale are both logged gray shale, no such color basis of correlation exists.

PHYSICAL AND CHEMICAL TESTS.

Udden[36] gives the following tests for determining hardness and other characteristics of cuttings:

TEST FOR HARDNESS.

Hardness is to be distinguished from toughness. Fine-textured anhydrite and some clay-ironstone is hard to drill on account of the toughness of these materials, but these rocks have no great hardness. Hardness is the quality enabling one substance to penetrate, cut, or scratch another substance. A hard rock, if it is brittle, may be easier to drill than a softer rock. The tests for hardness, as well as most other tests, require much practice and good judgment. Most determinations can be made with nothing more than the point of a pocketknife. With the exception of a few minerals, among which are hematite and limonite, hardness is a quite constant characteristic for each kind of rock and mineral. The hardness test is relatively quite decisive.

Soft enough to be crushed under the thumb nail.	Soft enough to be scratched with a knife blade. Too soft to scratch when pressed against glass.	Hard enough to scratch glass when pressed against it with a piece of hard wood.
Clay, most shales, chalk, gypsum, anhydrite, talc.	Limestone, dolomite, clay-ironstone, anhydrite, chalk, barite, feldspar (some kinds).	Sandstone, flint, chert, quartzite, quarts, pyrite, feldspar (some kinds).

ACID TEST.

Hydrochloric acid attacks all carbonates, causing effervescence or bubbling. A drop of the acid may be let fall on the sample. A better way is to place a few drops of acid on a clean flat glass or on the bottom of a cup or of a saucer turned upside down, select clean fragments of the particular material to be tested and place them in the acid on the glass or cup and watch results carefully, under a magnifying glass if necessary. In powdered condition, the material tested effervesces most rapidly, usually producing a froth. The strength of the acid generally used is 20 per cent. This should be kept in a small glass-stoppered bottle.

Examine in 20 per cent hydrochloric acid by placing a small clean fragment in a few drops of the liquid.

Effervescence brisk.	Effervescence slow.	Effervescence very slow; to be seen best only when material is finely crushed or powdered.	Effervescence lacking.
Caliche. Limestone. Chalk, and possibly marl. Calcareous sandstone.	Dolomite, possibly calcareous clay, marl, or sandstone.	Clay-ironstone, possibly marl, or calcareous shale or clay.	Sandstone (pure). Quartzite. Quartz. Chert. Feldspar. Flint. Gypsum. Anhydrite. Clays amd shales, free from calcareous material Igneous rocks. Coal. Lignite. Asphalt. Barite.

[36] Udden, J. A., Aids to identification of geological formations: Univ. of Texas Handbook Series No. 1, 1919, pp. 65–69.

TEST FOR FUMES.

This test can, with some materials, be made by heating to a point short of redness on a sheet of iron ("tin") or in a spoon (or shovel) over the forge. Better results are obtained if a glass tube or brass or iron tube is used. This must be closed at its lower end. The material is then introduced dry and shaken down to the closed end, after which the closed end is heated. Moisture will come first, and on cooling will deposit drops on the inner side of the tube. Oil and asphalt follow next, and can be recognized by their odor. Sulphur, present in pyrite, gypsum, and anhydrite. follows with the bitumens or at a little higher heat. This is also usually easily identified by the sulphur or "rotten egg" odor. In case of gypsum and anhydrite, if no odor is detected, the presence of sulphur fumes may be ascertained by their blackening a bright silver coin placed against the open end of the tube. Ammonia fumes are present in many shales, clays, and limestones, and may be recognized by their peculiar pungent odor. The ammonia fumes come at a temperature just below first redness.

Odor like rotten eggs, or like sulphur.	Odor like burning coal.	Odor like burning oil.	Odor like ammonia.
Anhydrite. Gypsum. Barite. Pyrite. Marcasite.	Lignite. Coal.	Bituminous rock. Asphalt.	Many bituminous shales.

FIRE TEST.

When rocks are heated to redness while exposed to the air some undergo changes by which they may be recognized. Some can be known by the fact that they withstand the effects of heat to a greater extent than others. High heat drives away the carbon from carbonates and the sulphur from sulphates and sulphides, thus changing their appearance and physical character. The fire test is one of the earliest and surest known. It is best performed with a blowpipe, but can also be performed in other ways. The heat nearest to a derrick is that of the forge, and the following observations are designed to be made on cuttings heated on a strip of sheet iron or "tin" in a forge. Only a small quantity of washed cuttings should be used, and a magnet should be used to pick from these, before heating, any particles of iron, steel, or rusty scale which have come into the sample from the drill or from the tubing in the boring.

Material will slake in a little water after heating to redness.	Material turns white, or at least lighter, in fire and becomes powdery, but will not slake in water after heating to redness.	Material remains unchanged, if not fused, after heating to redness.	Material is attracted by a magnet after heating to redness for a few minutes.	Material glows for a moment, or burns with a flame.
Limestone. Dolomite.	Gypsum. Anhydrite.	Flint. Chert. Sandstone. Quartzite or shale; possibly an igneous rock.	Pyrite. Marcasite. Clay-ironstone. Hematite. Limonite.	Coal. Lignite. Asphalt, if it fuses.

CONTAMINATION OF SAMPLES.

In the preceding methods of taking samples of drill cuttings, contamination or mixing of samples is always possible. This possibility is minimized in cable-tool holes when casing is constantly carried close to the depth at which the bit is working. A sample of cuttings from thin-bedded formations will probably contain fragments of rocks from several beds. Fragments of hard rocks may be carried with the drill for a considerable distance. In searching for more definite information on the distance a rock may be found below its depth of origin, Udden [37] examined a number of formation records of wells passing through coal seams. He found 20 wells where coal has been seen in samples in which it evidently did not belong; in 1 well it appeared to have come from a seam 4 feet above the depth at which the sample was taken, in 6 wells 5 feet above, in 2 wells 6 feet, in 3 wells 7 feet, in 1 well 8 feet, in 4 wells 10 feet, in 2 wells 12 feet, and in 1 well 26 feet above its position in the sample.

PRESERVATION OF SAMPLES.

Formation samples should be saved, as they are important for examination and future reference. The company should provide the driller with small wide-mouthed bottles with screw caps, in which to place samples, with labels to show the well number and the depths between which the sample is taken. Tobacco tins are satisfactory as temporary containers, but samples kept in them indefinitely become discolored by rust.

For filing samples one company has a large cabinet of drawers about 30 inches long and 6 wide and 3½ inches deep; the body of each drawer is made of metal and the face of wood. On the face is shown the well number and the depths between which the first and last samples in the drawer were taken. Within the drawer the sample bottles are arranged in rows according to depths. At any time parts of the written formation record in the log of the well can be quickly compared with samples of a formation.

CORE DRILLING.

MOST ACCURATE METHOD OF PROSPECTING.

The most accurate method of prospecting strata, especially with oil-well tools, is by some kind of core drill. Although this is the slowest method for making hole, it should receive the serious consideration of the oil operator, provided he is willing to spend the time

[37] Udden, J. A., Some deep borings in Illinois: Illinois State Geol. Survey Bull. 24, 1914, p. 15.

and money for careful work. The author believes that the use of some form of core barrel is the most practicable solution of the present problem of obtaining accurate formation samples from rotary drilling.

ROTARY CORE BARREL.

In drilling with rotary tools, several feet of core can be milled out of the rock with a hollow drill and removed. Various tools that cut out a sample of formation and remove the sample in some kind of container are classed as core barrels, but, strictly speaking, some of these are more samplers than core barrels. The tools are divided into two general classes, those that cut and remove a core from formation without disturbing the natural arrangement of the material, and those that cut and remove a sample of a formation in the form of cuttings.

One of the objections to the forms of rotary core barrel now in use is that the hole must be underreamed after drilling a core, with the exception of the core-barrel attachment with fishtail bit mentioned on page 119. A core of firm material is comparatively easy to take, but with most core barrels various devices must be used to take a core of loose material, such as sand, that washes out of the barrel.

Ambrose[38] cites two wildcat wells drilled by rotary in northern Louisiana in which core samples were taken with rotary tools. In the first well no core barrel was used, and the operator thought he had reached the producing Woodbine sand common to the Caddo oil field. In the second well a core barrel was used, and good fossils were obtained that showed that the hole in the first well was actually stopped several hundred feet above the Woodbine sand. The core barrel more than justified its use.

W. W. Scott[39] describes the core barrel used by him in these wells as follows:

The core barrel that we have used is very simple and effective, especially in the lower Tertiary and Upper Cretaceous formations in the South. We have taken cores from 30 feet to as deep as 3,300 feet with core barrels made of 8, 6, 4, and 3 inch pipe. We seemed to have better luck with 6 and 4 inch casing of ordinary weight. If for geologic purposes, the larger the better; but if for determinations of formations, a small core is sufficient. Teeth can be cut in an ordinary joint with a hacksaw. In 6-inch pipe we usually put six teeth; in 4⅝-inch pipe, about four teeth. The teeth are bent alternately in and out. The teeth bent in make a core smaller than the inside of the pipe, and the teeth bent out make a hole larger than the pipe to facilitate taking a long core; that is, you must make clearance for the mud returns. It is essential to have holes in the core barrel to let the fluid out when the pipe is pulled.

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[38] Ambrose, A. W., Underground conditions in oil fields: Bull. 195, Bureau of Mines, 1921, p. 23.

[39] Personal communication to A. W. Ambrose.

In order to take a sample with this type of core barrel it is necessary, of course, to make a "special" run. Often the core, when cut, can not be removed on that run. Constant rotation of the barrel has a tendency to straighten the teeth and it is difficult to get the core loose. A core barrel must be run with very little weight on it or the teeth will turn in. It is desirable to have the teeth turn in when it is time to remove a core. For the purpose of removing the core the pipe should be spudded, or the core barrel run with the weight of the pipe on it. This will bend in the teeth under the bottom of the core, so as to hold the core in the barrel while it is pulled out of the hole.

In sandy shale and gumbo and shale it is comparatively easy to cut and catch a core in the same run by rotating the pipe without circulation. This seals the bottom, holds the core in the pipe, and tends to detach same. To catch a sand core it usually takes rotating with the weight of the pipe, or spudding, to bend in the teeth.

The tool handled by oil-well supply houses for taking a core sample with rotary outfit is the adamantine, or chilled-shot, core barrel. This core barrel is attached to the drill pipe with a reducer or swage-nipple connection. Chilled-steel shot, or adamantine, is run into the hole with circulating fluid. Circulation at the bottom of the hole causes continual agitation of the shot, which are carried around in the grooves on the inside, outside, and bottom edge of the barrel, thus milling out a core. A core when made can be wedged into the barrel by injecting coarse sand into the circulating stream, which will cause the core to "freeze" in the barrel; it can then be twisted off and removed.

The following information on core barrels was furnished the writer by J. R. Suman, development engineer of the Rio Bravo Oil Co., Houston, Tex.:

For soft formations some companies use a coring device in which the fishtail bit is made with a hollow tube of about 1½-inch diameter up to the center. This 1½-inch opening in the shank of the bit is threaded and sufficient pipe is screwed into it to take the amount of core desired. The opening up the center of the bit is tapered slightly from top to bottom so as to catch the core and hold it when the drill pipe is pulled from the hole. The hole is held to a standard gage when this device is used, and the drilling is done in the same manner as with an ordinary fishtail bit. The only objections are that the sample as obtained is not kept in its original state, and the length of sample in the core barrel does not give the thickness of the formation.

The core barrel shown in Figure 7 probably has a wider use than any other. It is made by cutting and blacksmithing a bended lip over the bottom of a piece of pipe. It cuts like an ordinary post-hole auger. When pulling out of the hole the lip holds the sample in the barrel. The sample, of course, comes out in the form of cuttings or

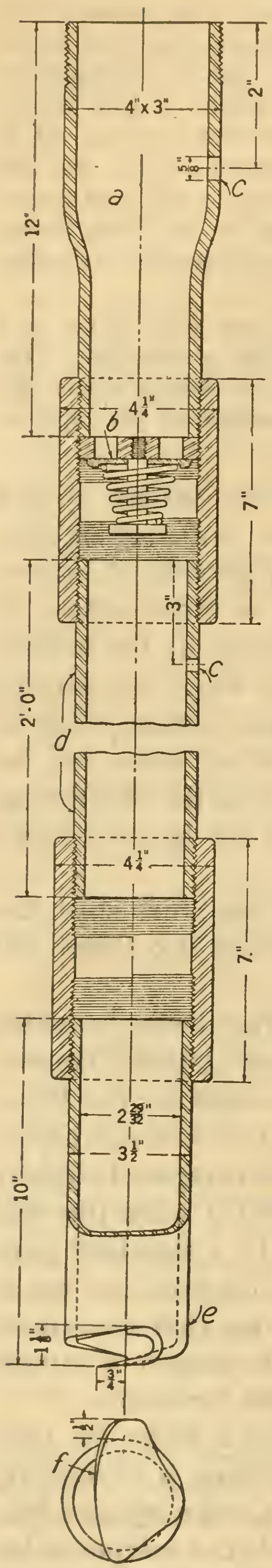

FIGURE 7.—Core barrel for taking samples of soft formations.

chunks and not as a solid core. The Gulf Production Co. uses this device in preference to all others.

A coring device has been used by W. A. J. M. van der Gracht, president of Roxana Petroleum Corporation, for taking cores in soft formations when drilling with the rotary system. It was used successfully in prospecting for coal deposits in northern Holland. The only complication about this device is the shoe, which is screwed onto the 6-inch drill stem. The core barrel can be of 4-inch pipe and long enough to take the amount of core desired. A 30-foot core can be taken at one time if wanted. The core barrel is made of 1-foot lengths of flush-joint pipe and the bottom length is screwed into the steel shoe, which has water-courses running through it. In the bottom of this shoe are slots to hold cast-steel cutting teeth, which are set into the shoe in somewhat the same way as removable teeth are fitted into circular saws in sawmills. As fast as the teeth are worn out they are taken from the shoe and new ones inserted; hence no blacksmithing has to be done in using this core barrel. On the inside of the shoe are attached small springs that keep the core from falling out, once it is

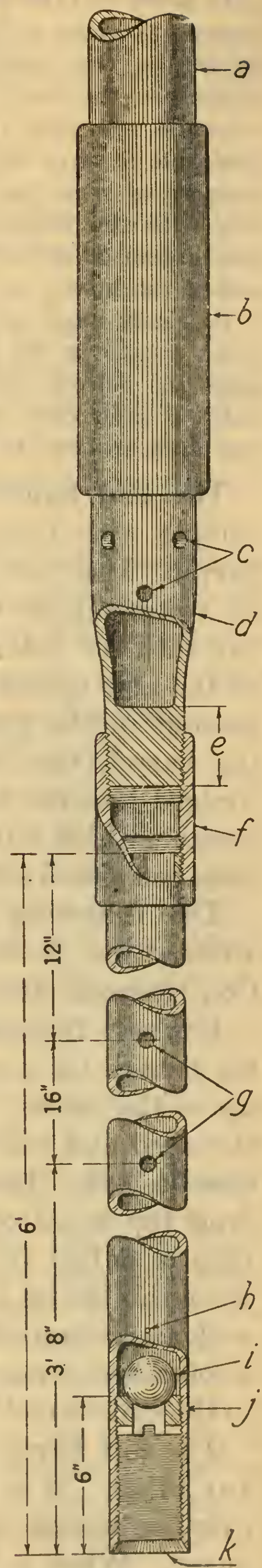

FIGURE 8.—Formation sampler used by the Rio Bravo Oil Co.

taken. On the top of the core barrel an ordinary back-pressure valve is fitted which allows the mud and water contained in the barrel to be forced out as the core moves up the barrel and prevents the drill mud from entering the top of the core barrel.

