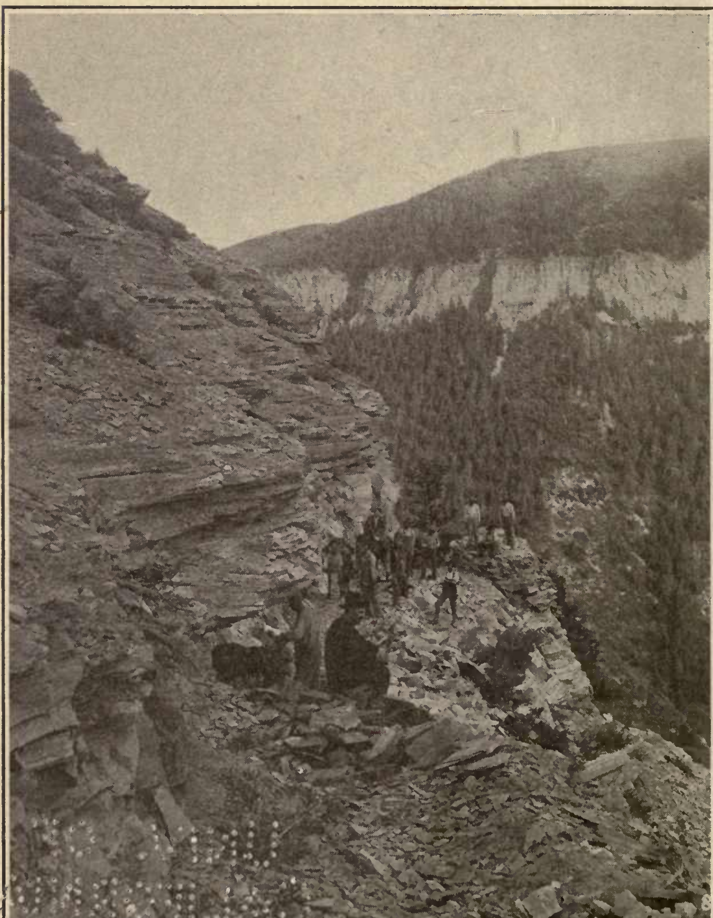
POPULAR OIL GEOLOGY

ZIEGLER

E. P. Mills



Prospecting Colorado Oil Shale.
(D. & R. G. R. R.)

POPULAR OIL GEOLOGY

BY

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TO MY UNCLE

LEONARD KIMM

THIS BOOK IS GRATEFULLY

DEDIDATED

PREFACE TO FIRST EDITION

The following pages represent an elaboration of a number of popular lectures in the geology of oil and gas. These were delivered during the past winter, in part at the Colorado School of Mines and in part in the City of Denver, under the auspices of the Colorado State Oil Commission. This little book is not intended to be a general treatise on the subject of oil and gas geology. It is not intended for the experienced oil geologist. It is written for the man without technical or scientific training in this branch of geology. Every attempt has been made to present in as simple language as possible the fundamental principles of oil geology, and to render these intelligible to the layman who may be interested in this subject from the practical standpoint, or for the sake of making investments, or perhaps only because of a desire to add to his general knowledge. Anyone who wishes to continue his studies in this subject is referred to the treatises mentioned below, or to the author's "Principles of Oil Geology", which is now in preparation, and to which this little book is really an introduction.

I have not hesitated to draw liberally on the literature of petroleum. Because of the nature of the book, and in the desire to keep it as free as possible from unnecessary material, I have purposely refrained from citations and acknowledgments in the text. I have used most freely the following works: Bacon and Hamor, "The American Petroleum Industry"; Johnson and Huntley, "Oil and Gas Production"; A. Beeby Thompson, "Oil Field Development"; Hager, "Practical Oil Geology"; and Cunningham Craig, "Oil Finding".

VICTOR ZIEGLER.

Colorado School of Mines.
February 15, 1918.

PREFACE TO SECOND EDITION

In preparing the new edition of this work, parts of the book have been rewritten, notably the chapter on oil shales, the migration of oil and gas, and on the anticlinal theory. Much new material has been added along the more theoretical lines of geology. The principles especially important in the examination of prospective oil land have been emphasized in the hope that the difficult character and nature of the work of the oil geologist may be properly appreciated.

More is required of the oil geologist than the ability to map a structure, and to recognize an anticline. He must have the broad vision and mentality to comprehend the geological features of the area investigated, the engineering problems and technical difficulties which must be faced in its development, and the probable influence of the general industrial and business situation on the problem in hand. The geologist, to be successful, must view these factors in their proper relationship, must recognize their interdependence, and must correctly evaluate their relative importance.

VICTOR ZIEGLER.

Denver, Colorado.
April 26, 1920.

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I. The Rise and Development of the Petroleum Industry

Present Status.

The rise and development of the petroleum industry is one of the interesting industrial romances of the present day. Starting with an insignificant beginning of two thousand barrels in 1859, the production of the United States has risen to a total of 360,000,000 barrels for 1919, a figure so large that it is difficult to form a conception of its magnitude. Collected in one spot the oil would form a lake six feet deep, covering an area of thirteen square miles. The value of the crude oil may be roughly estimated at $600,000,000. Large as this figure is, it does not correctly represent the magnitude of the petroleum industry. Thus, for the year 1919 the value of the refined products will greatly exceed $1,500,000,000, a value greater than the combined value of the production of gold, silver, copper, lead, and zinc, for the same period. This is in spite of the excessive high production of the last three products for war materials, and their corresponding high value.

The accompanying chart shows graphically the production of crude oil in the United States since 1859. While production has increased from 250 million barrels in 1913 to 360 million barrels in 1919, consumption has increased much more rapidly. It is estimated that consumption has doubled in the last four years, and now exceeds production by nearly 15 percent.

This excessive consumption causes serious concern, especially because our known oil fields are rapidly nearing exhaustion. Thus the United States Geological Survey gives the following estimates as of January 1, 1917, to show the percentage of exhaustion of the various oil fields:

Ohio, Indiana	93%
Appalachian	70%
Illinois	51%
Oklahoma, Kansas	25%
California	26%

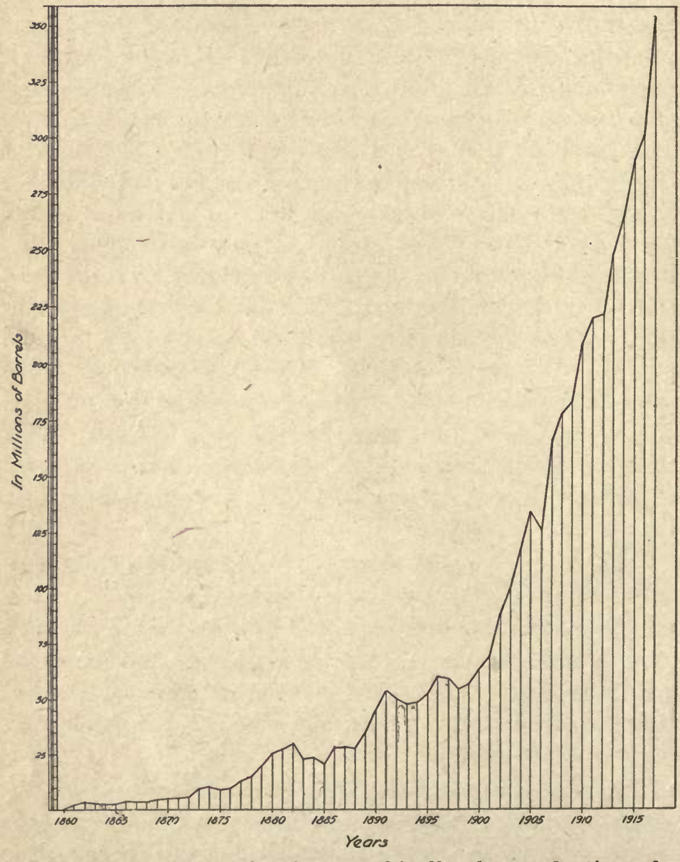


Figure 1. Chart showing graphically the production of Crude Oil in U. S. since 1859.

The total estimated production of the United States since 1859 is four billion barrels; the total available supply is seven billion six million barrels. At the present rate of consumption, this is sufficient for only about twenty years. As a result of this condition the value of crude oil is higher than it has ever been before, in consequence of which there has been intense interest in oil stocks, both for investment and for speculation. Hundreds

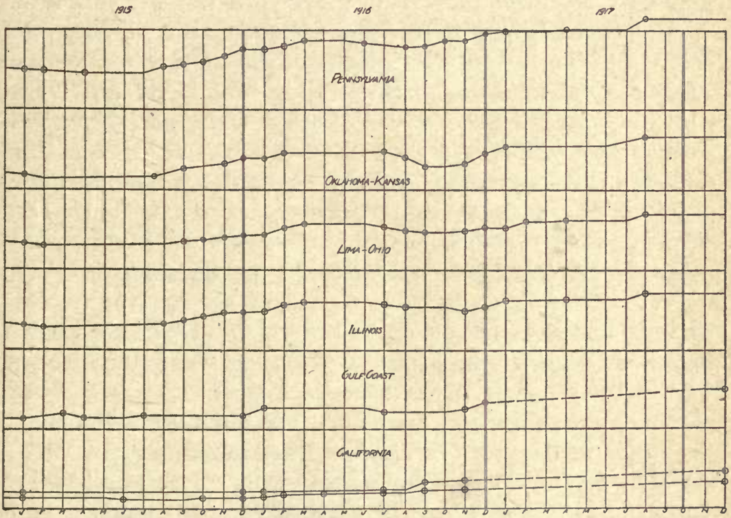


Figure 2. Chart showing fluctuations in the value of Crude Oil for the prominent American oil fields. Each horizontal division indicates three dollars.

of new oil companies have been organized, mostly for the purpose of exploiting or prospecting for new fields. Another result is the elimination of wasteful methods formerly characterizing the oil industry. Engineering and scientific methods are adopted, both in production and refining. Among all of these the most important is the general appeal of the oil man to the geologist.

The Application of Geology.

In the early days of the oil industry, drilling was carried on in an unsystematic manner, without any regard for geological features. The presence of salt water, of oil and gas seeps, which experience has often shown to be delusive, were considered indications favorable enough to warrant extensive drilling campaigns. As a matter of fact, there was a marked distrust shown toward the geologist. This was not surprising, because in general the geologist followed the oil man and did not precede him. It remained for an American geologist, I. C. White, in 1885, to give us the first clear outline of the application of geological methods to the finding of oil and gas fields and to the locating of wells. Indeed while geologists had been active before his day, they had not recognized the fact that geology could actually be used for this purpose. When White announced his discovery, it was received with derision by his own colleagues, who were only convinced when its practicability was actually demonstrated.

Practical men remained skeptical, and only the serious condition of the oil industry in the last few years, and a consequent employment of geologists in large numbers, with the results they have achieved, convinced them that geology is indeed far more important than the most enthusiastic thought. It has been estimated that, in 1913, only three geologists were employed in the Kansas-Oklahoma fields. Today, in the same field, two hundred and fifty are employed. As a result of their labor, the chance for success of wildcat, or prospect wells has been reduced from one in one hundred and fifty, to one in three. Virtually every large oil company of importance maintains a geological staff, the duties of which are to prospect for new favorable areas, to locate test wells, and to map out a drilling campaign insuring the most economical production and maximum yield from a given field.

The value of geological services are attested by the success of many new companies to such an extent, that it has become generally recognized that a disregard of geological conditions is virtually an assurance of failure.

Petroleum in Antiquity.

In the introductory remarks, the petroleum industry was said to be about fifty years old. Its extreme youth is very surprising, because oil and its products had been known for many centuries and were used long before the Christian era. Antiquarian explorations in Asia Minor and Egypt have proved that asphalt was generally used in place of mortar for building purposes. Herodotus mentions that the walls of Babylon and of Ninevah were so constructed. According to the Old Testament asphalt was also used in the walls of the Tower of Babel. The ancient civilization of the Incas in Peru, and of the Aztecs in Mexico employed asphalt for architectural purposes. The Old Testament also mentions the fact that the Ark of Noah and the woven basket of Moses were made waterproof by an application of oil. Among the Egyptians, oil was used in embalming. Indeed, the word "mummy" is said to be derived from the term "mumiya", the Persian for asphalt. Records show that since time immemorable, oil has been used for lighting in the cities of the Red Sea, as, for example, Ras Gemsah and Gebel Zeit. The medicinal value of oil was recognized by the Indians long before white men set foot on America. Marco Polo, writing in the thirteenth century, relates that the Russians of the Baku region, on the Caspian Sea, drank oil, both as a cordial and as a medicine. As a matter of fact, modern investigations prove that the Persians sought the oils of Baku centuries before the Russians occupied the Caucusus. In view of these many uses, it is perhaps natural that oil and gas should become objects of worship. Most famous were the "Eternal Fires of Surakhani", on the Aspheron peninsula in the Caspian Sea. Here were the sites of sacred shrines and temples, to which the Parsees, or fire-worshipers, conducted pilgrimages, recorded as far back as 600 B. C. A modern Hindu temple, about two hundred years old, marks the site of the ancient shrines. The "Eternal Fires" are really gas seeps which, once ignited, will continue to burn.

Rise of the Modern Petroleum Industry.

The first elementary and crude attempts at the production of oil on a large scale were made by Peter the Great, in 1723. He, at that time, granted a private monopoly for oil production in the Baku region, which, it is interesting to note, continued in force to 1872.

The real pioneer in oil production, however, was the United States. The first record of oil in America dates back to 1627, when the Franciscan friar, Joseph de la Roche d'Allion, described in a letter the oil springs of Allegheny County, New York, which were highly prized by the Indians. Oil received only passing attention in the early part of the nineteenth century. There was, however, great interest in salt and natural brines, which led to the devising of methods for drilling wells. The first drilled well in the United States was sent down in 1806, on the bank of the Kanawha River, in Virginia. This well was eighty feet deep and produced, in addition to salt water, about twenty barrels of crude oil a day. In 1820 drilling methods were so perfected that it was possible to drill wells one thousand feet deep. The general demand for salt and brines resulted in the drilling of a great number of wells along the Kanawha. A great number of these produced oil, which was considered obnoxious and was permitted to flow into the river. From this practice originated the name of "Old Greasy", by which the Kanawha River was known for many years. During this period a small trade was established which exploited the use of oil for medicinal purposes. It was generally advertised as a cure-all, guaranteed to alleviate and cure all the ills of the human body. Especially famous were the so-called "Seneka Oils", and Krier's Petroleum Rock Oil. Krier was a druggist in Pittsburgh who had an excess production of crude oil beyond that needed for medicinal purposes. He therefore erected a homemade still and refined oil, selling the light products for illuminating purposes. During this period natural oil had to meet the competition of the coal-oil industry, which was based on the distillation of illuminating oils from coals. Indeed the common term "coal-oil", for kerosene, is a survival of this industry. In the early part of the nineteenth century it was thought that the supply of crude oil was apparently insufficient and was too spasmodic in its occurrence to insure extensive commercial use. A few people, however, had faith in the possibilities of the natural oil and, in 1854, organized the first oil company of America, "The Pennsylvania Rock Oil Co." Like many of its successors, this company became involved in financial difficulties and was reorganized in 1858 as the "Seneca Oil Co." This company secured Col. E. L. Drake as superintendent of field operations, who drilled the first well in 1859, at Titusville, Pennsylvania. At a depth of fifty-eight feet a flow of oil of twenty-five barrels a day was encountered. Drake's well marks an epoch in the history of petroleum because it was the first well drilled for the purpose of securing oil. The well demonstrated the feasibility of drilling for oil. It therefore insured the rapid development of the petroleum industry and at the same time paralyzed the coal-oil industry, then at its climax.

Vigorous drilling followed all along the Allegheny River, spreading eventually into Ohio, West Virginia, Indiana, and New York, and resulting in the development of the Appalachian oil fields, for many years the leading producer in America.

The chief competitor of the Appalachian field was the Baku region on the Caspian Sea. Here the first well was drilled in 1889 and proved such a heavy producer that the news, which exceeded the most sanguine expectations, was regarded with suspicion for many years.

The development of oil fields proceeded slowly because the progress everywhere was hindered by lack of transportation facilities. Thus both in the American and Russian fields the oil was hauled in carts to the railroad stations. The first pipe line of importance was laid in 1875 from the oil country to Pittsburgh. Russia quickly adopted this convenient method of transportation. As may be imagined, the carters vigorously opposed pipe lines and went to such extremes in attempting to prevent their construction that for several years strong guards were maintained. The construction of pipe lines, however, did not solve the transportation problem. Containers suitable for water and rail transportation were still lacking. It was customary to ship the oil in wooden barrels, the cost of which ordinarily exceeded the value of the oil. It remained for a Russian firm, Nobel Brothers, in 1879, to construct the first tank steamer. Thus the great transportation problems were solved; America produced the pipe lines, Russia the tank.

For years, Russia and America were neck and neck in petroleum production. Russia, however, furnished most of the sensations up to 1902. Individual wells of tremendously large capacity were quite common. The Droojba was a gusher, spouting oil three hundred feet high, with a capacity of fifty thousand barrels a day. It was uncontrollable for four months. The Markoff gusher spouted oil to a height of four hundred feet, at a rate of about a hundred thousand barrels a day. Gushers, such as these were responsible for the fact that in 1901 Russia produced more than one-half the world's output of petroleum from an area of only ten square miles.

Remarkable discoveries in Texas and California enabled America to take the lead in 1903, since which time, aided by the tremendous production of the Oklahoma, Kansas and California fields, this lead has been gradually increasing, until today two-thirds of the world's production of petroleum comes from the United States.

Mexico is the third largest producer of petroleum. Its rapid development, so surprising because of unsettled political conditions, is due to the fact that Mexico has produced the greatest gushers known. Thus the famous gusher of Dos Bocas, in 1908, was estimated to have a capacity of two hundred and fifty thousand barrels a day. The accompanying tables show the comparative production of crude oil of the various states in the Union, as well as the production of the more important oil fields of the world, as nearly as can be ascertained under present conditions.

World's Production of Crude Petroleum, 1916.

United States	292,300,000	barrels	
Russia	72,360,000	barrels	(1915)
Mexico	32,910,000	barrels	.....
Roumania	13,230,000	barrels	(1915)
Dutch East Indies	12,386,000	barrels	(1915)
Galicia	4,158,000	barrels	(1915)
India	6,833,000	barrels	(1915)
Japan	3,431,000	barrels	.....
Peru, Etc	2,487,000	barrels	.....
Grand total	429,119,000	barrels, 1915.	

Production of Crude Oil in the United States, 1916-1917.

	1916	1917
Oklahoma	106,000,000 barrels	147,000,000 barrels
California	91,800,000 barrels	97,000,000 barrels
Gulf Coast	23,900,000 barrels	24,900,000 barrels
Appalachian	20,700,000 barrels	24,600,000 barrels
Illinois	16,300,000 barrels	15,900,000 barrels
Kansas	13,000,000 barrels	Included in Okla.
Louisiana	11,800,000 barrels	8,700,000 barrels
North Texas	8,800,000 barrels	....
Wyoming	6,700,000 barrels	9,200,000 barrels
Lima—Indiana	2,600,000 barrels	3,500,000 barrels

Crude Oil Prices—December, 1919.