When the core is removed from the hole, some difficulty will always be found in getting it out of the core barrel. When 1-foot lengths of flush-joint pipe are used they can be unscrewed and the core pushed out.

In Figure 8 is shown a coring device used by the Rio Bravo Oil Co., of Texas, for coring in soft formations. This device has worked satisfactorily, but only 4 or 5 feet of core can be made at one time and all hole made has to be reamed to size afterwards. Such reduction of hole is sometimes desirable in looking for a suitable casing seat or in feeling ahead for an oil sand above which a string of casing is to be set.

Suman states that A. R. Gamble, driller for the Humble Oil Co., at Stratton Ridge, in Brazoria County, Tex., who has probably taken more cores than any other driller in the Gulf coast fields, uses an ordinary piece of pipe in the bottom of which he cuts a small V-shaped notch. This core barrel is lowered into the hole and rotated on bottom; it makes core as fast as any other style in use, and will work in fairly hard formations. The barrel is rotated until the amount of hole desired has been made; cores from 8 to 10 feet long are commonly taken. The swivel on the derrick floor is then unscrewed and a double handful of small pieces of cast iron of about the size of one's finger nail are dropped into the drill stem. The swivel is screwed back on and the pump started, and as soon as these pieces of cast iron have reached bottom the drill stem is raised a few inches and lowered slowly a few times. The tools are then pulled out of the hole, and bring the core almost every time. The pieces of cast iron become lodged between the barrel and the core and hold the core in the barrel. When this type of core barrel is used the hole must be reamed before drilling is resumed.

The time required to remove and unscrew drill pipe and to set it for a fresh run and the necessity of underreaming are the principal objections to the use of the core barrel.

In Udden's[40] interesting account of the deep boring at Spur, some figures are given as to the depths of strata through which cores were taken. This hole was drilled entirely with rotary tools, using fishtail or roller bits except when cores were being taken. The core barrels used were pieces of ordinary casing with teeth

[40] Udden, J. A., The deep boring at Spur: Univ. of Texas Bull. 363, Sci. Ser. 28, 1914, p. 21.

cut in the end and adamantine was run into the hole to facilitate cutting. Cores were made through 8-inch hole to 1,357 feet and through 6-inch hole below that depth. Table 21 shows depths and nature of strata sampled with core drill. The aggregate length of cores taken was 456 feet, and only 23 feet of core was taken below a depth of 2,000 feet.

TABLE 21.—*Depths of strata sampled with a core barrel in the Spur well.*

Depth below surface.		Thickness.	Formations.
From—	To—		
Feet.	*Feet.*	*Feet.*	
913. 5	963	49. 5	Sand rock and hard blue rock.
969	1, 033	64	Red sand rock.
1, 035	1, 053	18	Do.
1, 055	1, 068	13	Do.
1, 082	1, 143	61	Gray lime and red sand rock.
1, 151	1, 169	18	Red sand rock.
1, 225	1, 250	25	Soft white rock.
1, 253	1, 270	17	Hard limestone.
1, 273	1, 280	7	Do.
1, 284	1, 287	3	Do.
1, 288	1, 309	21	Do.
1, 313	1, 320	7	Hard blue rock.
1, 331	1, 331. 5	0. 5	Hard limestone.
1, 369	1, 370	1	Hard lime rock.
1, 494	1, 510	16	Sand, lime, blue rock, fossils.
1, 525	1, 558	33	Blue sandy and slaty rock; hard gray rock.
1, 566	1, 627	61	Hard gray and blue rock.
1, 705	1, 713	8	Hard sand rock.
1, 806	1, 810	4	Hard flinty sand rock.
1, 827	1, 830	3	Hard sand and flint rock.
1, 838	1, 845	7	Flint and blue rock.
2, 244	2, 255	11	Hard sand and flint rock.
2, 256	2, 264	8	Hard sandstone.
2, 270	2, 274	4	Hard blue lime rock.

Rotary drillers in the Kemp-Munger-Allen field, Wichita County, Tex., use a method slightly different from the one described by Scott, page 114. By cutting four or five short beveled teeth in the end of an extra heavy piece of 4-inch pipe 3 or 4 feet long, a core 6 inches to 1 foot long is obtained in fairly hard formations. After the core is cut, a barrel, similar to the one described by Scott and called a "basket" by the drillers, is run to catch the core. The basket is raised and dropped a few times, whereby the teeth are bent inward and inclose the core.

It should be noted that often a long core showing minor stratigraphic variations is not so important as a true sample of formation from some given depth.

The most desirable features for core-barrel drilling are a bit that will make a hole without the need of subsequent underreaming, and a core barrel that will take and retain a sample of soft formations, such as sand, and of firm formations.

I. N. Knapp[41] has designed a tool that combines a vented core barrel for relief of pressure with a fishtail bit. This tool (Fig. 9) has taken cores successfully in ordinary rotary drilling in both soft and hard formations. As much as 16 to 18 feet of hole has been made on one run, giving 12 to 14 feet of core in pieces with a maximum length of 18 inches. Figure 9 is a sectional view of the apparatus complete; *a* is an ordinary 11-inch fishtail bit with a 6-inch shank bored out to 4-inch pipe; *b* is an ordinary 6-inch drill coupling; *c* is a 6-inch drill pipe; *d* is a special drill coupling that supports and swivels the core barrel and is provided with vent holes to equalize the pressure on the core; *e* is a piece of 4-inch pipe forming the lower end of the core barrel; it is held from dropping through the bit by the offset *f*, in the bit *a*, and from pushing up, by the ring *g*; *f* is an offset in the bit to prevent the loose piece of 4-inch pipe from dropping out; *h* is the main core barrel made of a joint of 4½-inch pipe, swaged to 2½ inches at the top.

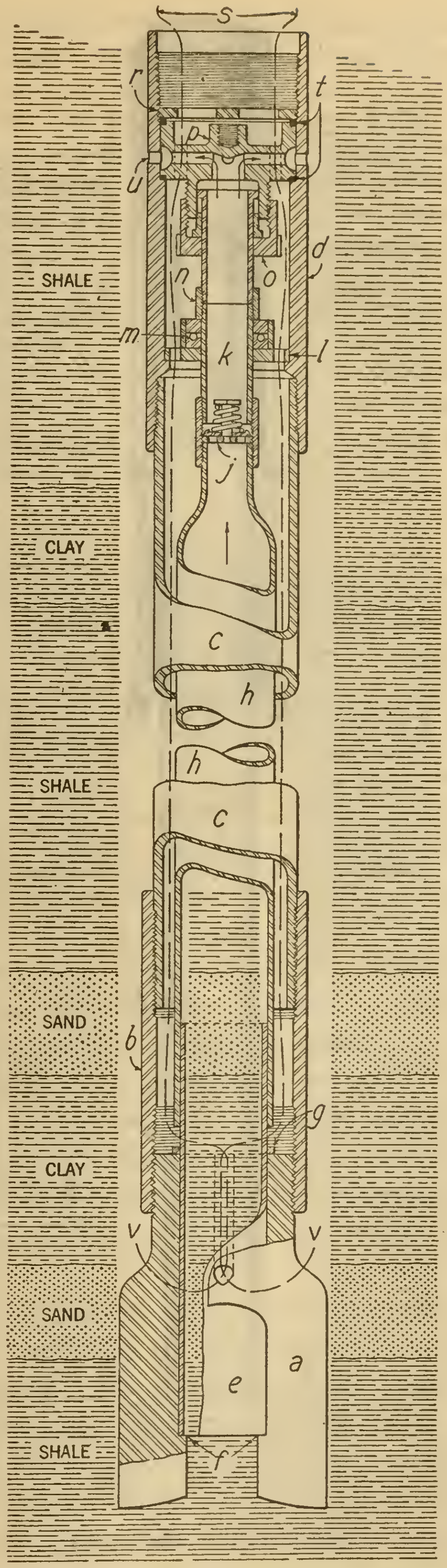

FIGURE 9.—Knapp fishtail core barrel taking core. For explanation, see text.

[41] Communication to J. O. Lewis, former chief petroleum technologist, Bureau of Mines.

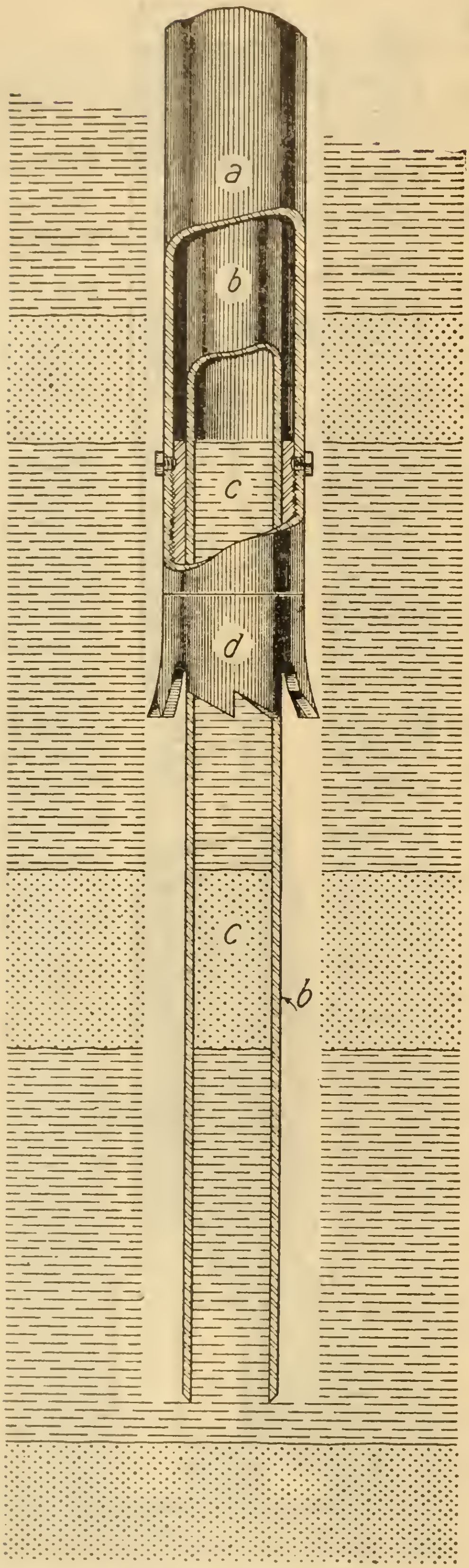

FIGURE 10.—Cable-tool core barrel taking core. *a*, hollow stem; *b*, core barrel; *c*, core; *d*, cutter.

and on this is attached a $2\frac{1}{2}$-inch coupling; *j* is a back-pressure valve; *k* is the swivel pipe; *l* is a perforated annular ring that supports the core barrel; *m* is a ball bearing supported on *l*, carrying the coupling attached to the swivel pipe and thus supporting the core barrel; *n* is a coupling supporting the swivel pipe and the core barrel; *o* is a stuffing box; *p* is the head through which the core barrel is vented to the ascending fluid; *r* is a perforated follower to hold *p* in place.

CABLE-TOOL CORE BARREL.

Core-drill samples may also be taken with a drill designed for cable-tool equipment in any reasonably soft material, such as coal, clay, soft shales, and sand. This tool should take a more representative core out of loose sandy materials than a rotary core barrel and can be pulled out quicker than rotary tools. It is especially adapted to prospecting with a portable rig for a marker stratum to determine geologic structure. Where a derrick is equipped for both rotary and cable drilling, the possibilities of shifting to cable tools and taking a core are worth considering.

The following description of the core drill and its use was furnished the writer through the courtesy of the Keystone Driller Co., Beaver Falls, Pa.:

The core drill, which is about 14 feet long, is jointed to the jars; the tool string being rope socket, jars, and core drill. The lower end of the top piece of the drill is threaded externally to receive the hollow drill stem, a wrought-steel tube about 10 feet long. The joint at the top must be set up as firmly as a drill bit. Before the tool is swung into the derrick the core-barrel head with its swiveled weight is inserted in the hollow drill stem. The core barrel itself should not be attached nor screwed into the swiveled head until the tool as a whole is suspended in the derrick. (See Fig. 10.)

For taking a core, the hole should be bailed or flushed clean of cuttings and an exact measurement of the depth of hole recorded. Then carefully lower the core drill on bottom and drill in the ordinary way at a moderate speed. The drilling stroke should be shortened to about 18 inches. As the barrel projects about 4 feet, it will not be lifted off the bottom by the motion of the drill. When from 20 to 30 inches have been drilled, draw out the tools. It may take a slight jar to break the core loose. At this point only is there danger of losing it. After the tools are swung to one side, the core barrel can be removed and a new one put in its place. The core is removed from the barrel by an extractor, which is a plunger operated by a long screw working through a threaded crosshead clamped to the barrel.

THE DIAMOND DRILL.

The diamond drill has been used extensively in prospecting for the precious metals, also iron, copper, and coal. According to Bowman,[42] diamonds were first used in drilling rock in 1863 by Rudolph Leschot, a French civil engineer. For deep-well drilling they were first employed in Pennsylvania to determine the existence and thickness of coal beds. The diamond drill is especially adapted to penetrate hard rock to great depths, and will bore a hole at any angle; hence it is especially useful in mineral prospecting work. However, it is somewhat restricted by the rock formation; for example, no diamond-drilling firm will send a drill into the lead and zinc districts near Joplin, Mo., for the ore-bearing limestone there contains many loosely embedded, chert nodules, which tear out the diamonds. The stones may also be lost in highly inclined and flinty rocks.

In prospecting for oil and gas the diamond drill can be used for drilling test holes to some key bed persistent over a large area in order to determine structure. Structural features may be masked by recent surface deposits, but by drilling several holes through these surface deposits to some key bed the attitude of this bed could be determined.

Burton[43] advocates the use of the diamond core drill and states that 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, he says, is entirely proportionate to the reward sought. A churn-drill hole costing $20,000 was drilled in the northwest corner of sec. 30, T. 23 N., R. 6 W., by the city of Enid, Okla., to a depth of 3,000 feet. This well is in an

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[42] Bowman, Isaiah, Well-drilling methods: U. S. Geol. Survey Water-Supply Paper 257, 1911, pp. 79–88.

[43] Burton, George E., Methods of exploring for oil and gas: Oklahoma Geol. Survey Cir. 8, July, 1917, pp. 6–10.

area where there are few outcrops and consequently the underground structure can not be determined from the surface. The sum total of information gained for an expenditure of $20,000 is that this particular hole is dry.

As shown by the log of the Enid well, at 830 feet is a limestone 2 feet thick and, no doubt, of considerable horizontal extent. Setting a maximum charge of $2 a foot for diamond drilling, Burton estimates that 12 drill holes could be put down to the 830-foot lime stratum for $20,000. The depth of contact with the key bed compared to the sea-level datum would give a set of data for underground contours on the key bed. It is possible also to determine the dip of the bed by the use of a compass device which, inserted in the hole, records the correct position of the core with respect to the rock from which it is taken. Of course, a vertical hole is difficult to drill with a core drill, especially in steeply-tilted strata, and this will sometimes complicate the possibility of taking accurate dips. The deflection of the compass by local magnetic[44] disturbances must also be considered.