(The Oil & Gas Journal)

Pennsylvania	$4.50	North Texas	$2.50
Lima (Ohio)	2.73	Caddo (La.)	2.50
Illinois	2.77	Canada	3.13
Kansas-Oklahoma	2.50	California	1.23-1.62
Healdton (Okla.)	1.35	Mex. Crude	1.05-1.10
Indiana	2.63	Homer (La.)	2.50

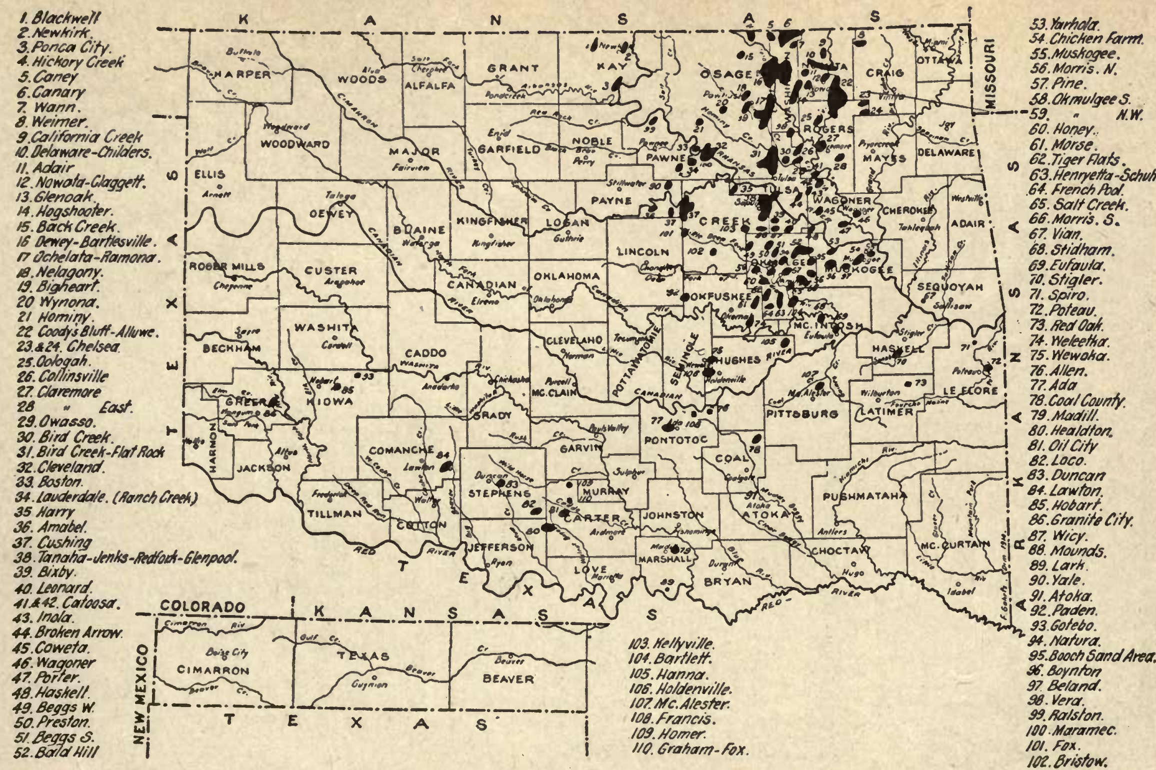


Figure 3. Map of Oklahoma showing location and names of oil and gas areas. (Okla. Geol. Sur.)

II. Composition and Properties of Oil and Gas

Elementary Principles of Chemistry.

Before discussing the composition of the various kinds of oil and gas found in Nature, it is necessary to take up very briefly a few of the fundamental ideas of chemistry.

Elements.

Chemists tell us that there are about eighty elements in Nature. By "elements" they mean those substances that cannot be subdivided by any known process. Familiar examples are iron, copper, and sulphur. It is customary to represent each element by a symbol; ordinarily the initial letter of the word standing for the element is taken. Thus, the element carbon, which is the chief constituent of coals and of oils, is represented by the letter "C". The other elements of importance in this connection have symbols as follows:

Oxygen	O
Nitrogen	N
Hydrogen	H
Sulphur	S

Compounds.

Most of the elements occur in Nature in combinations, which have characteristic properties quite different from those of the component elements, and which always contain the same proportion of each element by weight. Such combinations are known as "compounds." For example, the mineral making up limestone is a compound always carrying 40% of calcium, 12% of carbon and 48% of oxygen.

Table of Elements.

(After Frazer and Brown.)

Name	Symbol	Atomic Weight	State	Discoverer	Date
Aluminum.....	Al	27.1	Solid	Woehler	1827
Antimony.....	Sb	120.2	"	Valentine	1460
Argon.........	A	39.9	Gas	Rayleigh and Ramsay	1895
Arsenic.......	As	75.0	Solid	Schroeder	1694
Barium.......	Ba	137.37	"	Davy	1808
Bismuth	Bi	208.0	"	Agricola	1529
Boron.........	B	11.0	"	Davy	1807
Bromine......	Br	79.92	Liquid	Balard	1826
Cadmium.....	Cd	112.40	Solid	Stromeyer	1817
Caesium......	Cs	132.81	"	Bunsen	1860
Calcium.......	Ca	40.09	"	Davy	1808
Carbon........	C	12.00	"	Ancients	....
Cerium........	Ce	140.25	"	Berz. & Hisinger	1803
Chlorine......	Cl	35.46	Gas	Scheele	1774
Chromium....	Cr	52.1	Solid	Vauquelin	1797
Cobalt........	Co	58.97	"	Brandt	1733
Columbium....	Cb	93.5	"	Hatchett	1803
Copper........	Cu	63.57	"	Ancients	....
Dysprosium...	Dy	162.5	"	....	....
Erbium.......	Er	167.4	"	Mosander	1843
Europium.....	Eu	152.0	"	....	....
Fluorine......	F	19.0	Gas	Moissan	1886
Gadolinium....	Gd	157.3	Solid	....	....
Gallium.......	Ga	69.9	"	de Boisbaudran..	1875
Germanium...	Ge	72.5	"	Winkler	1886
Glucinum.....	Gl	9.1	"	Woehler	1828
Gold..........	Au	197.2	"	Ancients	....
Helium.......	He	4.0	Gas	Ramsay	1895
Hydrogen.....	H	1.008	"	Cavendish	1766
Indium........	In	114.8	Solid	Reich & Richter.	1863
Iodine.........	I	126.92	"	Courtois	1812
Iridium.......	Ir	193.1	"	Tennant	1804
Iron..........	Fe	55.85	"	Ancients	....
Krypton.......	Kr	81.8	Gas	Ramsay	1895
Lanthanum....	La	139.0	Solid	Mosander	1839
Lead..........	Pb	207.10	"	Ancients	....
Lithium.......	Li	7.00	"	Davy	1818
Lutecium.....	Lu	174.0	Solid	....	....
Magnesium....	Mg	24.32	"	Davy	1808
Manganese....	Mn	54.93	"	Gahn	1774
Mercury......	Hg	200.0	Liquid	Ancients	....

Table of Elements—Cont.

(After Fraser and Brown.)

Name	Symbol	Atomic Weight	State	Discoverer	Date
Molybdenum..	Mo	96.0	Solid	Hjelm	1782
Neodymium...	Nd	144.3	"	....	....
Neon..........	Ne	20.0	Gas	Ramsay	1895
Nickel.........	Ni	58.68	Solid	Cronstedt	1751
Nitrogen......	N	14.01	Gas	Rutherford	1772
Osmium.......	Os	190.9	Solid	Tennant	1803
Oxygen........	O	16.00	Gas	Priestley	1774
Palladium.....	Pd	106.7	Solid	Wollaston	1803
Phosphorus...	P	31.0	"	Brandt	1669
Platinum......	Pt	195.0	"	Wood	1741
Potassium.....	K	39.10	"	Davy	1807
Praseodymium	Pr	140.6	"	....	....
Radium.......	Ra	226.4	"	Curie	1903
Rhodium......	Rh	102.9	"	Wollaston	1803
Rhubidium....	Rb	85.45	"	Bunsen	1860
Ruthenium....	Ru	101.7	"	Claus	1845
Samarium.....	Sa	150.4	"	de Boisbaudran..	1888
Scandium.....	Sc	44.1	"	Nilson	1879
Selenium......	Se	79.2	"	Berzelius	1817
Silicon........	Si	28.3	"	Berzelius	1823
Silver.........	Ag	107.88	"	Ancients	....
Sodium........	Na	23.00	"	Davy	1807
Strontium.....	Sr	87.62	"	Davy	1808
Sulphur.......	S	32.07	"	Ancients	....
Tantalum.....	Ta	181.0	"	Ekeberg	1802
Tellurium.....	Te	127.5	"	Klaproth	1798
Terbium......	Tb	159.2	"	Mosander	1843
Thallium......	Tl	204.0	"	Crookes	1861
Thorium......	Th	232.42	"	Berzelius	1829
Thulium......	Tm	168.5	"	Cleve	1879
Tin...........	Sn	119.0	"	Ancients	....
Titanium......	Ti	48.1	"	Klaproth	1794
Tungsten......	W	184.0	"	De Luyart	1786
Uranium......	U	238.5	"	Péligot	1841
Vanadium.....	V	51.2	"	Sefstroem	1830
Xenon........	Xe	128.0	Gas	Ramsay	1895
Ytterbium..... (Neoytterbium)	Yb	172.0	Solid	Marignac	1872
Yttrium.......	Y	89.0	"	Woehler (?)....	1843
Zinc..........	Zn	65.7	"	Mentioned by Paracelsus	1540
Zirconium.....	Zr	90.6	"	Berzelius	1824

Atoms and Molecules.

The extremely minute particles of elements which serve as units of combination are known as atoms. It has been found that all elements combine in a definite proportion by weight. This is known as "atomic weight". All atoms are arranged in groups, known as molecules. These may be conceived of as being the smallest particle of any substance that may occur independently and still have the properties of that substance. It is also customary to express the composition of compounds by symbols. Thus, limestone is expressed by the symbol $CaCO_3$, which means that one molecule, that is, the smallest part of limestone that can exist, is made up of one atom of calcium, one atom of carbon, and three atoms of oxygen.

Both atoms and molecules are extremely small in size and probably will never be visible, no matter how powerful microscopes may become. Thus, one cubic inch of nitrogen gas is estimated to contain 110 billion billion atoms. It would require 76 million of these to make a row one inch long. Nevertheless, there are enough atoms in a single cubic inch, if placed end to end, to make a row 90 million miles long.

Natural Hydrocarbons.

Oil and gas are essentially compounds of carbon and hydrogen, or to speak more correctly, mixtures of such compounds. There are a great many possible combinations of the two elements, carbon and hydrogen, eighteen of which have been found and are known as hydrocarbon series. One of the most important of these carries carbon and hydrogen in the ratio of twice as many plus two, hydrogen atoms as carbon atoms. Thus the compositions may be expressed by the symbol C_nH_{2n+2}. This series is known as the methane or paraffin series. As will be evident the molecules may carry a few or very many atoms. The less atoms in the molecule, the more volatile the substance is. Thus CH_4 is a gas, known as methane, or marsh gas. $C_{20}H_{42}$ is a solid, known as paraffin.

Another series carries carbon and hydrogen in the ratio of two hydrogens to one carbon. Here also the number of atoms may vary, and we have compounds ranging from C_2H_4 to $C_{30}H_{60}$. Two series have this composition, one known as the olefine series, which is unstable, i. e., decomposes readily. The other series is known as the naphthene series. The paraffin and naphthene series are the most important constituents of oil and of gas. In addition members of the following series have been found, but all are of very minor importance:

The acetylene series........C_nH_{2n-2}
The aromatic hydrocarbons—
 The benzene series....C_nH_{2n-6}
 The naphthalene series...C_nH_{2n-12}
 The anthracene series....C_nH_{2n-18}

Composition of Gas.

All gas occurring in Nature may be classified as follows: First, mineral gas; second, swamp gas; and third, natural gas. Mineral gases are of inorganic origin. That is, they are not produced from or by living organisms nor from their dead remains. For example, the gas escaping from volcanic craters, such as the poisonous hot gases which rolled down Mt. Pelee and destroyed the city of St. Vincent on Martinique in 1902, as well as the gases escaping from some of the geysers of the Yellowstone Park, are inorganic.

Swamp gas is formed at the present time by the decay of vegetable matter under water. It is commonly found in marshes, swamps, and old wells. Swamp gas is essentially CH_4, which is hence known by the name "marsh gas." Occasionally marsh gas occurs in such quantities that after stirring up the bottom of the swamp vigorously, its surface may be ignited. The heat so generated is frequently sufficient to drive off the water. In this way shallow swamps in the northern part of Germany are frequently reclaimed for agricultural purposes.

Natural Gas.

Neither mineral gas nor swamp gas are of any commercial importance. All commercially valuable gases which may be used as fuel or a source of light are customarily included under the term "natural gas."

We distinguish two kinds of natural gas, known as "wet" gas and "dry" gas. Dry gas is essentially CH_4, and is ordinarily derived from decomposing coal beds, very rarely from oil pools. Wet gas is nearly always associated with oil pools. Some of the heavier hydrocarbons, such as gasoline, frequently drip from this gas. Hence the term "wet". Since this gas also has a tendency to collect in the top of well casings, it is known as casing head gas. Wet gas of this kind offers a possibility of condensing gasoline from it on a commercial scale. Plants of this nature are in active operation in a number of eastern states and in California.

In composition natural gas is essentially CH_4. Wet gas carries in addition C_2H_4, and C_2H_6. Gasoline is ordinarily present in quantities of a few pints per thousand cubic feet. Occasionally nitrogen is very high. Certain natural gases in Russia run up to 50% nitrogen, while some in Kansas exceed 80%. Practically every oil field carries gas. There are, however, many gas fields in which oil does not occur in commercial quantities. The pressure on gas is often enormous and so great as to completely wreck the drilling machinery and derricks if the gas is struck unexpectedly. Pressures of from 1,000 to 1,500 lbs. a square inch have been recorded from New York. A number of wells located in the Big Horn Basin of Wyoming have an estimated capacity of more than 100,000,000 cubic feet a day.

The following table gives the composition of natural gas from a few of the prominent fields of the United States:

Table of Analyses of Natural Gas.

	CH_4	C_2H_6	C_2H_4	CO_2	CO	O	N	H	He	H_2S
Iola, Kan.	94.00	0	0	0	0	0.23	5.08	0	0.2	..
Dexter, Kan.	14.85	0.41	0	0	0	0.20	82.70	tr	1.84	..
Pittsburgh, Pa.	98.90		0	0.40	..	..	0.70	..	..	..
Oil City, Pa.	95.44		..	0.05	..	tr	4.51	..	..	..
Shimston, W. Va.	15.09	80.0	0.4	0	0.4	0.2	3.96	..	..	..
Ohio—										
Findlay	92.61		0.3	0.26	0.50	0.34	3.96	2.18	..	0.2
Fostoria	92.84		0.20	0.20	0.55	0.35	3.82	1.89	..	0.15
Oklahoma—										
Blackwell	83.40	10.31	0.61	..	..	..	5.19	0.33	0.16	..
Indiana—										
Kokomo	93.6		..	0.4	..	..	6.0	..	..	..
California—										
Los Angeles	83.70	0.2	6.68	0.25	0.25	2.86	6.31	..	..	..
Greybull, Wyo.	81.70	17.3	..	0.20	..	0	0.75	..	..	..
Byron, Wyo.	64.05	33.28	..	0.47	..	0	3.20	..	..	..

Composition of Petroleum.

The geologist includes all natural oils under the term petroleum. Petroleum is essentially a mixture of the hydrocarbon compounds of the C_nH_{2n+2} (paraffin series), and of the series C_nH_{2n} (olefine and naphthene series). Oils carrying essentially the first series are known as paraffin base oils. Those carrying the second series are known as asphalt base oils. The oils of Wyoming and Pennsylvania are paraffin base; those of Texas and California are asphalt base. Those of Illinois carry equal proportions of both and therefore are known as mixed base oils. Although oils are essentially compounds of carbon and hydrogen; sulphur, nitrogen and oxygen are also present, as well as other impurities of minor importance. In percentage composition, petroleum shows the following extreme ranges:

Carbon, 79% to 88%
Hydrogen, 9.6% to 14.8%
Nitrogen, 0.02% to 1.1%
Sulphur, Trace to 4%

Sulphur may be present as free sulphur, or it may be present as a sulphide. In the latter case it imparts to the oil a very disagreeable odor, that of decomposing eggs, which is characteristic of the oils of Ohio and Texas. Nitrogen is present in the form of complex organic compounds. These are frequently edible, consequently such oils, as for example certain oils of California, when exposed to the air, become quickly infested with maggots.

Analyses of Petroleums.

	C	H	S	N
Findlay, Ohio	83.41	13.13	0.56	0.06
Oil City, Pa.	85.80	14.04	...	...
Baku, Russia	86.25	13.48	...	...
Beaumont, Texas	85.05	12.30	1.75	...
Ventura, Calif.	84.00	12.70	0.40	1.70
McKittrick, Calif.	86.06	11.45	0.87	...
Alsace, Germany	79.50	13.6	6.90	(Oxygen S N)
Rangoon, Burma	83.80	12.70	3.35	"
Java (DanDang-Ho)	87.10	12.0	0.9	"
Burning Springs, W. Va.	84.3	14.1	1.6	"
Amaze, Japan	84.66	13.22	0.22	0.36

Specific Gravity.

The weight of crude oils is dependent to a considerable extent on the chemical composition. Paraffin base oils are ordinarily the lighter. Consequently the expressions "light" oil and "heavy" oil have been used as synonymous with paraffin base and asphalt base oils, respectively. The relative weight of oil as compared with the weight of an equal volume of water is known as specific gravity. Considering the specific gravity of water to be one, oil lies between the limits of 0.73 and 1.0. It is more customary to express the weight of oil in terms of degree of the so-called Beaumé scale. This is usually read direct on a hydrometer immersed in the oil. The degree of Beaumé goes up as the weight goes down, therefore a light paraffin base oil has a high degree Beaumé, or is said to be a high gravity oil. A heavy asphalt base oil has a low degree Beaumé, and is said to be a low gravity oil. The appended table shows the relation existing between the degree Beaumé, the specific gravity, and the

B°	Sp. Gr.	Weight per Gallon	Weight per Barrel	Weight per Cu. Ft	B°	Sp. Gr.	Weight per Gallon	Weight per Barrel	Weight per Cu. Ft.
10	1.0000	8.328	349.79	62.301	45	.8000	6.663	279.83	49.841
11	.9929	8 269	347.31	61.859	46	.7955	6.623	278.26	49.560
12	.9859	8.211	344.86	61.422	47	.7910	6.588	276.68	49.280
13	.9790	8.153	342.45	60.993	48	.7865	6.550	275 11	48.999
14	9722	8 097	340.07	60.569	49	.7821	6.514	273.57	48.726
15	9655	8.041	337 72	60 152	50	.7778	6.478	272 07	48.458
16	.9589	7.986	335.42	59 740	51	.7735	6.442	270.56	48.189
17	.9524	7.932	333 14	59.335	52	.7692	6.406	269.06	47.922
18	.9459	7.878	330.87	58.931	53	.7650	6.371	267.59	47.660
19	9396	7.825	328.67	58.538	54	.7609	6.337	266 16	47.405
20	.9333	7.773	326.46	58.145	55	.7568	6.303	264.72	47.149
21	9272	7.722	324.35	57.765	56	.7527	6.269	263.29	46.894
22	9211	7.671	322.19	57.385	57	.7487	6.235	261.89	46.644
23	.9150	7.620	320.06	57.005	58	.7447	6.202	260.49	46.395
24	.9091	7.571	317.99	56.637	59	.7407	6 169	259.09	46.146
25	9032	7 522	315.93	56.270	60	.7368	6.136	257.73	45.903
26	.8974	7 474	313.90	55.909	61	.7330	6.105	256.40	45.667
27	.8917	7 426	311.91	55.554	62	.7292	6.073	255.07	45.429
28	.8861	7 379	309.95	55.205	63	.7254	6.041	253.74	45.193
29	.8805	7 339	307.99	54.856	64	.7216	6.009	252.41	44.956
30	.8750	7.287	306.07	54.513	65	.7179	5.979	251.12	44.726
31	.8696	7.242	304 18	54.177	66	.7143	5 949	249.86	44.502
32	.8642	7.197	302.29	53.840	67	.7107	5.919	248.59	44.277
33	.8589	7 153	300.44	53.510	68	.7071	5.889	247.34	44.053
34	.8537	7.110	298.62	53.186	69	.7035	5.859	246.08	43.829
35	.8485	7.066	296.80	52.862	70	.7000	5.829	244.85	43.611
36	.8434	7 024	295.02	52.545	71	.6965	5.801	243.63	43.393
37	.8383	6 982	293.23	52.227	72	.6931	5.772	242.44	43.181
38	.8333	6.940	291.48	51.915	73	.6897	5.744	241.25	42.969
39	.8284	6 899	289.77	51.610	74	.6863	5.716	240.06	42.757
40	.8235	6.858	288.05	51.305	75	.6829	5.687	238.87	42.545
41	.8187	6.818	286.38	51.006	76	.6796	5.660	237.72	42.339
42	.8140	6.779	284.73	50.713	77	.6763	5.632	236.36	42.134
43	.8092	6 739	283 05	50.414	78	.6731	5.606	235.45	41.935
44	.8046	6.701	281.44	50.127	79	.6699	5.579	234.33	41.735

Figure 4. Table showing the relation existing between specific gravity and weight of oil.