In a paper on development operations in Illinois, DeWolf[45] stated that an operating company was prospecting with diamond-drill holes through the glacial drift for the purpose of determining structure of Devonian shales in the Trenton area. The company contracted for 8,000 feet of hole, and would probably drill about 15 wells ranging from 400 to 1,000 feet in depth, depending upon the depth and slope of the key stratum below surface of the ground. The presence of a fossil, *Sporangites huronensis*, in the shales of Devonian age makes their identification in the drill cores relatively simple. The well drillers working in the area are not expected to identify this fossil but they are readily able to recognize the Devonian by an unmistakable chocolate-colored shale of the lower Devonian shale beds. This horizon will possibly be used as the key stratum rather than the one containing the *Sporangites*.

Holes drilled with a diamond drill to prospect for oil are uncommon. According to Mondell,[46] diamond drills were used in Wyoming in the early days of oil prospecting there. To prospect for oil with the diamond drill in shallow territory is feasible. Production through such holes would be difficult.

A notable instance of the use of the diamond drill for oil and gas prospecting was given the author by W. K. Gordon, general manager of the Texas Pacific Coal & Oil Co., Thurber, Tex. In the shallow

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[44] Fuller, Myron L., Magnetic wells: U. S. Geol. Survey Water-Supply Paper 341, 1911, pp. 87–93.

[45] DeWolf, F. W., and Mylius, L. A., A new Trenton field in Illinois: Bull. Am. Assoc. Petroleum Geol., vol. 4, March 20, 1920, pp. 43–46.

[46] Mondell, Hon. F. W., Oil-leasing lands: Hearings before Committee on Public Lands on H. R. 3232 and S. 2812, 1918, p. 622.

Strawn oil field of Palo Pinto County, Tex., holes were put down by diamond drills and the structure of a gas-bearing horizon was determined. Much of the early prospecting in the vicinity of Strawn and Ranger, Tex., was done with diamond drills. The data thus obtained proved valuable in the further development operations of the company. Gordon's experience in using the diamond drill in prospecting for oil has developed the following conclusions:

1. The diamond drill can be run at less cost than the percussion drill to depths less than 1,000 feet. At greater depths the time consumed in removing cores and running tools back into the hole cuts down the daily footage.

2. Quicksands, surface waters, and caves necessitate reducing the diameter of the hole in order to case off water and sand, which soon makes testing for oil impracticable.

3. Gas will show in diamond-drill holes, but oil will not. Oil-stained cores of an oil-bearing formation have been taken but they gave no indication of the quantity of oil in the stratum.

TEMPERATURES.

The increase of earth temperatures with depth is well known. The unit increase of temperature with depth for any area is called the geothermal gradient, which varies according to locality. Underground temperatures in oil fields, as pointed out by Rogers,[47] appear to be abnormally high. He determined the average geothermal gradient for a well in the Sunset-Midway oil field, California, as 1° F. for each 41 feet of depth, the temperature at 3,870 feet being 131° F. C. E. Van Orstrand, of the United States Geological Survey, determined a geothermal gradient of 1° F. for each 47 feet of depth for certain wells in the Ranger field, Texas, the average temperature at 3,000 feet being 131° F.

The temperature[48] of a well in Clarksburg, W. Va., at 7,310 feet was 158.8° F. In the Cznchow well in Germany, 182° F. was reported at a depth of 7,287 feet; however, the accuracy of the reading was questioned.

The following temperatures of a well of the Forest Oil Co., 12 miles southeast of Pittsburgh, Pa., are taken from oil and gas records of the West Virginia Geological Survey.[49]

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[47] Rogers, G., Geochemical relations of the oil, gas, and water of Sunset-Midway oil field, California: U. S. Geol. Survey Prof. Paper 117, part 2, 1919, pp. 49, 99.

[48] Bloesch, Edward, Discussion of value of oil geology in Mid-Continent: Amer. Assoc. Petroleum Geol. Bull. 2, 1918, p. 131.

[49] White, I. C., Petroleum and natural gas, precise levels: West Virginia Geol. Survey [Reports], vol. 1A, 1904, pp. 513–552.

Temperatures in Forest Oil Co. well.

Depth, feet	525	2,252	2,397	5,010	5,380
Temperature, °F	57	64	78	120	127

The temperature in wells of Coalinga Mohawk Oil Co., Coalinga field, California, is reported to run as high as 180° F. at 4,000 feet. Because of this high temperature special working barrels and plungers must be constructed for the pumps in order to equalize changes of size due to expansion. Excessive temperature is frequently the cause of poor pumping.

A careful record of underground temperatures may indicate change of strata. In the Casmalia oil field, California, a hot-water zone is entered at depths ranging from 1,500 to 1,800 feet. The entire oil and water horizon is a series of shale strata, some impervious and some fractured and creviced. There is no difference in the "feel" of the drill going through these strata. Oil comes into the hole at a higher depth than the water, but its entry precludes determination of the position of water stratum. The only physical guide to the proximity of the hot water is a record of temperatures. Table 22 shows that temperatures of wells producing a considerable proportion of water is much higher than that of wells producing little water.

TABLE 22.—*Temperatures of bottom water, Casmalia oil field, California.*

Well No.	Temperature.	Water.	Well No.	Temperature.	Water.
	°F.	*Per cent.*		*°F.*	*Per cent.*
2	130	50	10	126	25
3	124	40	11	122	40
4	128	50	12	126	40
5	128	50	36	98	6
6	124	32	37	113	8
7	130	35	38	115	8
9	132	40	39	126	36

Temperatures in these wells have been known[50] to rise to 142° in a well 1,850 feet deep. These temperatures are abnormal, however, although conditions somewhat similar are reported in the Baku[51] field in Russia.

In certain oil wells in Mexico careful and continuous records by recording thermometers furnish a reliable warning of the approach

[50] Collom, R. E., California State Min. Bureau Bull. 84, 1918, p. 382

[51] Thompson, A. Beeby, The oil fields of Russia, 1908, p. 268.

of hot salt water, apparently associated in the same reservoir with the oil. It has been noted that temperatures of fluid, high in water content, are higher than temperatures of clean, flowing oil. When the recording thermometers show a rise in temperature, such a rise is a signal that water is moving into the well with the oil. By regulating the rate of flow from the well the water content of the fluid is held to a minimum.

The high temperatures already noted for the "black lime" wells of the Ranger field, Texas, are probably one of the contributory causes of the spontaneous explosions of charges of nitroglycerin placed in the wells to bring in production. Well shooters in parts of the Ranger and Caddo fields of north Texas have adopted the custom of running a charge of nitroglycerin without a detonator into a hole and waiting for it to explode spontaneously. The author investigated this practice, and concluded that these spontaneous explosions are the result of continued reactions of unneutralized acids in the nitroglycerin, assisted by fairly high underground temperatures.

This method of shooting, to bring in production, saves the well shooter considerable time and trouble in preparing for an electrically detonated shot, but the method is entirely uncontrollable and, therefore, dangerous to life and may prevent proper completion of a well.

PART III.—TESTING FOR OIL, GAS, OR WATER.

INTRODUCTION.

SOME FUNDAMENTAL PRINCIPLES OF TESTING.

After the correct depth and nature of a possible fluid reservoir has been determined it should be tested for productivity. The fundamental principles that should control all testing operations are summarized as follows:

1. *No reservoir can be tested properly for fluid until fluid from all extraneous sources has been excluded.*

A well can not be successfully tested for oil until water is excluded from the formation to be tested. This has been demonstrated time and again, often at great financial loss. Various difficulties that may arise are discussed under factors of test for water shut-off.

2. *Content can not be determined from the appearance of a sand or other reservoir rock.*

A sand may look like a water sand when dumped out of the bailer, but to log it as such for that reason is ridiculous. Any kind of a porous rock is equally capable of storing oil, water, or gas, and a sand should not be called a water sand nor an oil sand unless water or oil is definitely proved to come from it.

3. *All porous strata penetrated by the drill will either give or take fluid.*

Water, oil, or gas moves from positions of high pressure to those of low pressure. Gas released from a high-pressure sand moves swiftly to the surface or back of an unprotected casing into some reservoir of a lower pressure. Drilling water, native water, or mud will move into an oil-bearing formation of lower pressure.

The neglect of these principles may cause productive oil or gas strata to be overlooked.

NECESSITY OF TESTS.

The fact that a well comes in a "gusher" or a big "gasser" does not guarantee that the well has been finished properly, or that water, which is a menace even to a gusher, has been excluded. Oil or gas and not water is the commodity sought and, therefore, the chief tests should be, first, to determine if water is excluded and all fluids used in drilling have been removed, and, second, if the stratum being tested contains oil or gas, or both, in commercial quantities. If such tests are made the operator will not have to speculate on the contents of a sand when deciding whether he shall attempt to produce from it or pass it by as a water sand and, perhaps, continue drilling.

A sample from a formation may have no visible signs of oil. It may not even show oil in a chloroform test and may look like a water sand, yet proper testing of the formation may indicate oil in productive quantities.

In logs of an area where several sands at successively greater depths are logged as water sands and no casing is set between them, one or more of the sands may be assumed to have been logged "by the looks." Unless there is a marked difference in fluid levels, or fluid yield, of two or more sands penetrated in open hole, the first sand from which water issued is the only one that can be relied upon until separate tests are made. Logs of two wells in the Burkburnett field, Wichita County, Tex., show this practice. In No. 2 well three water sands were logged between the shoes of the 13¼ and the 10-inch casings. Two more water sands were logged between the shoes of the 10 and the 8 inch casings. In No. 3 well three water sands were logged while drilling with cable tools below the shoe of 6⅝-inch casing, set at 1,664 feet. Possibly none of these sands in No. 3 well carries water. Water may have broken in around the shoe of the 6⅝-inch casing.

Logs of two wells in Burkburnett field.

Well No. 2.

[Cable tools.]

Casing record: 13¼-inch, 630 feet; 10-inch, 962 feet; 8-inch, 1,460 feet; 6⅝-inch, 1,920 feet.

Formation.	From—	To—	Formation.	From—	To—
	Feet.	*Feet.*		*Feet.*	*Feet.*
Clay shale	0	575	Gumbo	950	1,125
Oil sand	575	590	Water sand	1,125	1,150
Red shale	590	690	Shale	1,150	1,420
Oil sand	690	700	Water sand	1,420	1,450
Shale	700	715	Gumbo	1,450	1,590
Water sand	715	740	Water sand	1,590	1,630
Shale	740	820	Shale	1,630	1,760
Water sand	820	840	Broken lime	1,760	1,840
Shale	840	935	Gumbo	1,840	1,850
Water sand	935	950	Hard lime; full of water	1,850	2,030

Well No. 3.

Formation.	From—	To—	Formation.	From—	To—
With rotary:	*Feet.*	*Feet.*	With cable tools—Contd.	*Feet.*	*Feet.*
Shale and gumbo	1,415	1,604	Shell	1,700	1,710
Oil sand, *light show*	1,604	1,653	Water sand	1,710	1,720
Shale and gumbo	1,653	1,664	Shale	1,720	1,730
Show of *oil*	1,664	1,678	Water sand	1,730	1,882
With cable tools:					
Water sand	1,678	1,700			

When rotary tools are used, unless the mud suddenly becomes thin, water coming from a sand can not be detected. On the other hand, as shown above, water sands are recorded with questionable frequency in some cable-tool logs. Generally there is a strong tendency to fail to log water-bearing strata even when they are definitely recognized. The meagerness of such data is at once evident to any one investigating water conditions in a given area.

A large company in California at one time issued a ruling that all sands entered in drilling must be reported either as water sands or oil sands. This ruling was intended to overcome laxity in not showing oil sands in logs, but really caused the recording of many fictitious water and oil sands.

Frequently the inspection of a log of an alleged oil or gas well will give a reliable clue to the character of the company drilling the well. Logs of wells drilled on sales of promotion stock show many oil sands.

METHODS OF TESTING.

In dry-hole drilling, oil, gas, or water shows when a reservoir is penetrated, provided, of course, that the hole has not penetrated a locally impervious part of the reservoir. When cable tools and drilling water are used, if the pressure of oil, gas, or water in a sand is greater than the hydrostatic head of drilling water on the stratum, the fluid or gas will show. On the other hand, a hydrostatic head of, say, 3,000 feet of drilling water, equivalent to a pressure of 1,290 feet a square inch, will require considerable rock pressure to prevent its forcing its way into an oil sand and holding the oil back. Oil may not show at all in drilling. A reservoir should be tested by bailing, swabbing, pumping, or shooting, in order to get a correct gage of its productivity.

BAILING.

A bailing test, other than a test for water shut-off, is usually made to reduce the level of fluid in the hole regardless of its source, so that oil or gas if present can come into the hole. The amount of fluid taken out is expressed in terms of a certain number of bailers an hour and when so stated the size or capacity of the bailer should be known. Where small quantities of fluid enter the hole, bailing tests may be made for several days or weeks, especially at cable-tool holes, drilled wet, where water is showing with the oil and the hole is bailed with the hope of proving that the water is drilling water returning from porous formations.

A bailing test may show conclusively that an oil sand will not yield enough oil to warrant putting the well on the pump. The quantity of oil the well is capable of producing daily from the sand being tested should be computed. This can be done by running the bailer at regular intervals and reducing results to a basis of barrels each 24 hours.

When large quantities of fluid are to be handled a bailing test is not always practicable, because the fluid enters faster than the bailer can take care of it; therefore the well is either swabbed or put on the pump.

SWABBING.

Swabbing is a violent operation, which should be conducted with care. The swab in moving up the hole carries all the weight of the fluid on top of it and greatly reduces the pressure in the hole below it. It acts as a piston moving through a cylinder. A condition similar to that of vacuum pumping results, for the expulsive forces of hydrostatic or rock pressures in the productive reservoir are not gradually released, as when the fluid level in a hole is lowered by pumping or bailing. The action is much like that which would take place if the master valve from a steam boiler were suddenly turned wide open into an empty line, instead of slowly, as is necessary. Channels of flow in a reservoir may be started which are not conducive to the most efficient recovery.

The usual practice in rotary-drilled oil fields of Louisiana and Texas is to swab the wells to bring in production, especially to help a well "clear itself" of rotary mud. In the Burkburnett oil fields the wells are swabbed as long as there is enough fluid in the hole to permit running the tool. Such operations may hasten production in quantity, but continuous swabbing is likely to disturb a poorly-seated casing and thus let water into the hole or to cause collapse of casing.

PUMPING.

At many wells yielding considerable oil and water a pumping test is made for 30 days, or longer, in order to determine whether the quantity of water is increasing or decreasing. Where a packer is set on tubing below a string of casing that is suspected of having water moving around it a test for source of water can be made by pumping.

When a pumping test for oil is made the oil should be run into a tank or sump, so that it can be gaged. The importance of accuracy in production records can not be overemphasized. If the well is yielding oil and water, close estimates should be made of the oil and water produced daily, so that increases or decreases of either can be noted.

In the above discussion the well, whether drilled with cable or rotary tools, is assumed to have reached a stage of development where it can be bailed, swabbed, or pumped without endangering its physical condition and the opportunity for possible deeper drilling. Cable-tool holes can be bailed at any stage of drilling, and can be pumped, if necessary, if casing is in no danger of freezing. Rotary holes, other than at shallow depths in firm formations, can not be bailed or otherwise tested unless a string of casing is landed.

SHOOTING.

Oil or gas bearing strata are shot with nitroglycerin or some other high explosive in order to break channels and facilitate the expulsion of the oil from its reservoir into the well. Usually when a well is shot the stratum is already known or believed to be productive and may have already yielded some oil. Sometimes, however, a stratum not definitely known to contain oil can be more effectively tested by shooting, as was the so-called Breckenridge lime in certain parts of the Ranger field, Texas, and certain wells producing from the so-called "black lime" horizon, which are cited on page 125.

Although nitroglycerin has been used extensively for years in shooting oil wells, there is much uncertainty as to how a given formation should be shot to get the best results. One of the primary objects of shooting is to fracture the oil-bearing formation as far away from the hole as possible, without disturbing the nonproductive strata above and below. Oil-well shooters have developed a certain technique which is based primarily on using as much nitroglycerin as the hole, between the depths to be shot, will hold. The shooting companies manufacture their own nitroglycerin, and their main source of revenue is from its sale. The oil operators have little basis for an estimate of the necessary amount of explosive to use and, naturally, are not desirous of getting within observing distance of the hazardous proceeding. In many wells the quantities of explosive used are excessive and in many the shots are not placed effectively.

Nitroglycerin[1] is a member of a series of compounds known as nitric esters. Some explosives, such as black powder and nitrosubstitution compounds, are exploded by ignition, but the nitric esters are more effectively exploded by detonation through the use of an exploding device containing mercury fulminate or the hydronitride of a metal, or by the explosion of a contiguous mass of the same ester. When these esters are exploded by detonation, the molecules are literally shaken apart, the explosive being converted into highly heated and greatly expanded gases much more quickly than by ignition. Therefore, when the energy of an explosive is released by

[1] Munroe, C. E., and Hall, Clarence, A primer on explosives for metal miners and quarrymen: Bull. 80, Bureau of Mines, 1915, p. 21.

detonation the shattering effect on surrounding material is greatly increased.

The rate of detonation becomes the governing factor in selecting an explosive for a particular kind of work. Gunpowder and other similar explosives, if laid on top of rock and fired, do no particular damage, because they explode so slowly that the gases formed have time to lift the air and their energy is expended on the air rather than on the rock. On the other hand, nitroglycerin or dynamite exploded under similar conditions shatters the rock, because the detonation is so quick that the energy of the explosive acts on the rock before the air can be lifted.

All explosives exert pressure in every direction when exploded. A naval detonator (see Pl. IV, *B*, p. 100) filled with mercuric fulminate was exploded in a closed iron cylinder filled with water. The cylinder was blown into the form of a sphere and ruptured. An oil well is a cylinder filled with water or oil or both, which surrounds the explosive. The liquid envelope about the explosive is practically incompressible and the energy of the explosive acts equally in all directions. Further, the inertia of a few hundred feet of fluid on top of the shot offers quite as effective a resistance to the almost instantaneous detonation of the explosive as would so much solid rock.

If some arbitrary sphere of effective work be assumed for an arbitrarily chosen part of the charge, the sphere of work for portions at each end of the charge will be as great, provided the detonation is uniform, as that for any intermediate portion. The suggestion is made, therefore, that a charge should be considerably shorter than the thickness of stratum to be shot, for if the length of the charge equals the thickness of the supposed productive stratum, the sphere of work will extend above and below the ends of the charge into formations that are to be disturbed as little as possible.

Further, if a lime stratum lying between less resistant bodies of shale is to be shot, the shale may be shattered more than the limestone, even though less work is done on it by the charge.

Evidently the shot should be placed with respect to the vertical center of the stratum to be shot and the shell should be shorter than the thickness of the stratum. The greater the amount of work required at a given horizon the shorter the shot should be and the greater its diameter.

In considering the explosive reactions in the bottom of a drill hole filled with fluid, the reader should remember that the explosion does not push the fluid out of the way before shattering the wall of the hole. The incompressible water is really a hammer that transmits the energy of the explosive and shatters the rock.

One of the practical applications of the spherical distribution of the work done by an explosive is that when the top of a shot is placed within 5 to 10 feet of the shoulder upon which casing is to be seated, the rocks will probably be cracked above the depth at which casing is to be landed, even though the casing is not shattered, and channels for water will be made. Also, the shooting of easily shattered rocks may cause difficult cleaning-out jobs.

As nitroglycerin is exploded most effectively by detonation, a charge of nitroglycerin, say, 100 feet long, may be assumed to act most strongly near the top of the charge where it has contact with the detonator. This raises the question of the efficiency of the spontaneous explosion of nitroglycerin by the hot water in a well, as mentioned on page 125. Probably much of the effectiveness of the explosion is lost through prior decomposition of some of the nitroglycerin and the lack of proper detonation. Eventually a method of shooting wells will be developed wherein detonators can be spaced at regular intervals through the body of the charge. A timing device will also eliminate the present makeshift and hazardous methods of detonation.

CHEMICAL TESTS FOR WATER.

Porous strata can be tested for water even when drilling water fills the hole. A chemical analysis is first made of the drilling water. When a porous stratum is penetrated the well is bailed from the bottom so that any water in the porous stratum can move into the hole. Then a sample of water at the bottom is taken, with a tight bailer, and is analyzed. If no native water has entered the hole the two analyses should be similar. Water other than the drilling water will give a different analysis.

This test is limited by the relation of the level of the drilling water to that of the rock water. For results to be satisfactory, the fluid level of the water in the porous stratum at the bottom of the hole must be considerably higher than that of the drilling water; in other words, the hydrostatic head of the native water must exceed that of the drilling water.

OIL-FIELD WATERS.

STRATIGRAPHIC CLASSIFICATION OF WATERS.

Water is a hindrance to the successful development of oil and must be excluded from a reservoir before the maximum production can be obtained. An exception to this rule is the stimulation of production by properly directed flooding[2] in the rehabilitation of oil fields.

For the present purpose oil-field waters may be classified as top water, intermediate water, bottom water, and edge water. Top water overlies the shallowest productive oil zone in any given area. Intermediate water occurs in strata lying between any productive oil zones. Bottom water lies below the lowest developed productive zone. Deeper development may change the status of bottom water to intermediate water. Edge water occurs in the downslope of an oil stratum and takes the place of oil as it is removed. Edge water must be further classified as top, intermediate, or bottom edge water.

In untried ground, the operator who wishes to test thoroughly for oil will start his well with as large a hole as possible, and carry a large diameter of casing as far as formational and water conditions and the collapsing strength of casing will permit. Unexpected water sands will cause him to reduce the size of the hole immediately, unless formational conditions will permit his making a temporary shut-off.

The first top-water stratum entered will be shut off with a string of casing in order to drill the hole dry or to test the productiveness of sands at greater depth. The sands thus tested may not be as productive as the operator hopes or desires, but this in no wise lessens his obligation to protect them from infiltrating water. The contents of the same sand differ at different wells. Possibly another well drilled to it may prove profitable, but water not cased off in the first well will travel through the oil sand and become a menace to the productive well. In prospecting, therefore, the various fluid-bearing strata should be segregated for protection and for testing as they are penetrated.

In such a plan of prospecting every one of the waters classified may be found. After several wells have been carefully drilled in an area and the stratigraphic relations of the oil and water-zones determined, a less expensive development program can be adopted, which will be largely controlled by the relative fluid levels of oil and water found by prospect drilling. Casing off top waters and drilling certain wells to an upper or first oil zone only may appear advisable. Later, when the first oil zone is exhausted, these wells may be deepened to a second oil zone or new wells may be drilled while the former are still producing. This deeper drilling may penetrate intermediate water, and thus entail protection of the first and second oil zones, possibly by pumping mud fluid under pressure into the first oil zone and the intermediate water and then cementing a string of casing between the intermediate water and the second oil zone.

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[2] Lewis, J. O., Methods for increasing the recovery from oil sands: Bull. 148, Bureau of Mines, 1917, pp. 92–116.

The original prospecting may have shown that the second oil zone contains the deepest production available, and incidentally the prospect well may have been drilled into bottom water. Unfortunately, a few wells must be drilled into bottom water before it can be accurately located. After these wells have been plugged and the water shut off, future trouble with bottom water should not occur.

METHODS OF EXCLUDING WATER.

Water is excluded from a well and prevented from moving below a given depth by landing or cementing a string of casing at that depth. The operation is referred to herein as shutting off water, or a water shut-off. The two chief methods of shutting off water are formation shut-off and cement shut-off, which may be either permanent or temporary, depending upon the drilling program and the necessities of prospecting and testing. A formation shut-off is a casing with a plain shoe landed or driven into a stratum of shale or clay without the use of an artificial bond. For a cement shut-off hydraulic cement is used as a bond between the casing and the formation in which the shoe of the casing is landed or driven.

FORMATION SHUT-OFF.

Formation shut-offs are restricted to shallow wells. The dead weight of the casing and the friction against the walls of the hole prevent successful driving in a deep hole. Table 23 (p. 136) shows the extent to which formation shut-offs are used in California. Of 105 shut-offs, 62 per cent were at depths between 100 and 1,000 feet and 16 per cent at depths between 1,001 and 2,000 feet; the remainder were made with special casing at depths greater than 2,000 feet. Only 11 per cent of the formation shut-offs were failures. In the Ranger, Breckenridge, and other "black lime" fields of northern Texas formation shut-offs are made at relatively greater depths than in California. Landing a string of 6⅝-inch casing on a shoulder in lime at depths greater than 3,000 feet is common practice. Some recent water troubles would indicate, however, that a shut-off thus made is not permanent.

Formation shut-offs do not require the loss of time and the expense incident to a cementing job. However, cement jackets or thick mud around water strings will probably insure longer life to the casing by protecting it from corrosion.[3] A chemical analysis of the

[3] Collom, R. E., Report on Santa Maria district: California State Mining Bureau Bull. 73, 1917, p. 202.

waters entered will assist in determining whether or not casing is in danger of corrosion.

CEMENT SHUT-OFF.

In shutting off water, cement is used for the primary purpose of making an impervious bond between the foot of the water string and the formation in which it is seated. However, varying amounts of cement, in excess of the quantity sufficient for excluding water at the shoe, are often placed back of the casing for secondary purposes, such as to prevent corrosion to reinforce casing against collapse, to fill the space between the outside of the casing and the wall of the hole to prevent movement of all fluids from their native strata into other susceptible strata exposed by the drill, or to prevent the expulsion of mud fluid from porous formations that have been sealed with mud under pressure.

The cement jacket to prevent corrosion has already been mentioned under formation shut-off. The practice of pumping large quantities of cement back of a string of casing for the purpose of reinforcement is general in California and parts of Louisiana. Details of the secondary purposes are not within the scope of the present discussion.

DEPTH OF CEMENTING.

Cement shut-offs are not limited by depth of hole, although failures seem to increase with depth. Of 736 cement shut-offs tested in the oil fields of California, as Table 23 shows, 25 per cent were made between depths of 100 and 1,000 feet, 30 per cent between 1,001 and 2,000 feet, 27 per cent between 2,001 and 3,000 feet, and 16 per cent at depths greater than 3,000 feet. The proportion of failures for cementing at these depths is 14.9, 17.5, 18.3, and 20.4 per cent, respectively. However, the percentage of failures after rotary landings at these different depths is greater than after cable landings. The average excess of rotary failures for all depths is 7 per cent.

Table 23 shows statistics of failures for both methods of shut-off at various depths for both rotary and cable tools. The percentages are shown in heavy type.

TABLE 23.—*Percentage of failures of water shut-offs at various depths.*

Shut-off depth and method.	Success.	Failure.	Total.	Percentage of failures.	Cable landing.			Rotary landing.		
					Success.	Failure.	Percentage of failures.	Success.	Failure.	Percentage of failures.
100 to 1,000 feet:										
Formation	57	8	65	12.3	57	8	12.3	....	....	....
Cement	154	27	181	14.9	114	19	14.3	40	8	16.7
Total	211	35	246	14.2	171	27	13.6	40	8	16.7
1,001 to 2,000 feet:										
Formation	15	1	16	6.2	14	1	6.7	1	....	....
Cement	184	39	223	17.5	107	22	17.0	77	17	18.1
Total	199	40	239	16.7	121	23	16.0	78	17	17.9
2,001 to 3,000 feet:										
Formation	22	2	24	8.3	2	....	....	20	2	9.7
Cement	179	40	219	18.3	70	8	10.2	109	32	22.7
Total	201	42	243	17.3	72	8	10.0	129	34	20.8
Below 3,000 feet:										
Formation	....	....	....	....	....	....	....	....	....	....
Cement	90	23	113	20.4	67	15	18.3	23	8	25.8

No description of methods of shutting off water is given here, as Tough [4] has covered the subject in considerable detail.

TEMPORARY OR PROSPECT SHUT-OFF.

Either a cement or formation shut-off can be made temporarily for prospecting areas where formations are firm enough to permit casing to be moved a considerable time after it has been placed in the hole. Only a small quantity of cement is used in temporary shut-offs that have been used successfully in California.

In the Belridge field, California, where tar and water sands overlie the productive oil zones, the General Petroleum Corporation made a number of cement shut-offs for prospecting purposes. These sands seem to be lenticular and some of the tar lenses carry water. Under these conditions correlation by cross sections is impracticable for anything more than a rough estimate of the depth to water. If a water-bearing stratum is entered below the shoe after a prospect shut-off has been made, the water string is pulled up and carried below the sand for another shut-off. B. E. Parsons, general superintendent for the company, states that in nearly 50 of these shut-offs the shoe joint

[4] Tough, F. B., Methods of shutting off water in oil and gas wells: Bull. 163, Bureau of Mines, 1918, 122 pp.

was injured in removal only twice. Formation shut-offs, with mud fluid for preliminary seal, are being used in the Casmalia field, California. A temporary shut-off for prospecting was made by the California Midway Oil Co. in well No. 8, sec. 32, T. 31 S., R. 23 E., Midway field. The 6¼-inch casing was cemented at 3,185 feet in blue clay with 5 sacks of cement placed with a dump bailer. Later the company pulled the casing loose and carried it to a depth of 3,425 feet.

Bureau of Mines engineers have recommended temporary prospect shut-offs (see p. 136) in the Kemp-Munger-Allen field of Wichita County, Tex. The principle can be widely applied in systematic orderly prospecting.

Apparently from the examples given, small quantities of cement, when necessary for successful shut-off, do not prevent removal of casing. Water is frequently excluded by a combination of cement and formation shut-offs. Neat cement fluid as thick as can be handled is placed with a dump bailer, and then the shoe of the casing is driven into a few feet of small hole.

The following table shows the quantities of cement used and other data for temporary shut-offs made by the General Petroleum Corporation in the Belridge field, California.

TABLE 24.—*Data on temporary water shut-offs with cement.*

Total depth of hole drilled.	Water string.				Water shut-off.		
	Tools.	Casing.			Number of sacks of cement.	Method.	Result of test for water shut-off.
		Diameter.	Weight.	Length.			
Feet.		*Inches.*	*Pounds.*	*Feet.*			
588	Cable	10	40	586	5	Dump bailer	Hole bailed dry; 2 feet of water showed in 17 hours.
646	do	8¼	36	645	6	Dump bailer pipe driven 2 feet.	Hole bailed dry; 1 foot of water showed in 12 hours.
670	do	8¼	36	667	6	Dump bailer	Hole bailed dry; 1 foot of water showed in 18½ hours.
655	do	10	40	653	6	do	Hole bailed dry; 1 foot of water showed in 14½ hours.
595	Rotary	10	40	590	6	do	Hole bailed dry; 6 feet of water showed in 19 hours.
918	Cable	10	40	916	7	do	Hole bailed dry; 2 feet of water showed in 15 hours.
114	do	8¼	36	1,110	5	do	Job was failure; 10 feet of sand entered hole from behind the 8¼-inch casing.