(Payne & Stroud)

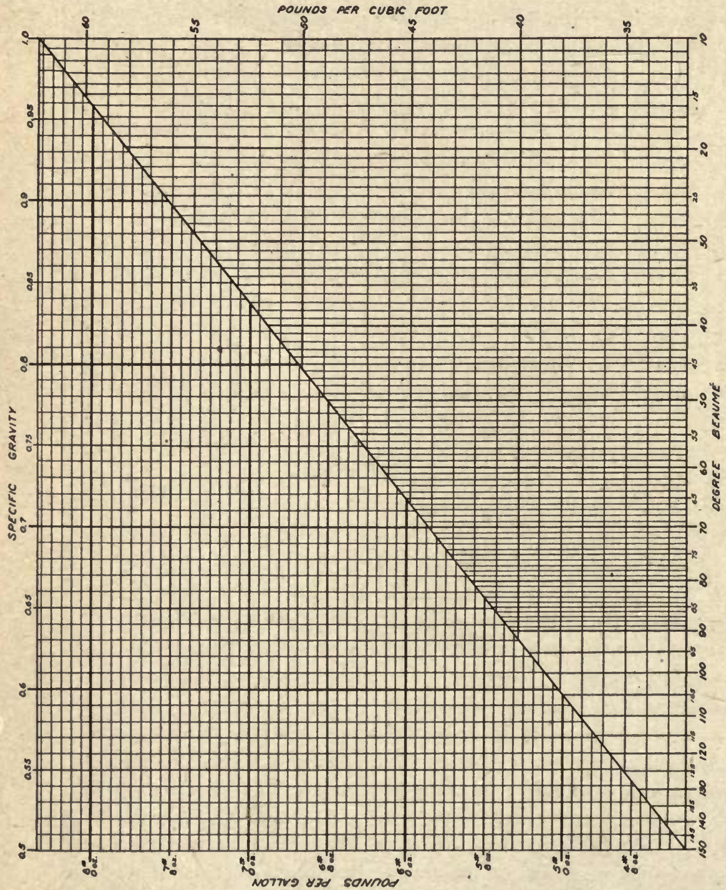


Figure 5. Diagram which shows graphically the relation existing between specific gravity, Degree Bé, and weight of Crude Oil. The diagonal line is the reference line.

weight of crude oil. The second table shows the specific gravity of a few typical oils.

Specific Gravity of Typical Oils.

	Sp. Gr.	Bé.
Pennsylvania	0.801 — 0.817	46.2 — 42.6
Ohio	0.816 — 0.860	42.8 — 32.5
Kansas	0.835 — 1.000	38.8 — 10.0
Colorado—		
Boulder	0.814	42.0
Debeque	0.809	43.0
Shale Oil	0.9138	23.0
West Virginia	0.841 — 0.873	37.6 — 30.0
California	0.920 — 0.873	30.0 — 12.3
Dutch East Indies	0.765 — 0.791	53.0 — 47.0
Peru	0.815 — 0.945	38.0
Roumania	0.736 — 0.8894	27.0 — 60.0
Mexico	0.809 — 1.000	43.0 — 10.0
Wyoming—		
Greybull	0.786	48.2
Grass Creek	0.8187	41.0
Grass Creek	0.7984	45.3
Byron	0.8174	42.0
Cody	0.8454	35.6
Salt Creek	0.8221	40.3
Salt Creek	0.8255	39.6
Shannon	0.910	24.0
Lander	0.9198	22.2
Lander	0.9126	23.4
Lander	0.9091	24.0
Plunkett	0.8121	42.4
Pilot Butte	0.875	30.0

Distillation Tests.

The percentage of the various products yielded on refining is most frequently used as a basis for comparing the different oils. Refining is simply a distillation process in which the oil is heated in retorts at various temperatures and the volatile material driven off and condensed. The very volatile matter is given off at low temperatures, the less volatile at increasingly higher temperature. The final residue is known as the base. This may be commercially valuable paraffin, as in the case of light oils, or an oxidized residue, which we call asphalt. A distillation analysis shows ordinarily four or five products.

First, the volatile oils, which include gasoline, naphtha, and benzene; second, the illuminating oils, or kerosene; third, the lubricating oils; fourth, fuel oils, which are of chief importance in the asphalt base oils; and last, paraffin, if present in commercial quantities. The following table gives the result of distillation tests on a few typical American oils:

	1	2	3	4	5	6
Volatile Oils	12.0	11.5	3.5	11.0	3.0	6.0
Illuminating Oils	67.0	43.0	39.0	41.0	15.0	18.0
Lubricating Oils	12.5	15.0	...	...	6.0	1.5
Fuel Oils	4.0	25.0	56.0	45.0	73.0	72.0
Paraffins	2.0	2.0	...	...	...	...

1. Appalachian
2. Lima, Ohio
3. Illinois
4. Oklahoma
5. Texas—Louisiana
6. California

Distillation Tests of Wyoming and Colorado Oils.

Locality—	Volatile Oils	Illuminating Oils	Residue	Paraffin	Gravity Be
Greybull, Wyo.	31.0	32.5	36.5	...	48.2
Basin, Wyo.	...	22.5	77.5	...	27.5
Basin, Wyo.	26.0	34.5	39.5	...	39.5
Basin, Wyo.	30.5	38.0	31.5	...	45.6
Grass Creek, Wyo.	22.0	42.0	36.0	...	41.0
Grass Creek, Wyo.	35.0	32.0	33.0	...	45.3
Cody, Wyo.	...	37.0	59.6	...	35.6
Cody, Wyo.	...	48.0	52.4	...	38.0
Byron, Wyo.	29.0	42.5	28.5	...	41.0
Salt Creek, Wyo.	8.0	38.0	49.3	4.97	40.3
Salt Creek, Wyo.	11.0	34.0	54.0	5.56	38.4
Shannon, Wyo.	...	12.5	86.9	1.14	23.9
Shannon, Wyo.	...	10.0	86.6	...	24.1
Lander, Wyo.	2.5	22.0	...	...	22.2
Lander, Wyo.	2.0	23.5	69.9	0.91	23.4
Plunkett, Wyo.	14.0	41.0	41.1	...	42.4
Pilot Butte, Wyo.	19.0	59.0	22.0	...	30.0
Douglas, Wyo.	8.0	38.5	53.5	2.00	35.9
Douglas, Wyo.	...	6.0	...	...	20.4
Rangeley, Colo.	...	60.0	...	20.00	43.6
Rangeley, Colo.	25.0	45.0	27.0	...	...
De Beque, Colo.	1.0	42.0	56.5	...	37.8
De Beque, Colo.	...	27.0	70.9	...	25.6
Boulder, Colo.	20—22	38—40	40.0	...	...
Florence, Colo.	4.15	30.45	65.4	...	...

Miscellaneous Properties.

The color of oils is variable and depends mainly on composition. Paraffin base oils are the lighter; yellow to brown by transmitted light, green by reflected light. Asphalt base oils are ordinarily dark brown to deep black in color.

The odor of certain oils is quite characteristic. The oils of Pennsylvania and Wyoming have the odor of gasoline. California oils have a pleasant aromatic odor. The oil of the East Indies has the odor of oil of cedar. Ohio, Indiana, Ontario, and much of the Texas oil has the unpleasant odor of hydrogen sulphide.

Another property of importance is viscosity, which may be defined as the internal resistance offered to flow. Paraffin base oils are ordinarily quite fluid. Asphalt base oils are viscous. Viscosity has quite an important effect on the transportation of oils. Some oils flow with such reluctance that they must be heated before they can be pumped through a pipe-line. Oils that remain fluid at temperatures of about 0°, are known as winter oils. Those which remain fluid only at temperatures of 40 degrees or higher, are summer oils. Summer oils are the heaviest oils, with high viscosity, which can only be shipped during the summer season.

Other physical properties, such as surface tension, optical activity, refraction, and expansion upon heating are frequently determined. They, however, possess only a slight practical value and are more important from the theoretical standpoint; hence they will not be discussed in detail.

Solid and Semi-Solid Hydrocarbons.

There are other natural hydrocarbons besides gas and oil. As a matter of fact, all gradations, both chemical and physical may be found from natural gas through oil into viscous and even solid bodies. A few of these deserve special mention. A viscous pasty black-colored hydrocarbon, representing the residue from evaporating heavy oil, is known as "maltha" or "chapopote". The natural wax or paraffin, ordinarily the result of evaporation of high-grade oil, is known as "ozokerite". "Gilsonite" and "grahamite" are very valuable, brilliant, black-colored, solid and brittle hydrocarbons, useful chiefly for varnishes, shellacs, and enamels. "Lake asphalt" is known only from the Island of Trinidad, and is a highly viscous, semi-solid substance, similar to common asphalt.

Occasionally the pores and openings in rocks are completely saturated with residues left by the evaporation of oils. Such rocks are known as "bituminous rocks". Sandstones, shales, and limestones, as well as gravels of this sort are known and are used quite extensively for road metal.

III. The Origin of Oil and Gas

Two questions are involved in any discussion of the origin of natural hydrocarbons. The first one concerns the original materials from which oil and gas are derived; the second deals with the manner and methods by which this material ultimately changes into oil and gas. The first question is fundamentally a geological one; the second is essentially a chemical and physical one.

Classification of Theories of Oil Origin.

The nature of the original materials from which the hydrocarbons are formed is a much disputed question. In general, all theories of origin fall in one of two classes, which for convenience we may call "inorganic theories", and "organic theories". Those of the first class maintain that the hydrocarbons are derived from inorganic materials. The second class, on the other hand, maintains their derivation from the remains of plants and animals.

Inorganic Theories.