Temporary shut-offs in prospecting, provided underground conditions will permit, are recommended for the following reasons:

1. As a hole deepens all fluid above any depth to be tested is excluded by a temporary shut-off. The hole is drilled ahead and the next porous stratum is tested by bailing.

2. The diameter of hole need not be reduced every time a new water stratum is entered. The casing is pulled loose from the temporary shut-off and the test hole, which was drilled ahead, is enlarged so that the same diameter casing can be carried ahead for a shut-off below the newly entered water sand.

3. When oil is finally reached, a permanent water shut-off is made with perhaps only one string of large diameter casing in the hole.

The chief disadvantage is the extra time required to drill the hole. Such work can not be done by contract unless the contractor is paid proportionately, but the cost of 15 or 20 days' time added to the drilling of a well is small compared with the ultimately larger return from careful drilling.

TEST FOR WATER SHUT-OFF.

In the above discussion it was assumed that a preliminary test was made of each shut-off to show whether it was successful. Only the last job mentioned in Table 24 was a failure. Whether the water shut-off is temporary or permanent a test should always be made before drilling proceeds.

The usual pumping or bailing test for water shut-off is made to determine only whether or not water is kept from passing around the shoe of the water string and into the well. When a pumping or production test is made, a positive answer can be given only if the production shows no water. If water is present its source can not be determined by the mere act of pumping the well, and bridging or plugging under the water string or other tests are necessary to determine the source.

Pumping or production tests, although they may seem expedient for quickly getting a well to producing, should be avoided if possible. As the well is sunk through formations below the shoe of the water string, testing and repairing become increasingly difficult. Tests for water shut-off should be made when the number of complications that affect the result are at a minimum. The following are the steps necessary in a bailing test.[5]

1. Bail the well to the bottom or to a predetermined fluid level. The correct depth to bail a hole depends on (*a*) the fluid level of water back of the casing, (*b*) the resistance of the casing to collapse,

[5] McLaughlin, R. P., Method of testing water shut-off at oil wells: 2d Ann. Rept. State oil and gas supervisor: California State Mining Bureau Bull. 82, 1918, pp. 57–58.

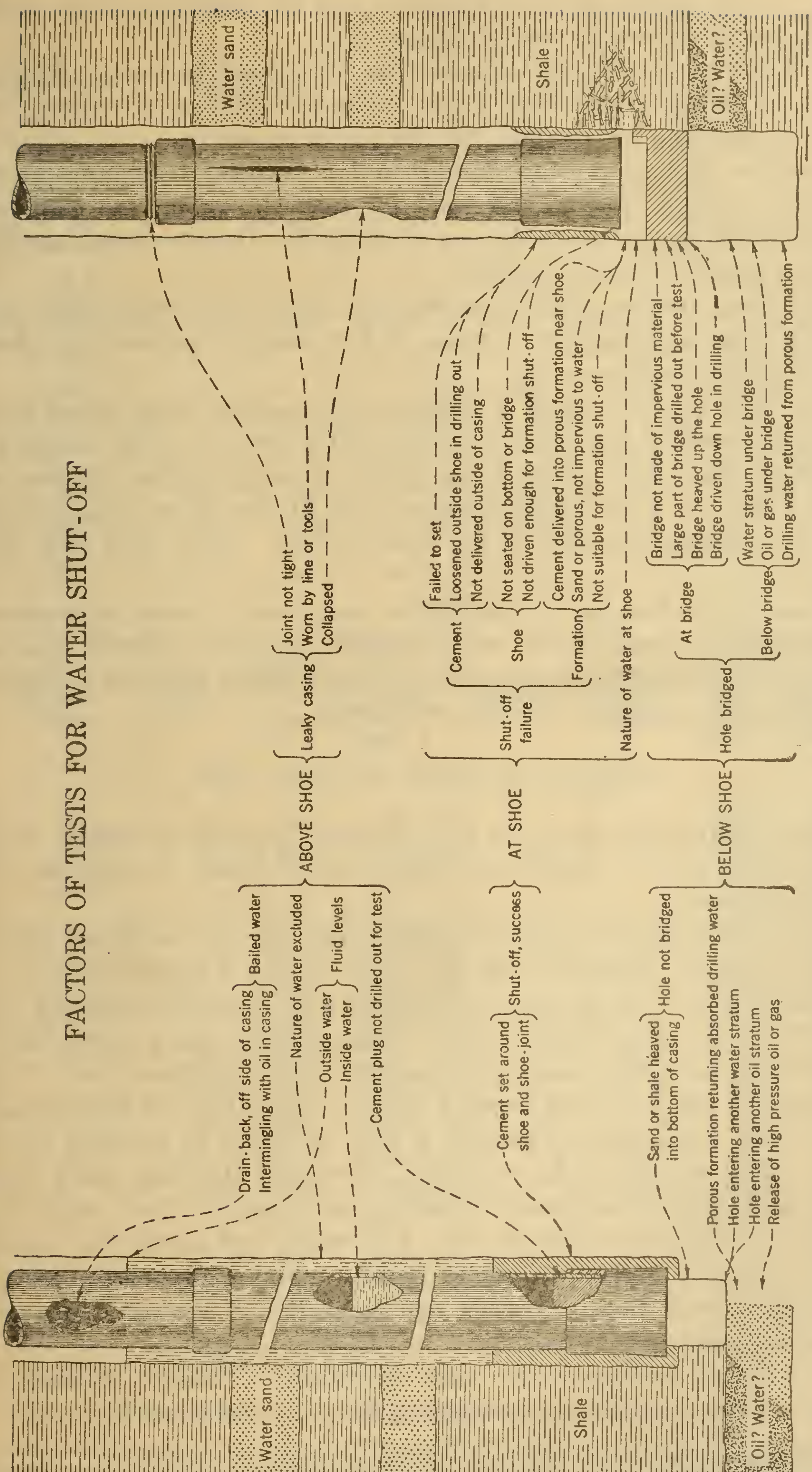

FIGURE 11.—Factors of tests for water shut-off.

and (*c*) the nature of the formations and the condition of the hole at or shortly below the shoe of the casing.

2. The well should stand undisturbed for at least 12 hours. Bailer, tools, or casing should not be run in the hole during this time.

3. At the time for the test, run the bailer to determine the amount of increase of fluid and the depth of hole. Careful determination of the exact depth of shoe and tests for leaks in casing are assumed to have been made before the test of shut-off. Bailer or tools should show a sample of the formation.

For ideal testing conditions the hole should be open below the casing shoe to formation in place and no deeper; ordinarily 5 feet ahead of the shoe is enough.

The most positive result is obtained when, after being bailed dry, the hole remains dry for the period of the test; or when bailed to a certain fluid level, there is no change of level during the period of the test; or when water appears, it is known to be coming into the hole around the shoe of the water string. Such ideal tests are few.

Usually the test or the inspection incidental thereto is complicated by the possibility of water entering at three different points, as follows: Above the shoe, at the shoe, and below the shoe. Figure 11 shows the possibilities under each group.

ENTRANCE OF WATER ABOVE THE SHOE.

Water may enter above the shoe through leaks in the casing, such leaks being due to insufficient tightening of joints, to collapse, or rarely, to wear.

A good example of a leak in water string, due to insufficient tightening, occurred during a test of a well of the Associated Oil Co., Casmalia field.[6] At the time of the first test water was entering the well from an undetermined source. The company ran a casing tester and found the casing leaking at the rate of 670 gallons a day. The casing, 960 feet long, was screwed up 26 inches; then the tester when run to the former depth showed 1 pint of water in one-half hour. The casing was 12½-inch, 40-pound. Probably the leak could have been more easily determined by bailing the casing to a safe depth before the cement was drilled out. A pressure test inside the casing will not prove as conclusively as bailing whether or not the casing is tight, because pump pressure can be sustained against a number of small leaks.

Injudicious bailing causes many collapses of casing. Extensive tests to determine that a water string has collapsed are seldom neces-

[6] McLaughlin, R. P., 3d Ann. Rept. State oil and gas supervisor: California State Mining Bureau Bull. 84, 1919.

sary. In fact, unless the casing can be swaged, the well never comes to a test. Collapse of unsafe lengths of 12½-inch, 40-pound casing, which has a collapsing strength of 500 pounds a square inch (see Table 25), the lowest collapsing strength of any size or weight of casing in common use, has occurred frequently in California. The Doheny-Pacific Petroleum Co., in the Casmalia field, lost a string of 12½-inch, 40-pound casing through collapse. The casing was originally cemented at 1,803 feet and collapsed at 1,140 feet on bailing. In well No. 1, Quintero, of the Union Oil Co., a water string of 12½-inch, 40-pound casing, after cementing and bailing, collapsed at about 1,200 feet. Swaging did not exclude water. In Darlington well No. 1, of the California Star Oil Co., Montebello oil field, a string of 12½-inch, 40-pound casing was cemented at a depth of 1,821 feet and on bailing to a depth of 1,380 feet for test of water shut-off, collapsed at 1,500 feet. Because of the excessive lengths of these three strings, nothing but collapse should have been expected.

TABLE 25.—*Collapsing strengths of various diameters of casing in common use.*

Size of casing (nominal), inches.	Weight per foot (nominal), pounds.	Collapsing strength, pounds per square inch.	Depth of water giving pressure enough to collapse casing,[a] feet.	Size of casing (nominal), inches.	Weight per foot (nominal), pounds.	Collapsing strength, pounds per square inch.	Depth of water giving pressure enough to collapse casing,[a] feet.
4¼	16	4,715	10,880	8¼	36	2,635	6,080
4½	13	2,900	6,700	8¼	38	2,880	6,640
4½	15	3,605	8,320	8¼	43	3,510	8,100
5⅝	20	3,295	7,620	9⅝	33	1,285	2,970
6¼	20	2,345	5,420	10	40	1,425	3,290
6¼	24	3,215	7,420	10	45	1,795	4,140
6¼	26	3,650	8,420	10	48	2,025	4,680
6¼	28	4,080	9,420	10	54	2,510	5,800
6⅝	20	1,980	4,570	11⅝	40	835	1,930
6⅝	26	3,075	7,080	12½	40	500	1,150
6⅝	28	3,490	8,060	12½	45	750	1,730
6⅝	30	3,850	8,900	12½	50	1,010	2,330
7⅝	26	1,945	4,480	12½	54	1,215	2,800
8¼	28	1,660	3,840	13½	50	650	1,500
8¼	32	2,150	4,960	15½	70	795	1,840

[a] The figures in this column should be divided at least by 2 in determining the maximum depth at which it is safe to use any given diameter and weight of casing.

Some operators follow a policy, rather strenuous at times, of bailing a water string to the bottom, regardless of the lowest probable depth to which fluid will be reduced during the life of the well. If danger from collapse, heaving sands, or gas strata of high pressure prohibit bailing dry, the well should be bailed to a depth at which there is several hundred feet difference between fluid levels inside and outside the casing. For this reason, if for no other, the fluid levels of water strata entered in drilling should be carefully recorded. At a rotary hole the making of such observation is difficult.

One of the commonest sources of small quantities of water in a well at the time of a test is the drainback of water sprayed on the inside of the casing from leaky or gassing bailers during the preparation for the test.

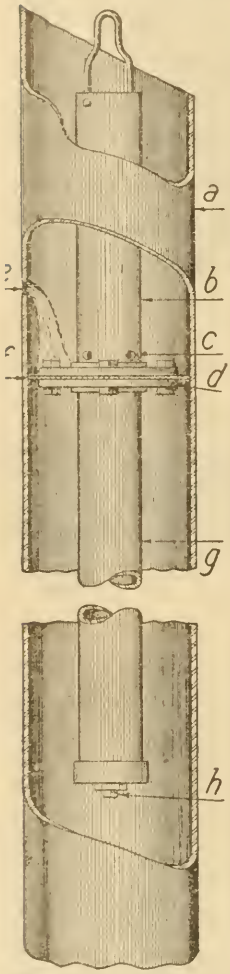

FIGURE 12.—Swab bailer or casing tester.

TESTING FOR CASING LEAK.

By plugging in the shoe of the casing and making bailing tests, the existence of a casing leak and the rate of flow can be detected. The position of the leak as well as the rate of flow can be determined by the use of a casing tester or swab bailer such as is shown in Figure 12. All testers have a closed bottom. The casing must be bailed free of fluid below the depth to be tested. The tester is run to a predetermined depth and allowed to stand for a given length of time. When the tester is removed, the amount of fluid therein can be measured and the rate of leakage calculated to 12 or 24 hours flow.

REPAIR OF CASING LEAKS.

The method of repairing a leak depends largely on the nature of the leak.

If the leak is caused by loose casing (see p. 140), which is usually due to lack of care when the casing is lowered into the well, the trouble is usually remedied by screwing the casing tighter.

A leak was found at 1,460 feet in $6\frac{1}{4}$-inch casing landed at 3,993 feet in a well of the Standard Oil Co., Coyote Hills field. A $\frac{3}{8}$-inch rip, 8 inches long, was made at 1,550 feet, and 50 sacks of cement were pumped through the rip into the space between the $6\frac{1}{4}$-inch and $8\frac{1}{4}$-inch casings by the Perkins method. The plug in the $6\frac{1}{4}$-inch casing was drilled out from 1,540 to 1,560 feet, and the wooden plugs (used for bridge) were pushed down to 2,950 feet with 4-inch rotary pipe. Water was bailed to 2,000 feet. After the hole had stood 51 hours water rose 1 foot. The repair work was successful.

In a well of the Southern Pacific Co. fuel-oil department, Coalinga field, a leak was found in the $8\frac{1}{4}$-inch casing cemented at 1,430 feet. The leak was repaired by setting a packer at 1,394 feet. The fluid level before the packer was set was 90 feet from the top and afterwards was 600 feet from the top. After the well had produced for one week, the fluid dropped to 1,200 feet, the old level of the well.

CHEMICAL ANALYSES OF WATER.

Some of the advantages of chemical analyses of oil-field water have already been mentioned. If fresh water is identified above the shoe and sulphur water is bailed at test, it is reasonable to conclude that the sulphur water does not come from around the shoe. A derrick-floor determination of the nature of the water excluded, whether fresh, brackish, salt, or sulphur, will often assist in determining the result of a test. Generally, gallon samples should be taken of all waters entered in drilling, and a comparative record of their chemical analyses kept.

Analyses must be reduced to a common standard for comparison. Clarke[7] states that the analysis of a water can be reported in several different ways, as in grains per gallon or parts per million, in oxides, in supposititious salts, or in radicles, so that two analyses of the same water may seem totally dissimilar, although in reality they agree.

Ambrose[8] has described the application of chemical analyses to a classification of oil-field waters.

DYE TESTS FOR WATER BACK OF CASING.

In order to determine if the water appearing in a hole is moving from behind the casing past the shoe, operators occasionally place some coloring medium, such as Venetian red or an aniline dye, back of the casing in the hope that water moving past the shoe will show color in the hole. However, a negative test, which shows no color, is not of value, as the course the dye may have taken after leaving the surface is unknown. For a bailing test all water must be removed from behind the casing, in order to bring the dye from the surface of the water there by the shoe and into the hole.