The older and more strictly chemical theories postulate a derivation from inorganic substances. Some of these theories are very crude and purely speculative. Others are more refined, and are based on exhaustive laboratory work and synthetic experiments carried on by Russian and French chemists. Although there are a number of inorganic theories, attention will only be called to two representative ones.

Cosmic Theory.

One of the older ideas was that both oil and gas were constituents of the original nebular matter from which our solar system was formed; that, as the earth cooled down from high temperatures, the oil was precipitated as rain, was disseminated through the rocks, and was subsequently collected in reservoirs to give us our oil fields. This theory, also known as the "Cosmic Theory", is an

Fig. 6. Sketch map showing distribution of oil fields in Texas and Louisiana. (After Gardner)

example of the purely speculative type, which has absolutely no scientific foundation behind it.

Mendeleef's Carbide Theory.

As an example of the more refined chemical theories we may mention the theory of Mendeleef, who presupposes the existence of metallic carbides in the interior of the earth. (Metallic carbides are compounds of a metal and carbon, similar to the calcium carbide which is used extensively for the generation of acetylene gas.) These carbides, at high temperatures in the interior of the earth, react with water to form acetylene, just as this gas is produced in our commercial carbide plants. Subsequently, when subjected to different degrees of heat and pressure this acetylene is changed into the various hydrocarbons found in Nature.

Inorganic theories are more generally accepted among chemists than among geologists. Eugene Costé, a Canadian geologist, however, is the most vigorous advocate of this view, and cites the following facts among others, which he believes definitely proves that oil is derived from inorganic materials:

1. Hydrocarbons have been found in meteorites.
2. Hydrocarbons have been found in the spectra of the stars and nebulae.
3. Hydrocarbons have been made artificially in the laboratory from inorganic materials.
4. They have been found in igneous rocks, in veins, and in volcanic emanations.
5. Minute quantities have been found in cast iron.

It may be of interest to add in this connection that there is a strong probability that the oil that occurs in igneous rocks and in volcanic emanations is derived from some oil-bearing rocks under the earth's surface, and consequently not inorganic. In any attempt to discover the origin of petroleum, we must carry in mind the fact that the question at issue is not "How may petroleum be produced", but "How can *commercial accumulations* of oil be formed?" Although all geologists are willing to admit the possibility of oil formation from inorganic materials, by far the greater majority deny the probability of producing large quantities in this way. There is absolutely no evidence to show that the oil of any commercial field is derived from inorganic sources.

Organic Theories.

There are a number of different theories which postulate the derivation of hydrocarbons from the dead remains of organisms. Five such groups of theories are worth specific mention, all of which differ in that they start with different organic materials. These postulate one of the following as original materials:

1. Coal and similar carbonaceous matter.
2. Accumulation of plant remains.
3. Accumulation of animal remains.
4. Oozes, muds, and slimes made up in large part of the remains of micro-organisms.
5. Plant and animal remains in combination.

Within the limits of this discussion, it is impossible to treat all of these in detail. Several of these theories may be selected as most representative, and will be briefly described:

Coal Theory.

The oldest of the organic theories postulates a derivation of oil from coal fields, and is suggested by the association of coal and oil in the older known fields. It is also a fact worth noting that certain of the gases which escape from coal and which are often so dangerous in mines are similar in composition to the hydrocarbons in oil fields. Again, it is possible to distill from coal, at high temperature and pressure, certain gases and oils, indistinguishable from those met in Nature. In this connection attention has already been called to the derivation of the word "coal oil", which is used synonymously with kerosene, and which emphasizes the fact that illuminating oils were originally manufactured from coal. In several localities, as for example, in Scotland, at Vendee in France, and on the

Island of Trinidad, oils may be seen oozing out of coal beds. In recent years, however, a great number of oil fields have been found which show no relation whatever to coal fields, and which consequently throw discredit on the idea that all oils are derived from coal. In a few cases the theory is capable of application, and at least tentatively established.

Plant Theory.

There are many modifications of the theory which postulates a derivation from plants. Probably the one best established states that gelatinous plants, such as algae, are most likely to give oil under favorable conditions. Indeed, all our knowledge of the chemical principles involved lead us to the belief that plants with hard, woody tissue are more likely to yield coal rather than oil. The adherents of this theory believe that the accumulated remains of gelatinous plants forming along the ocean shore, are buried under the mud and sand, accumulating there, and are protected in this way from decomposition. Subsequently those remains are distilled into the various gases and oils met in Nature. In the laboratory, it is possible to distill oils from such plant remains. Geographic study proves that such plants accumulate in considerable abundance. Therefore the probability of such origin must be granted. As a matter of fact, certain of our oils very high in paraffin, such as the oils of Pennsylvania, are probably of this derivation.

Engler-Hoefer or Dual Theory.

The strict vegetable origin cannot explain all oils. Thus the many oils, high in nitrogen, sulphur, and with an asphalt base, can probably not be derived from plants alone. On the other hand, there are many objections to the theories which attempt to explain the derivation of oil and gas from animal remains alone. Thus, for example, it is necessary to dispose of virtually the entire nitrogen content and preserve at the same time the fat of the animal. The abundance of scavengers in the ocean which

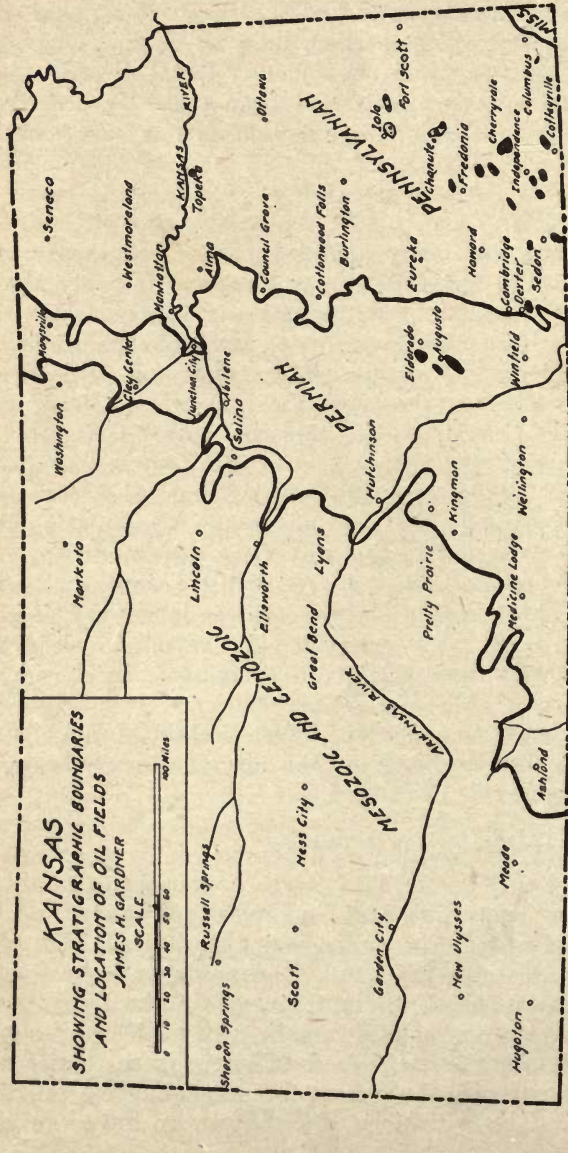


Figure 7. Geologic sketch map of Kansas, showing locations of Oil and Gas Fields.

will, under ordinary conditions, devour the dead bodies of all animals, is often cited as another objection against this theory. Because of these reasons the so-called "Dual-theory" has been developed which postulates a derivation of oil and gas from both plant and animal remains. Probably the greater number of geologists favor this view, at the same time emphasizing the relatively greater importance of animal remains as a source of oil. It is believed that the decay of dead plants and animals is retarded by the salinity, or perhaps coldness, of the ocean water at the time of accumulation, and that there is a sort of selective putrefaction followed subsequently by burial. As a result of later distillation our oils are formed. In this connection it is of interest to note that a number of different chemists have succeeded in making oils from mixtures of plant and animal remains in the laboratory, which were in every respect similar to natural oils.

That the animal theories are fully competent to meet all the requirements of commercial oil fields is certain, in spite of the greater liability of the rapid decomposition and of being eaten by scavengers. Thus it has been estimated that the annual catch of herring in the North Sea for 1300 years is sufficient to yield all the oil produced in Galicia. If we carry in mind the fact that the annual catch of herring is only an insignificant fraction of the total number of herring in the North Sea, and that the herring themselves represent an infinitesimally small portion of animal life in the oceans, the fact becomes apparent that the most insignificant fraction of life forms only need be preserved to give us all the oil we find in Nature. It is certain that the organic origin of oil is best supported both by the geological evidence and by the chemistry of the hydrocarbons. Animals are probably the most important source. There is no evidence to show that any commercial oil field derives its oil from inorganic materials.

Processes of Oil Formation.

In the preceding discussion we have come to the conclusion that organic matter represents the raw materials from which petroleum is produced. We shall now discuss the manner and methods by which these have become converted into the different kinds of oils. A great deal of experimental work in the synthesis of oil has been done by chemists, much of it, however, under conditions not found in Nature. As a result a number of false ideas have been advanced and have gained current acceptance. Reasoning and work along this line should be based on conditions as determined by geological observation. Thus we know:

1. That the formation of petroleum is a general process.

2. That the original materials represent both animals and plants.

3. That the process of alteration is one of selective putrefaction and distillation, taking place under the following conditions:

a. At comparatively low temperatures.
b. Under comparatively great pressures.
c. In the presence of water, usually salty.
d. During a great space of time.

The temperature under which the alteration takes place can be determined roughly by the depth of burial of the oil rock. There is every reason to believe that this probably never exceeds 300 degrees Centigrade. The pressure is at least partially due to the weight of the over-lying rocks, and in most cases is probably not less than one ton a square inch.

Causes of Varieties of Oil.