An aniline dye may be used, however, in determining the course of travel of water through productive strata. The dye should be placed at the bottom of an idle well in the group; then the appearance of dye in adjoining wells indicates that the wells are taking water from a common source, but it does not indicate that the well in which the dye was placed is the offender.

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[7] Clarke, Frank W., The data of geochemistry: U. S. Geol. Survey Bull. 491, 1911, p. 59.

[8] Ambrose, A. W., Underground conditions in oil fields: Bull. 195, Bureau of Mines, 1921, p. 104.

ENTRANCE OF WATER AT THE SHOE.

Failure to shut off water causes leaks at the shoe and, therefore, at least part of the entering water is from behind the casing. Such failures may be due to the nature of formations in which landing was made, to improper preparation of the hole for shut-off, to ineffective placing of cement, or to the water string being damaged by swabbing or shooting.

In making a cement shut-off the cement may fail to set because of gas or fluid rising through it. In order to keep back gas, the maximum hydrostatic head is held in the casing after cement is placed. This will also largely prevent movements of the fluid cement.

In a well of the Interstate Oil Co., Sunset field, California, inspection showed a shut-off failed because iron in the bottom of the hole kept the casing from seating. The Doheny-Pacific Petroleum Co. found that a shut-off in one of their wells in Casmalia field, California, was a failure because the cement was pumped into porous formations near the shoe. Although 100 sacks of cement were used, the casing was easily removed, inspection showing that the cement had extended only 4 feet above the shoe. Evidently an impervious formation in which to set casing is necessary for a successful shut-off.

When a shut-off fails, the casing may be pulled, or, if necessary, the water string may be cut off and cleaned out or redrilled, and another shut-off made at a higher, lower, or equal depth. A cement shut-off may be recemented, usually under pressure, or the casing may be ripped near the shoe and cement forced through the rips. If a formation shut-off fails, the casing may be driven further, or jarred loose and the hole drilled deeper and another attempt at landing made, or, after loosing, the casing may be cemented again, with a dump bailer or by other method, at the same depth. When the depth of failure is not close to oil-bearing formations, drilling ahead and landing or cementing another string of casing or cementing a liner may be advisable. When the depth of failure is close to oil-bearing formations, a packer on a smaller string of casing or tubing can be set in suitable formations below the shoe.

The method of correcting failures of formation shut-offs has already been discussed on page 134.

ENTRANCE OF WATER BELOW THE SHOE.

The possibility of the presence, at test, of water other than that coming from back of the water string, has been mentioned, also that as a rule the hole should be drilled only enough ahead of the shoe to enter formation in place. Several complications impede testing when a hole is drilled into formations that differ from that in which shut-off was made.

Sand or shale heaving into the bottom of the casing may interfere with a test by preventing movement of water past the shoe and into the casing when the shut-off is a failure. If the sand or shale plug can not be permanently removed with tools or by bailing, a string of casing with two or three joints of perforated or screen pipe should be run into the hole to hold back the heaving formation during a test.

When the hole is drilled a considerable distance ahead of the shoe the drilling water may be, and frequently is, absorbed in porous formations; then when the well is bailed for a test, this water flows back into the hole. The rate of inflow decreases on continuous bailing and often stops completely during the test. Until such a decrease can be positively noted, however, the test is not conclusive.

In many wells where the hole breaks into an oil stratum, or where high pressure causes the oil confined below a thin crust to "drill itself in," a production test is the only recourse, other than bridging. A high-pressure restricted flow of either oil or gas will undoubtedly hold back water. A well[9] is noted from which a flow of gas, when unrestricted, allowed a flow of 700 barrels of water a day. The method at Mexican wells of preventing the flow of water with the oil has already been mentioned (p. 124).

When the hole has been drilled ahead into a sand stratum and considerable water appears at the time of test, it is difficult to determine whether the drill has entered a water stratum below the casing shoe or whether water has not been shut off above the shoe. Sometimes the whole question of success or failure in developing a well, or even a producing sand underlying an entire property, hinges upon knowing definitely that the water alleged to be coming from a new sand below the shoe actually comes from that sand and not from around the shoe. The possibilities that a sand below the depth of shut-off is a new water sand seems to furnish more uncertainty as to the condition and prospective future of a drilling well than any other single feature. If the water actually is due to failure of the shut-off at the shoe, yet the operator believes that it comes from the new sand, which, as a water sand he plans to shut off with another string of casing, he may actually shut off the very oil sand he is seeking.

Such a sand can not be assumed to be a water sand until the space between the shoe of the casing and the sand has been plugged and the well, after being bailed and allowed to stand, has shown no change in fluid level. To meet this test a successful shut-off and open formation between the bottom of the shoe and the top of the plug are required.

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[9] McLaughlin, R. P., Method of testing water shut-off at oil wells: California State Mining Bureau Bull. 82, 1918, p. 59.

BRIDGE BELOW SHOE.

In this discussion it is assumed that a well is bridged below the shoe for one of two purposes, either to form a solid seat, in contact with a suitable formation, at a depth less than the total depth drilled for cementing the water string, or to plug the well above oil, water, or gas formations to determine whether water is excluded at the shoe.

For either purpose the bridge must be made of impervious material, must be well bonded with the formation, and be deep enough to withstand the impact of heavy drilling or heaving pressures from below. Bridges are made of rock, bricks, lead-wool, or other material with a neat cement capping. Bundles of wire line should not be used; they are hard to drill out or to sidetrack. The bridge should be at least 20 feet deep if the thickness of suitable formations will permit. A solid and well-bonded bridge will eliminate all uncertainty regarding the conditions immediately below the casing shoe.

The following notes on proposed operations and tests at a well of the Pan-American Petroleum Corporation, in the Casmalia field, California, illustrate the necessary requirements in bridging and the possibility of failure. The hole was bridged at 2,450 to 2,307 feet, and was drilled out below the 8¼-inch casing to test a shut-off. The hole filled 2,000 feet with water. Another bridge was placed just below the shoe of the 8¼-inch casing in order to test for shut-off, but the test was not conclusive. The hole was drilled out, another bridge made, and the test showed a small amount of water. The conclusion was that if water was coming through or around the bridge, the flow would increase on drilling out the hole. This conclusion proved to be correct. Water entered at the rate of 89 gallons an hour before drilling. The fluid level at 9 a. m. was 1,700 feet. Drilling was begun at 11 a. m., and at 12.30 p. m. the fluid level was 1,235 feet, showing that 465 feet of water had entered the hole during the period of two hours in which the bridge was intact and the one and one-half hours after drilling started—an average inflow of 370 gallons an hour for the three and one-half hours—but the water came in much faster after the drilling was done, the average increase after drilling out bridge being 281 gallons an hour.

The various sources of water mentioned change from determinable to indeterminable, or the reverse, according to the extent and efficiency of drilling, bridging, plugging, or other work done during the test.

Table 26 indicates the condition of hole necessary to determine whether the source of fluid is above, at, or below the shoe.

TABLE 26.—*Condition of hole necessary to determine source of fluid entering a well.*

Position of factor.	Source of water.	Condition of shut-off.	Mechanical condition of hole.			
			Plug or bridge in shoe joint.	Hole open just to formation in place.	Tight bridge just below shoe.	Leaky bridge or no bridge.
Above shoe	1. Leaky casing.	Success.	Determinable by bailing.	Determinable by casing tester.	Determinable by casing tester.	Excepting presence factors 4 and 5, determinable by casing tester.
		Failure.	......do.........	Indeterminable, except occasionally by casing tester.	Indeterminable, except occasionally by casing tester.	Indeterminable.
At shoe....	2. Drain back.	Success.	......do.........	Determinable by bailing.	Determinable by bailing.	Do.
		Failure.	......do.........	Indeterminable.	Indeterminable.	Do.
	3. Water around shoe (factor 1 excepted).	Success.	Indeterminable.[a]	No factor......	No factor......	No factor.
		Failure.	......do.[a].......	Determinable.	Determinable.	Indeterminable.
Below shoe.	4. Drilling water (factors 1 and 5 excepted).	Success.	......do.........	......do.........	......do.........	Determinable.
		Failure.	......do.........	Indeterminable.	Indeterminable.	Indeterminable.
	5. Native water	Success.	......do.........	Excepting presence of factor 1, determinable.	Excepting presence of factor 1, determinable.	Excepting presence of factor 1, determinable.
		Failure.	......do.........	Indeterminable, except by elimination factor 3[a].	Indeterminable, except by elimination of factor 3.[a]	Rarely determinable, except when fluid level is higher than that of water excluded.
Above shoe	Oil and gas..	Success.	Determinable by perforating opposite oil stratum indicated by log or correlations.	Indeterminable.	Indeterminable.	Indeterminable.
		Failure.	......do.........	......do.........	......do.........	Do.
Below shoe.	......do.........	Success.	Indeterminable.	Determinable by bailing.	Determinable by bailing.	Factor 5 excepted, determinable. Frequently necessary to bail, swab, or pump.
		Failure.	......do.........	Frequently indeterminable.	Frequently indeterminable.	Frequently indeterminable.

[a] Success or failure of shut-off is inferentially determinable by perforating or ripping shoe joint above cement plug.

OIL AND GAS PRODUCTION OVERLOOKED IN DRILLING.

Opposing pressures, roughly classified as artificial hydrostatic pressure and natural rock and hydrostatic pressure have a marked effect in determining the content of formations. All bailing, swabbing, or pumping tests are made for the purpose of reducing the artificial pressure after drilling, so that the natural pressures may cause oil and gas to move from their reservoirs into the well. When artificial pressures are not reduced, sands capable of producing oil and gas in commercial quantities may be passed up. Any firm reservoir of sandstone or limestone showing favorable signs of oil should be shot with high explosive and tested.

Oil and gas are not always passed up because there is no indication of their presence. Frequently the showing noticed is interpreted as a dead oil sand, or a tar sand, or a gas pocket, and no substantiating test is made. In the region southwest of Olean, N. Y.,[11] on the outskirts of the Bradford oil field, the early wells were all sunk to the Bradford sand, at a depth of 1,000 feet or so below the valleys. In some wells shows of oil were at a certain depth, but were cased off, as a producing sand was not expected above the Bradford. Later, when the Bradford supplies ran low, the sand at the upper oil show was developed into a producer, now known as the Chipmunk sand. In the wells for which accurate records had been kept, the casing was locally removed and both sands were drawn upon; but where because of no records this could not be done, new wells had to be sunk at an aggregate cost of many thousands of dollars. In the Bellevernon and other gas fields in southwestern Pennsylvania, gas wells were similarly cased off.

According to Kirwan,[12] the Standard Oil Co. "passed up" a productive oil zone, the first oil zone in at least 30 wells drilled in the Whittier field of southern California. Three wells produce from the first zone only. During August, 1917, the combined production of these three wells was 4,523 barrels of oil and 687 barrels of water. The first zone was not protected from water at any of the wells drilled through it and a study of the records filed by the company indicates that this zone was not tested to determine its productiveness, possibly because the water above it was not effectively shut off. An adjoining well was averaging 120 barrels of oil a day from the first zone at the time that zone was cased off in the well under study.

Probably some of the first wells drilled and abandoned in the Ranger field of Texas, would have been producers if properly tested

[11] Record of deep-well drilling for 1904: U. S. Geol. Survey Bull. 264, 1905, p. 17.

[12] Kirwan, M. J., Report on Murphy-Whittier property of Standard Oil Co.: California State Mining Bureau Bull. 84, 1918, p. 239.

by shooting with nitroglycerin. The differences in the behavior of three wells in that field show the advantage of shooting. All three were drilled dry with cable tools and therefore fluid that had access to the hole would show. In Hagerman well No. 2 of the Sinclair Oil Co. there were no signs of oil or gas when the well was completed. The hole was shot with 400 quarts of nitroglycerin in black sandy lime between 3,390 and 3,526 feet, and after cleaning out, flowed 25 barrels of oil a day. Hagerman well No. 3, of the same company, 750 feet south and 500 feet west of well No. 2, was shot with 160 quarts of nitroglycerin between depths of 3,263 and 3,273 feet, and 3,295 and 3,327 feet, and after cleaning out showed no oil. Stanley well No. 1 of the Texas Co., when completed started flowing 500 barrels a day without being shot. It is 500 feet east of Hagerman No. 2.

OIL AND GAS "PASSED UP" BY ROTARY.

The main reasons why oil and gas-bearing strata have been "passed up" in rotary drilling are here summarized, and specific wells cited as examples:

1. A showing of oil or gas may have appeared in the ditch without driller noting it.
2. A showing of oil or gas was noted and logged, but either because the operator was bent upon drilling for deep oil or the showing was considered insignificant, the necessary expense of landing casing and bailing for test was not undertaken.
3. Because of the mud fluid being thick, the oil or gas stratum was plastered and sealed as the tools passed through it, and no showing of oil appeared at the surface.
4. The bit plunged through a fine-grained oil-bearing sand and neither sand cuttings nor oil showed in the ditch.

Near Walters,[13] Cotton County, Okla., a well was drilled by the Gladstone Oil and Gas Co. in the spring of 1918. Rotary tools were used in drilling and no oil was discovered. A year later the Chapman well, one-quarter of a mile south, came in, making 450 barrels of oil a day and much gas. Then the casing in the Gladstone well was ripped for a few inches at a zone corresponding to the producing zone of the Chapman well and the well on testing produced 75 barrels of oil and 35,000,000 cubic feet of gas a day. Here a well became a producer on the strength of information obtained by the careful drilling of an adjoining well.

The Palmer Union Oil Co. drilled a prospect well in the Cat Canyon oil field, Santa Barbara County, Calif., with rotary tools.

[13] Ambrose, A. W., Underground condition in oil fields: Bull. 195, Bureau of Mines, 1921, p. 20.

Several sands were penetrated above 2,800 feet and the showings therefrom were logged as "tar"; 8¼-inch casing was landed at 2,800 feet and the well was drilled with rotary tools into flinty brown shale, showing signs of oil below a depth of 3,200 feet. Pumping for test failed to show commercial quantities of oil. Then the company redrilled the hole below the bottom of the 8¼-inch casing (2,800 feet) with cable tools, thinking, perhaps, that the rotary mud had mudded off the oil in the lower part of the hole. The well was again put on pump for test, but failed to produce oil. The company seriously contemplated abandoning the hole, but as a last resort the superintendent perforated the 8¼-inch casing (set at 2,800 feet) opposite the tar sands of the rotary log and put the well on pump. For a few days considerable rotary mud and sand and a little oil came into the hole. Then the gas in the sand began to work and soon the well was producing over 400 barrels of oil, 12° B., and considerable gas.

Oil showings were willfully concealed, it is said, in a well drilled with rotary tools in the Montebello field, Calif. Affidavits of drillers[14] state that the superintendent said to keep the mud heavy, as he did not want any oil whatever to show on the ditch. This would seem to prove that the use of thick mud can conceal oil or gas showings.

A driller for the Interstate Oil Company, Sunset oil field, Calif., testified[15] that he drilled with rotary through an oil sand about 20 feet thick in the first oil-zone in that field, and recorded it as a soft formation. After drilling into the soft formation he had some doubts as to the nature of the formation, stopped drilling, and circulated mud fluid through the hole. About 2 hours were allowed for cuttings from the "soft" formation to appear at the surface, but, as these first-zone sand strata are fine grained, no sand nor oil appeared, and drilling proceeded. When asked if in his opinion a sand of a thickness such as the one discussed could be passed up without its character being discovered, he replied, "You certainly can if you are not very careful."