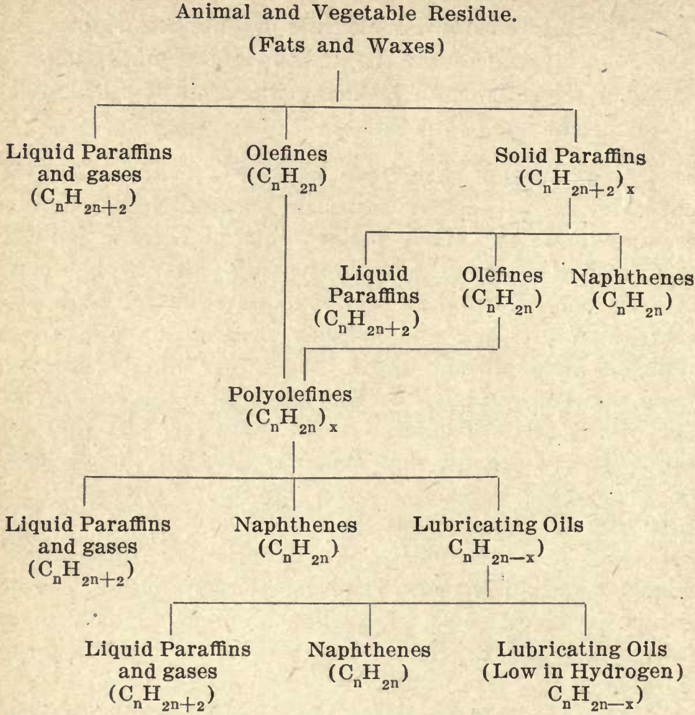
In the preceding discussion we have called attention to the fact that there are different kinds of oils in Nature, such, for example, as paraffin base oils, asphalt base oils, oils high in sulphur, or high in nitrogen. A number of explanations have been advanced to account for these varieties. These may be tabulated as follows:

1. Difference in the original organic material.
2. Physical conditions at the time of formation.
3. Migration and resulting filtration of oil.
4. The age of the oil.

A number of American geologists believe that the character of oil depends upon the nature of the original organic material. They believe that high-grade paraffin oils are derived from gelatinous plants; that asphalt base oils are derived from animal remains; that the high percentage of nitrogen and sulphur present in certain oils indicates also animal origin. A larger number dissent from this view and believe that physical conditions or the age of the oil will determine its character, and that the same type of organic material may give all the varieties of oil we have, depending upon physical conditions at the time of formation. Thus there is much evidence to show that high pressure means the retention of volatile constituents and a light oil. High temperature means a rapid formation of oil and a production of much asphalt. Low heat means a slow gradual change with the production of paraffin.

There is good reason for the belief that oil is seldom retained in the place where formed. Ordinarily it has migrated through the rocks and become entrapped subsequently in a reservoir. In moving through the earth's crust, oils seep through various kinds of rocks, all of which may exert some influence. Thus oils traveling through clays are separated into two portions, a light oil, which percolates through the clay, and a heavy residue which is retained. That this process is active in Nature is certain.

Another explanation is based on the fact that there are a definite series of stages in the alteration of organic matter to oil; that the older oil is the better, and that the older oil retains the greater proportion of gas. The following table shows in graphical manner the stages in the alteration of fats and waxes into oil.



The table shows that the first products of distillation of fats and waxes are stable paraffins and olefines, and unstable solid paraffins. The solid paraffins produced, break up into liquid paraffins and naphthenes, both of which are stable and remain unaltered, while the olefines produced from the original fats and waxes as well as from the solid paraffins, break up into poly-olefines, which in turn are distilled to form liquid paraffins, naphthenes, and lubricating oils. As in the case of the first distillation, the liquid paraffins and naphthenes remain unaltered, but the lubricating oils break up to form more of the light paraffins and naphthenes, and in addition relatively stable lubricating oil, low in hydrogen.

To summarize, we may conclude that the varieties of oils may be caused in part by differences in the material from which they are formed, and in greater part they may represent the result of alteration of the same material under different conditions. High temperature and consequently rapid alteration mean a heavy asphalt base oil, chiefly useful as fuel. Low temperature, high pressures, slow alteration, old age, and much migration result in high-grade light oil, extremely valuable because of the high proportion of gasoline and other volatile constituents retained.

IV. Rocks and Their Properties

Classification of Rocks.

Geology as applied to petroleum work is concerned with the different kinds of rocks and with their arrangement in the earth's surface. It is customary to divide all rocks into three great classes, known as "igneous rocks", "sedimentary rocks", and "metamorphic rocks", respectively.

The igneous rocks represent those that have solidified from an originally molten condition. They may reach the earth's surface like the lavas flowing from volcanoes, or they may harden deep below like granite. The sedimentary rocks represent materials deposited in layers by the action of the waves, of the wind, or of ice. In small part they also represent materials deposited from solution. They accumulate most commonly under water in oceans, seas, lakes and rivers. The metamorphic rocks were originally igneous or sedimentary rocks that have been so acted upon by heat or pressure subsequent to their formation, that they have lost their original characteristics. Both metamorphic and igneous rocks are frequently included under the term "crystalline". In physical characteristics they are quite compact rocks, ordinarily very hard, and crystalline in structure. They never carry commercial accumulations of oil.

Kinds of Sedimentary Rocks.

We recognize four kinds of sedimentary rocks; conglomerates, sandstones, shales and limestones. Conglomerates are gravels consolidated into rock; Sandstones, as the name implies, represent consolidated sands; Shales are hardened and consolidated muds and clays; while Limestone represents the accumulations of the hard parts and shells of various marine animals, such as, corals, oysters, and other shell fish.

Conglomerate.

Conglomerate ordinarily represents the coarse material deposited along the edge of the ocean shore. It consists of boulders of various sizes cemented to a greater or lesser degree. The boulders and pebbles are usually well worn and rounded. Rocks made up of angular fragments instead of boulders are known as breccias. Conglomerates are of minor importance in oil fields.

Sandstones.

The sandstones are chiefly made up of grains of the mineral quartz. A cement of oxide of iron gives the rock a color varying from pale yellow to a deep red or brown. Lime, or calcium carbonate and silica form the common cement of the white sandstone.

Shales.

Shales are very compact rocks made up of excessively fine-grained material, especially mud and clay. The shales, to a greater degree than sandstones and conglomerates, show a well-defined bedding. Their most characteristic property is to split in thin, paper-like sheets. Oil-bearing shales are dull in color. Black, dark gray, or dull brown are the most common. Bright-colored shales, such as red or green of various shades, are the exception in oil regions.

Limestones.

Limestones are essentially calcium carbonate. They may have various colors, but dull drab colors are the most characteristic in oil fields. Limestones tend to occur in beds thicker and considerably harder than the layers of shale. They can be recognized by the fact that a fragment dropped in a glass containing a strong mineral acid will effervesce vigorously. Occasionally it may be necessary to heat the acid in order to get the effervescence.

Transitional Rocks.

The sedimentary rocks do not commonly occur in pure layers. Thus, sandstones are very frequently mixed with a small amount of clay, while shales frequently contain a small amount of disseminated sand. The same is true of limestone. For these reasons we speak of shaly sandstone, calcareous sandstones, shaly limestones, sandy shales, and calcareous shales. All of these terms are self-explanatory in meaning. The relationship is shown graphically on the accompanying triangular diagram.

Sandstone
/ \
Calcareous Sandstone Shaly Sandstone
/ \
Sandy Limestone Sandy Shale
/ \
Limestone—Shaly Limestone—Calcareous Shale—Shale

Formation.

Sedimentary rocks may consist of a collection of pure sandstones, pure shales, or pure limestones, but more frequently they consist of several of these rocks in more or less rapidly alternating layers. Any collection of such strata which may be conveniently considered together is known as a "formation". In order to distinguish formations, it is customary to apply the name of a town, river, mountain or other geographic locality to it. Thus we have a Denver formation, a Big Horn formation, a Niagara formation, and many others.

Stratification.

The sedimentary rocks occur in more or less well-defined and parallel layers or beds. These were originally horizontal. Each individual layer is spoken of as a stratum, and the sedimentary rocks are said to be stratified. Strata may be massive layers as much as twenty feet in thickness, or they may be thin and platy like sheets of paper. In the latter case the rocks are said to be laminated.

Cross Bedding.

Occasionally the well-defined, massive beds of rocks are made up of many smaller inclined layers. The inclination of these may be more or less constant, which is true of those sediments that are deposited by strong currents of water. In other rocks these inclined layers may be very eccentric and irregular in direction, suggesting the deposition by the shifting winds. Any inclined lamination of this sort is known as cross-bedding. It is most characteristic of sandstones.

Variations in Rocks.

All rocks show more or less tendency to vary in their characteristics. This is especially true of their thickness. Changes in composition are also common. One rock may grade into another when traced over a large area. The pure limestone layers deposited in the quiet and deeper parts of the oceans today, change into shaly limestones and eventually into shale as we approach the ocean shore.

Erosion Forms.

The configuration of the earth's surface is subject to continual change, so that the hill of today may become the valley of the future. The falling rains and the driving winds tear down the earth's surface at one point and build it up in another. This process is known as erosion. No one has expressed the importance of this process in words finer than the following:

"The hills are shadows, and they flee
From form to form, and nothing stands;
They melt like mists, the solid lands,
Like clouds they shape themselves and go."

Naturally erosion is most active on the softer rocks, and on these the valleys are usually located. The harder rocks give us the elevations. The differences in hardness of the individual layers of a rock are clearly shown in any exposure. The harder layers project as ribs or knobs; the softer layers are worn away and leave pits, cavities, and irregular depressions.

Topography depends to a great extent on the attitude of the underlying rocks. In regions of horizontal rock, the harder portions project above the surrounding country as flat-topped elevations of small or large surface area, known respectively as "buttes" and "mesas". In regions of inclined rocks, the harder layers form long narrow ridges which we speak of as "hog backs".