On the cover page of a California State Mining Bureau publication[16] is a photograph of an "oil well flowing 10,000 barrels of oil a day, Coyote Hills field, Orange County, Calif." According to the caption under the picture, the production from this well, Standard Oil Co. No. 61, is coming from an upper zone or formation that was drilled through and overlooked.

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[14] McLaughlin, R. P., 3d Ann. Rept. State oil and gas supervisor: California State Mining Bureau Bull. 84, 1918, pp. 59–72.

[15] Collom, R. E., 3d Ann. Rept. State oil and gas supervisor: California State Mining Bureau Bull. 84, chap. 2, 1918, pp. 117–118.

[16] McLaughlin, R. P., 5th Ann. Rept. State oil and gas supervisor: California State Mining Bureau, vol. 5, No. 1, July, 1919.

In the Burkburnett town site and northwest extension oil fields of Wichita County, Tex., there is strong reason to believe that shallow oil-bearing strata have been passed up by the rotary contractor in his haste to complete a well to the main producing sand. In fact, a number of logs examined by the author record showings of oil at depths ranging from 700 to 1,150 feet. These showings could not be tested during the speculative orgy that made Burkburnett famous.

A careful investigation of subsurface conditions in the Burkburnett field may indicate the existence of shallow productive sands, as is suggested by the history of a certain well in the Burkburnett townsite pool, where wells were drilled on every town lot. This well produced so little oil from the 1,700-foot sand that it was turned over to a salvage company to be abandoned. In order to remove the 6⅝-inch casing, one of the steps of abandonment, the casing had to be shot in two at about 1,400 feet. When the casing had been pulled up the hole about 250 feet the well began to flow oil and had to be plugged with a wooden plug and mud to hold the oil back so abandonment could be completed. The salvage company estimates that the hole produced from 400 to 450 barrels of oil before it was plugged. Ordinarily this would be a fairly good clue to a productive sand between depths of 1,100 and 1,200 feet, and if the economic possibilities of a field were considered steps would be taken to obtain the oil.

SPECIFIC APPLICATIONS OF THE PRINCIPLES OF PROSPECTING.

In conclusion, some of the principles discussed in this paper are summarized below and their specific application in the development of certain producing fields is noted. Three fields have been chosen, as follows: (1) An oil field drilled with rotary tools, the Kemp-Munger-Allen field, Wichita County, Tex.; (2) an oil and gas field drilled with cable tools, parts of Ranger field, Stephens County, Tex.; (3) a high-pressure gas field drilled with rotary tools, the Monroe gas field, Ouachita and Morehouse Parishes, La.

A DRILLING PROGRAM FOR THE KEMP-MUNGER-ALLEN OIL FIELD, TEXAS.

In the Kemp-Munger-Allen field, Wichita County, Tex., about 25 miles from Wichita Falls, the discovery well, K. M. A. No. 1, was brought in during October, 1919. This well was drilled with cable tools to a depth of 1,778 feet at a cost of $65,000. A large flow of salt water was reported at depths of 1,730 to 1,740 feet. Below this water sand the drill entered 2 feet of a black formation, in which

6⅝-inch casing was cemented, and the hole was drilled 2 feet deeper into a fine brown oil sand, which flowed oil at the rate of 250 barrels a day. Unfortunately part of the drilling record of the discovery well was lost, and the following formation record of the well is incomplete:

Formation record of K. M. A. well No. 1, Kemp-Munger-Allen field, Wichita County, Tex.

[Drilled with cable tools.]

Formation.	From—	To—	Thickness.
	Feet.	*Feet.*	*Feet.*
Shale, lime, sand	0	1,166	1,166
Slate	1,166	1,170	4
Lime	1,170	1,175	5
Brown sand	1,175	1,179	4
Red shale	1,179	1,206	27
Lime	1,206	1,208	2
Shale	1,208	1,245	37
Sand	1,245	1,247	2
Brown shale	1,247	1,249	2
Sand	1,249	1,256	7
Brown shale	1,256	1,262	6
Red, gray, and brown shale	1,262	1,348	86
White sand	1,348	1,365	17
Gray shale	1,365	1,382	17
Sand	1,382	1,384	2
Shale	1,384	1,411	27
Black slate	1,411	1,413	2
Black sand, show of oil	1,512	1,514	2
Light shale	1,514	1,540	26
Water sand	1,540	1,545	5
Gray shale	1,545	1,547	2
Black slate	1,586	1,588	2
Salt sand	1,657	1,663	6
Blue shale	1,663	1,669	6
Sand	1,669	1,674	5
Water sand	1,674	1,684	10
Dark sand	1,684	1,718	34
Blue shale	1,718	1,732	14
Sandy shale	1,759	1,766	7
Oil sand	1,766	1,768½	2½
Shale	1,768½	1,775	6½
Sand	1,775	1,778½	3½

Because of the nature of the formations and the high cost of drilling the discovery well, all subsequent drilling in the field has been with rotary tools. The contractors and drillers face drilling conditions entirely different from those in the Burkburnett field or elsewhere in Wichita County. One of their chief difficulties has been to set the final string of casing and to drill into the producing sand with rotary tools. In the Burkburnett field the average thickness of the producing sand is about 25 feet and, because it lies at regularly graded depths, the rotary driller had little more to do than to make about 1,700 feet of hole, land the casing, and turn the hole over to the operator. In the Kemp-Munger-Allen field, however, the average thickness of sand, as reported from rotary logs, is 4½ feet. Many of the wells in the field are producing large quantities of salt water. Up to November, 1920, the exact source of the water had not been determined, as a water stratum is difficult to detect in rotary drilling. Some operators believed that salt water was close to the top of the producing sand; it also occurred not far below this sand. Unfortunately, little reliable information had been obtained to show the exact position of suitable formations above the producing sand in which to land casing to shut off water.

As the necessity for more detailed data on formations was realized rotary contractors started to use core barrels to take samples—a step in the right direction. Some over-enthusiastic contractors, however, advocated the use of the core barrel in drilling into and through the producing sand as the only sure way to get oil to flow from the sand. This method probably gave a good record of formations, but it did not eliminate the danger of sealing part or all of a thin oil sand with mud.

The practice which is general in Wichita County, Tex., of drilling fairly close to producing sands with rotary and then changing to cable tools for drilling into the sand, would probably have given the necessary information for depths at which to shut off water. However, the unusual stratigraphic conditions seemed to call for the devising of new practice in drilling, and contractors did much costly experimenting at the investor's expense. Even elementary operating practice seemed to have failed; for example, cement often could not be used because it would not set in salt water.

W. A. Snyder, expert driller for the United States Bureau of Mines, spent six weeks or more in the Kemp-Munger-Allen field working with operators and making observations. One of the operators turned over to Mr. Snyder for testing a well that was given up for lost after having been drilled to 1,800 feet with rotary tools at a cost of $30,000. After the water was temporarily excluded with plugs and packers the well flowed oil. Because of its physical condition the well probably could never be made a producer, but the information gained as to the relations of the oil and water sands should be of more value to the operator than the well itself, either before or after the tests.

From the results of tests in this field the following development program was deemed advisable:

Drill with rotary tools, to about 1,675 feet, a hole (11 inch) to carry 8¼-inch casing.

Take core-barrel samples with rotary tools, from 1,675 to 1,700 feet or slightly deeper, until a suitable formation is found in which to land 8¼-inch casing to shut off water. Former practice was to use 6⅝-inch casing at this stage.

Cementing the casing would then be advisable by the Perkins or some similar method. The practice of running cement into the hole on top of the first plug has not been satisfactory. Rotary mud must be pumped from inside the casing, and the cement pumped into and back of it.

The cement must be allowed to set 10 to 15 days. Then the casing should be bailed and tested for leaks before the cement is drilled out. Drill out 2 feet below the shoe and bail the hole to test for water shut-off.

After water is shut off, drilling should be continued with cable tools. For such drilling calf-wheel and Ideal rig irons will be necessary in order to carry 6⅝-inch casing to make temporary shut-off of any water sand that may be developed below the shoe of 8¼-inch casing. The hole can then be drilled "dry," with less danger of missing water or oil-bearing formations.

If a water sand is found 20 feet below the shoe of the 8¼-inch casing, the 6⅝-inch casing should be landed below this water sand, the hole bailed and dry drilling continued with 6⅝-inch hole. If another water sand is penetrated, the 6⅝-inch casing should be loosened, the hole underreamed, and the 6⅝-inch casing reset below the second water sand. Thus water can be kept out of the hole so that any oil present can enter. The hole can be bailed and tested for water or oil whenever desired.

Considering the thinness of productive formations in the Kemp-Munger-Allen field, if rotary is used to drill into productive formations, the drill is very likely to pass entirely through the sand, fill it with mud, and even if the hole were bailed and tested no oil would appear.

Each oil well admittedly presents an individual problem both in drilling and in producing; however, certain fundamental principles apply to all fields, and the Kemp-Munger-Allen furnishes a normal example for a development program with rotary tools in medium-depth territory.

A DRILLING PROGRAM FOR THE RANGER OIL FIELD.

In the Ranger oil fields, Texas, operators are confronted with development conditions that are entirely different. Wells are drilled to depths greater than 3,000 feet, with cable tools; this work is done by contract. Holes are drilled dry, and as many water sands are entered in drilling several strings of casing are used. The usual drilling program begins with 15½-inch casing and finishes at the top of the black lime with a string of 6⅝-inch casing at, say, 3,000 feet. The well is then completed with a liner into the black lime. After the well has been shot and has begun producing, the larger strings of casing are drawn. For example, 15½, 12½, and 10 inch strings of casing may be removed, and a string of 8¼-inch casing left at 2,800 feet to protect the hole from upper waters. Or perhaps the 10 and 8¼ inch casing may be pulled and a string of 6⅝-inch casing set on top of black lime to protect the well.

This lack of uniformity in a development program does not interfere with drilling, and the operator has been able to get back a number of the extra strings of casing required in drilling to keep the hole dry. However, the ultimate result is a lack of uniformity in depths for shutting off water, which seems to be one of the main causes for salt water showing with the oil in January, 1921.

The following suggestions and criticisms are offered as a guide to the correction of similar faults in development, the data being taken from the wells of an area that the author studied for the Bureau of Mines at the request of interested operators:

These wells (Pl. V) lie about 7 miles northeast of Ranger, Tex. The diagrammatic cross section in Plate V is plotted to the top of the black lime as datum. Oil in producing quantities is confined to the black lime (Bend series of the Pennsylvanian) in this area. Logs are shown only from 1,000 feet below surface to total depths. The casing records are not reliable, especially for 10-inch casing in several of the wells. Ten-inch casing are known to have been removed from a number of wells since the logs were made, but the data recorded are mainly for original physical conditions of the wells.

In order to understand clearly the reasons for the author's recommendations and conclusions attention is directed to the segregation of strata in Plate V. The main water-bearing strata of the area are designated as Zone A, "Big salt water"; below them lies a body of shale body containing streaks of lime, its average thickness being 500 feet. Below this shale lies a series of sandy beds in the Strawn formation, and possibly some sandy lenses in the Smithwick shales. These sands are classed as Zone B. Some of the sands, probably the upper ones, contain water, although it is not logged. The lower limits of Zone B are not definite. The purpose of segregating sandy beds in this way is to emphasize possible channels of travel for water from one well to another.

Salt water is the chief hindrance to the successful production of oil in this area. Indications are that this water entered the wells as the result of faulty development. Table 27 shows the relative importance of various water strata entered in drilling.

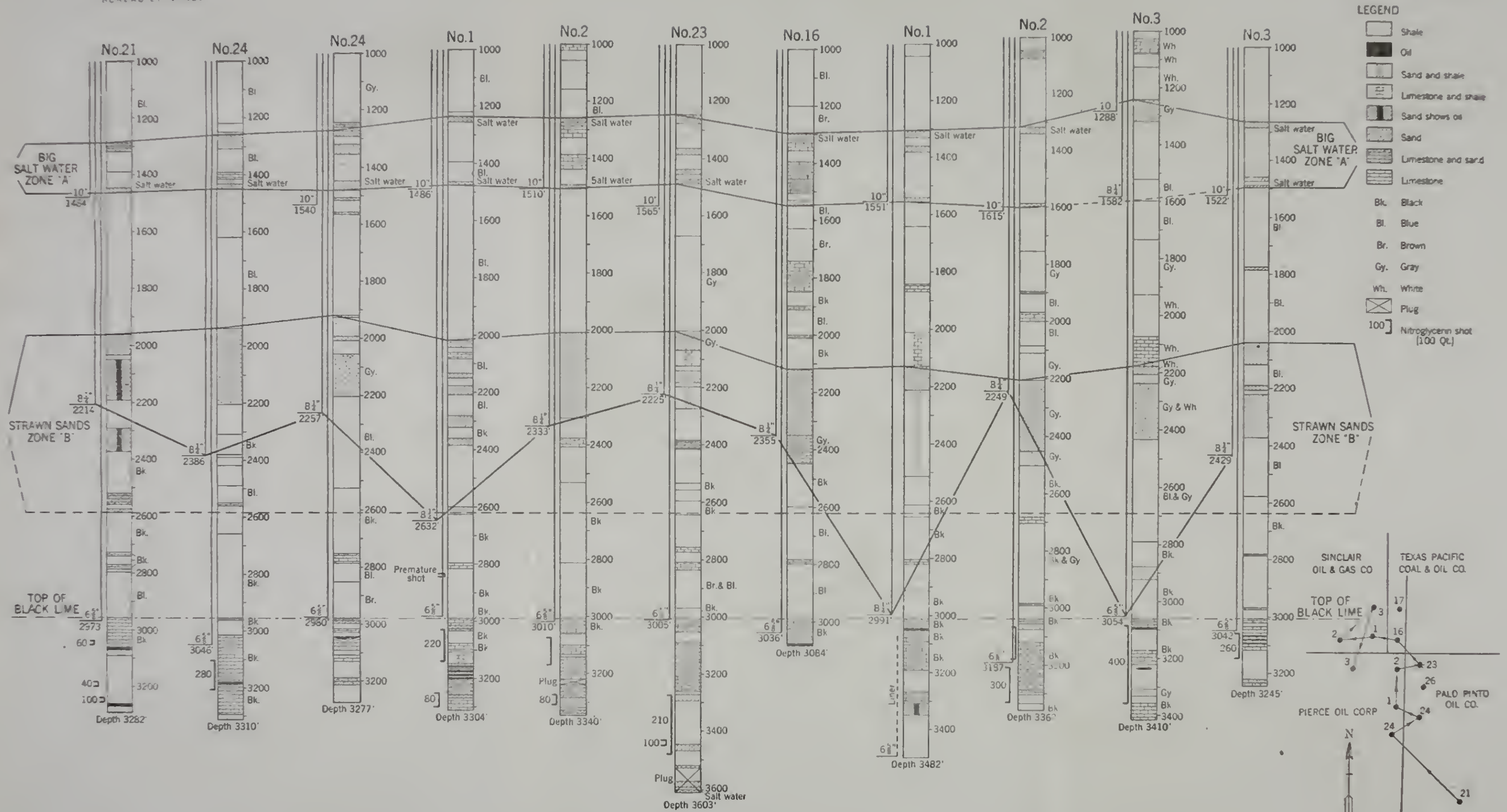
TABLE 27.—*Water strata logged in wells in Satterfield area, Ranger field, Texas.*[a]

Company.	Lease.	Well No.	Upper water.	"Big salt water," Zone A.
Sinclair Oil Co.	Satterfield	1	2 bailers an hour	1,305–1,330; 1,540–1,550; hole full of water.
	Do.	2		Water at 1,320–1,340.
Palo-Pinto Oil Co.	Swenson	21		1,454–1,484; hole full of salt water.
	Do.	23		1,440–1,460; 1,476–1,490; salt water.
	Do.	24		Hole full of salt water, 1,460–1,490.
Pierce Oil Corporation.	Thomas	1		Salt water, 1,230–1,240. Fluid level, 1,300 feet; water, 1,469–1,479 feet.
	Do.	2		Water, 1,263–1,273, 1,494–1,501.
	Do.	3		Water, 1,273–1,288; hole full of water.
	Do.	24	6 bailers an hour, 162–185.	Water sand, 1,435–1,452.
Texas Pacific Coal & Oil Co.	Satterfield	16	First water, 225. Second water, 765.	Third water, 1,300–1,320. Fourth water, 1,535–1,555.

[a] Water in Zone B reported to the writer by drillers, but not logged.

Water-bearing beds classed as upper water lie above 800 feet. This upper water is not shown in Plate V. The salt water of Zone A lies between these upper waters and the producing formations. The importance of identifying and logging these upper waters should not be discounted, but the present purpose is to show how to plan a drilling program that will give permanent protection from infiltrating waters.

The "Big salt water," Zone A, is more important than all other water-bearing strata because (1) it has a fluid level that fills drilling holes to the surface and is therefore potentially more dangerous should it flood the oil sands; (2) the water sands in this zone are stratigraphically continuous throughout the area; and (3) the flow is



DIAGRAMMATIC CROSS SECTION OF A GROUP OF WELLS NEAR RANGER, TEXAS

greater than from any other zone. In drilling wells the water of Zone A has been excluded with 10-inch casing.

Drillers have told the author that water is found in the formations of Zone B in almost every well. This water is not logged, but is considered to be near the top of the zone. Probably more water was being developed in Zone B in January, 1921, than when the first wells were drilled. The normal pressure of the water sands of Zone B had increased to an average hydrostatic head of 2,200 feet per square inch on account of water let into the sands by the removal of the casing that shut off Zone A. The quantity of water capable of doing damage to oil production is also increased.

In the general program for casing, the salt water of Zone A is excluded during drilling with a 10-inch casing, which is landed at a fairly uniform stratigraphic level. The depths of landing of 8¼-inch casing, however, are not uniform in or through Zone B, and, as already explained, on removal of the 10-inch casing the quantity and pressure of the water increased in Zone B. This lack of uniformity is shown by the heavy line, Plate V, that connects shoes of 8¼-inch or other casing shutting off water from Zone B. Probably in some wells the water moves directly down the hole to the shoe of the 6⅝-inch casing, which is solely an oil string and enters the oil sands through fractures from shots and through faulty casing seats.

Water also reached productive strata by cross infiltration through the sands of Zone B. Plate V shows that no two strings of 8¼-inch casing are landed at the same stratigraphic depth through Zone B. A string of casing landed at the bottom of Zone B, or lower, turns water into all of the sand strata of that zone, and this water can reach and enter any well at which the casing is landed at a stratigraphically shallower depth.

In view of the conditions outlined above, the following suggestions are made for a more uniform drilling program in this and similar areas:

A temporary water shut-off, below Zone A, should be made with 10-inch casing. Then, before 8¼-inch casing is landed the sands of Zone B should be thoroughly mudded, and the 8¼-inch casing carried to a depth not more than 350 feet above the top of the black lime, and cemented. Afterward the 10-inch casing and any larger strings can be removed. Such procedure will exclude and seal all sands of Zone B and prevent cross infiltration of water from Zone A, exposed to the sands by removal of 10-inch casing.

If mudding the sands of Zone B before cementing the 8¼-inch casing is not desirable, the 10-inch casing should be cemented in shale at least 20 feet below the lowest water sand of Zone A and left permanently in the hole.

The casing depth recommended for 8¼-inch casing is close to the line indicating the assumed lower limit of Zone B. There is a geologic unconformity between the sands of Zone A and Zone B (Strawn series) and the underlying Smithwick shales (Bend series). The 10-inch casing should be uniformly landed with respect to the water sands of Zone A, and the 8¼-inch casing should be landed with respect to the top of the black lime. The ultimate purpose of the 8¼-inch casing should be to protect the oil-bearing formations from infiltrating water; therefore the casing should be landed in stratigraphic uniformity with these formations.

The correction of conditions that now exist would necessitate tests and alterations, but a discussion of these is not within the scope of this paper.

A DRILLING PROGRAM FOR THE MONROE GAS FIELD.

The Monroe gas field is in Ouachita and Morehouse Parishes, La., its most southerly part lying about 7 miles northeast of the city of Monroe. Part of the field is west of the Ouachita River, but the wells are thickest in T. 19 N., R. 4 E., and T. 20 N., R. 4 E. The field is irregularly crossed with bayous and is dotted with low sandy hills, its average elevation above sea level being about 80 feet.

The geologic formations entered in drilling are mostly Eocene, unconsolidated beds of sand and gravel interbedded with clay which grade with depth into shale and thin layers of sandstone. Beds of lignite are recorded at depths between 200 and 300 feet. Fresh artesian water is found at depths usually less than 400 feet and has a closed pressure of about 40 pounds per square inch. Artesian salt water, logged at depths ranging from 450 to 1,100 feet, is an important consideration in any development and conservation program for the Monroe gas field.

Up to January, 1921, about 50 wells had been drilled for gas. The main gas "sands" which are in chalk rock, probably the Anona chalk of the Upper Cretaceous, are developed at depths ranging from 2,000 to 2,300 feet. The productive area in January, 1921, was roughly 170 square miles, and included the Huber well on the extreme southern end of the fields, the wells of the Federal and Texas companies on the western border, the discovery well on the eastern border, and the Morehouse well at the extreme northern end of the field. The air-line distance from the Huber well to the Morehouse well is about 21 miles.

Potentially this field is extremely large, probably the largest gas field in the United States. Well logs indicate the probability of two distinct reservoirs of gas. In 1921 most of the wells were producing gas from the upper sand, at about 2,100 feet. The wells showed an initial production varying, according to estimates, from 2,000,000 to

30,000,000 cubic feet of gas a day, and the initial rock pressure of the gas was as high as 1,050 pounds per square inch. In 1921 the consumption of gas from the Monroe field was estimated at 50,000,000 cubic feet daily, of which carbon-black manufacturers took a large proportion, the remainder being used for domestic and industrial purposes in the city of Monroe. The gas has shown by absorption tests a gasoline content as high as 125 gallons per million cubic feet, on the strength of which several absorption plants have been installed. The late reports from the field seem to indicate that the gasoline content is diminishing. A run[17] on 8,500,000 cubic feet recovered only 150 gallons of 72° B. gasoline.

An estimate of the probable volume of natural gas stored in these reservoirs would be aside from the purpose of this paper. The potentialities of the field are so great that the most practicable and economical means should be used in development . The operator's problem is to drill and complete his wells so that when a drill hole enters the high-pressure gas stratum the gas can be immediately put under control and utilized without waste above or below ground.

Gas wells in the Monroe field are drilled and finished into the gas sand with rotary tools. Unconsolidated formations probably prohibit the use of cable tools above the gas horizon even though these formations are not highly charged, as they are, with wasted gas. A string of 6-inch, 20-pound casing, is seated and supposedly cemented near the top of the gas sand, and when the well is drilled into the sand the gas is held under pressure in this casing. Tubing to reduce the internal pressure on the casing is not used.

Development in the Monroe gas field has become increasingly difficult because of underground waste, which occurs either when the producing string of casing is not gas tight, or when, having gained headway through casing leaks, a well blows wild in open hole around the casing and the gas moves in large quantities and under high pressure into all overlying strata of lower pressure until the hydrostatic head of the water in some exposed water stratum locally overcomes the rock pressure of the gas. Waste and damage do not end here, however, because water has gained access to the gas-bearing formations.

This waste of gas into overlying porous strata has made drilling much more difficult. A drilling contractor told the writer that the first well he drilled in the field gave him no trouble, and that he had to use very little mud in order to hold back loose formations, but in 1921 the upper water strata were charged with gas under considerable pressure, which caused blow-outs and made drilling through the upper sands difficult. When the Sandidge well, of the Ouachita Nat-

[17] May 15, 1920.

ural Gas Co., sec. 27, T. 21 N., R. E., Ouachita Parish, was being drilled between depths of 500 and 600 feet, large volumes of water and migratory gas blew over the top of the derrick and the hole had to be abandoned. The general supposition is that this hole went wild at this depth because gas had migrated into the upper sands from leaky casing in a neighboring well. Many wells have been improperly drilled and several wild wells have not been repaired. The quantity and extent of leakage of gas from the gas sands into the upper sands can not be estimated.

The so-called wild wells in the Monroe field offer the most visible evidence of waste fuel damage from improper development methods. Three of these wells are described, and the probable reasons for their going wild are given:

Smith No. 1 well, in sec. 27, T. 20 N., R. 4 E., started to blow wild in the latter part of January, 1920; its initial production was about 8,000,000 cubic feet. By February 3, 1920, a large crater had formed and the casing sloughed into the hole. When the writer visited the well on February 24, 1920, much gas and water was flowing from the well. (See Pl. VI.) The gas caused a continual turbulence in the water as it flowed from the crater into the bayou. The most probable explanation why Smith No. 1 went wild is either that leaking gas gradually made channels around the shoe of the 6-inch casing landed above the gas sand, or that upper artesian water sands, charged with gas, blew out back of the 10-inch casing. The well threw sand across the bayou when it first started to leak. After a crater had formed about the casing, bodies of sand shifted laterally and cut off the inside string of casing and the well went wild.

Perryville No. 2 well, in sec. 19, T. 20 N., R. 5 E., went wild in June, 1919. In February, 1920, it was still bubbling gas in a crater possibly 100 feet in diameter. This well went wild because the men drilled into the gas "pay" without first having landed and cemented casing, the gas being encountered sooner than expected. Drillers' estimates of the depth to gas were based on the depth in a well several thousand feet distant, which emphasizes the necessity of accurate calculations to probable depth of gas and depth to land and cement casing. In Perryville No. 2 the pressure and volume of gas was so strong that a large crater soon formed, undermining the derrick and causing abandonment of the hole.

Smith No. 3 well, in sec. 29, T. 20 N., R. 4 E., was being blown for an open-flow test on September 16, 1919, when it began to show a large quantity of sand and water, showing that it was in bad condition. An attempt was made to set a packer at the bottom of the gas string, on tubing, in the hope of cutting off leaks in defective casing. The tubing was accidentally dropped while being run into the hole and as it was not fished out the well went wild.

WILD WELL, MONROE GAS FIELD, LOUISIANA.

A review of the histories of these wild wells shows that not one of the incidents would have been necessary had the mechanical details of drilling and subsequent manipulation been carefully planned. The three wells illustrate the chief weaknesses in the drilling methods used in the Monroe gas field, and therefore serve as a basis for suggestions on improvement. Great care must be taken in drilling new wells in order to prevent further leakage of gas into the loose formations overlying the gas sands.

In Perryville No. 2 well the depth to the pay sand was, it is understood, about 40 feet shallower than was expected, the estimate of depth being based on the depth to gas in a well about one-half mile away. No allowance was made for the difference in surface elevation of the two wells, or for the possible dip of the gas stratum. A little preliminary engineering work would probably have prevented the loss of this well and the subsequent waste of gas. Accurate elevations and locations of all wells should be taken. Then well-log cross sections can be made that will show the dip of gas-bearing formations, and will enable close estimating of the depth to land the final string of casing in a new well, to be done before drilling into gas. Obviously the operator should have the assistance and advice of an engineer.

A good program for casing was adopted in February, 1920, in the field, as follows:

Land and cement a string of 10-inch casing to exclude surface waters.

Land and cement a string of 8-inch casing to exclude artesian waters entered at depths as low as 1,100 feet.

Land and cement a string of 6-inch casing as close to top of gas sand as practicable.

Use plenty of cement back of each string of casing.

The 8-inch casing is to be used to shut off the artesian salt-water sands that have become charged with gas. Hitherto these sands have been shut off by the 6-inch casing, which was landed and cemented just above the producing formations, but the efficiency of this procedure is questionable, as investigation will probably reveal that some jobs neither exclude descending waters nor ascending gas.

When the string of 8-inch casing is cemented, mud fluid pumped under pressure into the artesian water strata back of the 8-inch casing would give an added insurance against local disturbance of strata from the pressure of migrating gas. By setting a packing head or gas clamps on the 10 and 8 inch casings mud fluid can be pumped down through the 8-inch casing and back of it into the sands instead of through the surface outlet between the 10 and 8 inch casings.

An excess of cement is advisable, so that the first cement fluid that goes back of the casing will completely displace the mud near the shoe, thus permitting a good bond between cement and formation. Also, the jacket of cement formed around the casing will reenforce it against disruption by external or internal pressures.

As the 8-inch casing excluded the most troublesome water-bearing strata, a test for water shut-off should be made after it is cemented. The contractor will probably object to making such a test and he should be compensated for the loss of drilling time during the test. The 6-inch casing should be tested for water shut-off also. A successful test will be a double guarantee because it will prove that water can not enter the hole nor gas leave it. No such test can be made after the well is drilled into the gas horizon.

Should bailing show that water is not shut off, the operator will have the choice of several remedies. In this particular area probably the best procedure is to cement a string of 6-inch casing in the first suitable formation below the shoe of the 8-inch casing and to finish the hole with 4½-inch pipe. Normally, the well would be finished with 6-inch casing as gas pipe, but production of gas through 6-inch pipe is open to the following criticisms:

1. The so-called 6-inch casing is drill pipe used in drilling the well; the weight of that used in 1920 was 19.2 pounds a linear foot. In the continual use of drill pipe, screwing and unscrewing during drilling, threads are liable to become worn and the casing to develop collar leaks. An internal gas pressure of 1,000 pounds or more on the collars will increase these leaks. To overcome this wear of threads rotary tool joints for setting up stands of three joints of casing are recommended.

2. The casing, as it is run into the hole, is machine laid and may become cross threaded; it should be set and started by hand for three or four turns. The drillers can then tell whether it is cross threaded or not.

3. When casing is machine laid, the threads and couplings are not carefully inspected to make sure that they are free from sand and grit. A few grains of sand will mill off threads, especially those poorly greased. Careful attention should be given to lubrication of threads.

When 6-inch drill pipe is to be used as the gas string, testing each joint of casing by internal-water pressure is recommended before a string of casing is made up for the final run into the hole.

Deeper drilling below the present gas horizon in the Monroe gas field, either for other gas sands or for oil, should be discouraged for the present at least. Drilling into the present proved gas stratum must be done with care, and any deep prospecting for oil will undoubtedly be done at the sacrifice of the gas, as the prospector for oil is not usually interested in the conservation of gas, nor could he easily be required to adhere to the present casing program. As the overlying formations are unconsolidated, the rock pressure and volume of the gas would make drilling through the "pay sand" extremely hazardous. Deeper drilling, whether for gas or oil, will complicate problems already serious enough.

After rock pressures and volumes have declined, a deeper drilling for new reservoirs can be done, but if present reservoirs are properly drilled and protected, the operator need not worry about deeper supplies for some time to come. When deep drilling is attempted, cable tools are recommended for prospecting through and below present gas horizons and the mud-fluid method of shutting off gas as used in Oklahoma. As long as present reservoirs are productive they must be protected.

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