DRILLERS' ROCK CLASSIFICATION (After Knapp)

General Class	Rotary-drillers' Term	Use in Rotary System	Cable-drillers' Term	Use in Cable-tool System	Technical Equivalent
Sands..................	Sand	Any uncemented sand.	Sand	Any uncemented sand; also many slightly cemented sands or very porous formations.	Sand
	Water sand	Sands, the samples of which appear clean and bright. Sands tested and found to produce water.	Water sand	Sands producing water.	Sand
	Quicksand	Sands that cave and settle rapidly.	Quicksand.	Sands that cave and settle rapidly.	Sand
	Heaving sand	Sands that cave and are forced up the hole.	Heaving sand	Sands that cave and are forced up the hole.	Sand
	Oil sand	Sands or other porous formations containing oil.	Oil sand	Sand or other porous formation containing oil.	Oil sand
	Gas sand	Sands or other porous formations containing gas.	Gas sand	Sand or other porous formation containing gas.	Gas sand
Gravel, boulders........	Gravel	Any formation having the feel of gravel while drilling.	Gravel	Correctly used.	Gravel
	Boulders	Large loose pieces of any formation.	Boulders	Correctly used.	Boulders
Clay, shale.............	Clay	Clay or soft shale; usually not sticky.	Clay	Correctly used.	Clay, or sandy clay
	Gumbo	Soft sticky clay.	Gumbo	Soft sticky clay.	Clay
	Shale	Formations having parallel bedding.	Shale	Consolidated clays.	Shale
Consolidated formations	Rock	Any consolidated formation.	Rock	Term not used.	Rock
	Gas rock	Any rock formation containing gas.	Gas rock	Term not used.	Rock
	Chalk rock	Applied to light-colored chalk only.	Chalk rock	Correctly used.	Chalk
	Sand rock sandstone	Terms used interchangeably for all cemented formation.	Sandstone	Correctly used.	Sandstone
	Packed sand	Loosely cemented sand.	Packed sand	Correctly used.	Sandstone
	Shell	Thin layer of hard material.	Shell	Thin layer of hard material.	Rock.
	Shell rock	Any consolidated formation containing fossil shells.	Rock with shells	Formation containing shells.	Rock with shells
	Flint or flinty rock	Any very brittle rock.	Flint or flinty rock	Correctly used.	Flint
	Limestone	Limestone, also hard shale.	Limestone	Correctly used.	Limestone
	Lignite	All fossil wood.	Lignite.	Correctly used.	Lignite or fossil wood
	Gypsum	Correctly used when recognized also reported as limestone or shale or sticky gumbo.	Gypsum	Correctly used.	Gypsum
Miscellaneous...........	Shells	Fossil shells	Shells	Fossil shells.	Fossil shells

V. Stratigraphic Geology

The part of geological science that deals with the order of succession of rock layers, and attempts to determine their relative ages, is known as Stratigraphic Geology. In attempting to compare or "correlate" rocks one of three methods can be followed:

Tracing Outcrops.

Occasionally it happens that a particular bed of rock, such as a limestone, yields a more or less continuous exposure or "outcrop" on the earth's surface, which can be followed for a considerable distance, and which will hence serve as a basis for comparison. This method is, of course, subject to limitations. The time required to trace a formation from a known field to the one in question may be so great as to make its cost prohibitive. There is also the probability that the outcrops may be covered for a considerable area. This is generally the case.

Comparing Lithological Characteristics.

A known formation may be characterized by certain physical properties, such as its color, its hardness, its characteristic layering or bedding, and its composition. A similar formation in a different locality may represent the same layer. This is frequently assumed, but is not necessarily true, because experience has shown that no matter how peculiar and unusual certain characteristics may appear to be, they may recur any number of times. The comparison of successive layers of rocks, of their characteristics and thicknesses is a more valuable method of correlation. An illustration will make this clear. In a known field we find a conglomerate three hundred feet thick succeeded by eight hundred feet of red sandstone, which in turn is followed by eleven hundred fifty feet of alternating red and green shales. Some distance away we find a succession of rocks similar in characteristics and thickness. Therefore, we may argue with some safety that these two groups are probably equivalent in age. This method, while capable of more general application than the first, is also subject to limitations. The liability of change, both in the thicknesses and characteristics of the rock layers, must be considered. In the case of widely separated fields, the individual rock layers may have changed so much as to make this method of correlation infeasible.

Use of Fossils.

About one hundred years ago the British civil engineer, William Smith, discovered the fact that each layer of rock carries fossils which are characteristic, and that these fossils can be used to prove that widely separated rocks are of the same geological age. This discovery enabled us to make the geological time table, especially after the doctrine of evolution had been worked out in detail.

Evolution.

The theory of evolution teaches us that the various types of animals and plants have developed by descent from pre-existing types. In general, progress has been from the simpler towards the more highly organized and complex types. Indications are that all animals and plants are the descendants of a very few simple organisms not unlike the simpler protozoans. The various living types of animals and plants do not form a series showing a complete gradation from the most simple to the most complex. Instead, they represent a genealogical tree, the branches of which exhibit very different degrees of divergence from the parent stock. Indeed, many of these branches are now known only by their fossil remains. Close resemblance among animal groups, such, for instance, as that between man and the anthropoid ape, does not mean descent of one from the other, but indicates a common ancestral stock.

Geology has proven the fact that every species of animal and plant lives only for a limited time on earth, then it dies out, and once extinct never returns. If we arrange the sedimentary rocks in a column with the oldest at the bottom and the youngest on top, similar to the chronological table given later, we will find that each species of animal or plant has a certain vertical range which represents its period of existence on earth. The vertical range of species is not the same in all parts of the earth. A particular animal has its origin in some definite locality and spreads laterally from there over the surface of the earth and then dies out. It does not necessarily survive last in the area of origin.

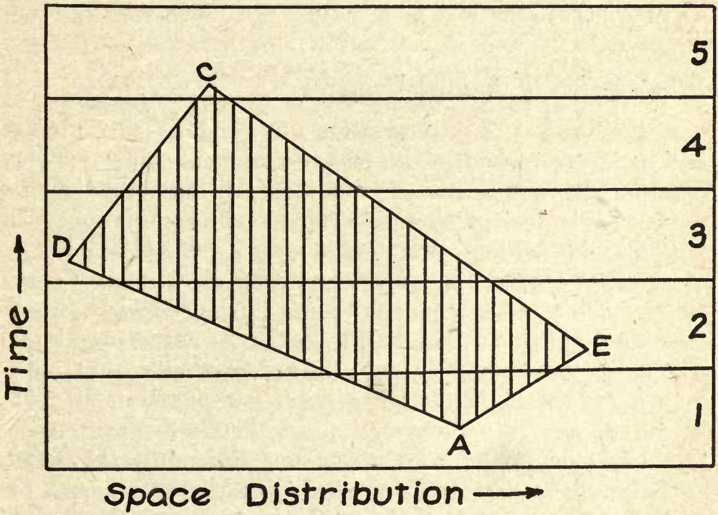


Figure 8. Diagram to show space and time distribution of a fossil.

The accompanying diagram illustrates this fact graphically. The horizontal line represents distance on the earth's surface; the vertical line represents time; 1, 2, 3, 4, etc., represent the sedimentary rocks deposited in order. A is the point of origin of a particular animal which spreads laterally and with different velocities to the points E and D, and eventually disappears at the point C. The shaded area, therefore, gives us both the time distribution and the space distribution of this species on the earth.

If we examine the rocks deposited at the locality A, E, or C, we will find this species characterizing rocks of slightly different age because of differences in the time of appearance and of disappearance of this species. To make a fossil especially useful for correlation it should have a small vertical range, that means short life on earth; and in addition it must be easily and rapidly distributed over a large area. Ordinarily we use not a single fossil, but a whole collection of fossils as a basis of comparison. The group of animal fossils characterizing a formation is known as a "fauna"; the group of plant fossils, as a "flora".

Preservation of Animal Remains.

Fossils are the impression or remains of animals and plants entombed in the rocks by natural causes. Preservation depends on the character of the organism. Only those with bony structures are capable of preservation. It will also be evident that the home of the animal has a great effect on liability of preservation. Water, and especially marine animals, are far more likely to leave a fossil than land animals. The fleshy portion is never preserved. The only exception to this rule are elephants that have been found frozen in the arctic gravels in northern Siberia, in which case the preservation of the flesh was due to excessive cold. Under ordinary conditions only the bones and the shells can form fossils. Occasionally bones or shells are preserved in their original condition. More frequently, however, they have been replaced by some mineral matter. This simply means that the bone has gradually gone into solution and that simultaneously for each particle of bone dissolved, a particle of mineral matter has been deposited.

There occur quite commonly in the rocks eccentric shaped bodies which are the result of water circulation and the deposition of mineral matter about some nucleus such as a leaf or a small fossil. These bodies which we call concretions often simulate in shape animals of various sorts, the legs and arms of human beings and almost anything else, provided the imagination of the observer is vivid enough.

Geological History.

The sedimentary rocks are deposited in a systematic order with the oldest at the bottom and the youngest at the top. The order of deposition and the chronological relationship of rocks has been worked out in great detail. The systematic study of the rocks and of their succession enables us to deduce the series of events that characterized the past history of the earth. For example, the character of the rock tells us the conditions under which it accumulated. Thus bright-colored rocks associated with salt and with beds of gypsum, are characteristic of deposition in arid or semi-arid regions such as deserts. The preservation of mud cracks, of the tracks of animals, of ripple marks in the sand, all tell us of deposition in very shallow water exposed at intervals to the drying sun. Very pure sandstones, made up of uniform sized spherical sand grains and characterized by a very eccentric and irregular bedding, indicate deposition by drifting winds.

The succession of rocks indicates to some extent the changes on the earth's surface. In the present day the rain, the driving wind, and the flowing water all tear down the earth's surface and transport the fragmental material through creeks and rivers into the sea. Here, as a result of wave action and of shore currents, this material is washed, sorted and deposited according to size. The coarsest material next to the shore; the finest a considerable distance away, out in the quiet water. Thus fringing the ocean shore, we expect first, a zone of boulders and gravel, next, a zone of sand, and in the quieter waters, a belt or zone of mud. Animal life is especially plentiful and flourishing in the clearer water, and here the shells and skeletons accumulate upon death. Applying these principles, we may argue that a succession of rocks, such as conglomerates at the base, followed in order by sandstone, shale and limestone, all grading into each other, means a gradual deepening of the sea over that point. A succession in reverse order means a shallowing of the sea. Thus the succession of the strata enables us to work out the great advances and recessions of the sea that have characterized the past history of the North American continent. While we cannot go into detail at this point, it may suffice to state that the American continent has not always been of the same size it is today; that it has been subject to profound geographic changes; that at times the whole continent, with the exception of northeastern Canada, was covered by ocean water; that a number of times it emerged from the ocean only to be submerged to a more or less complete degree afterwards.

It is customary to divide geological time into larger divisions known as eras, and smaller divisions known as periods. The accompanying table shows the classification of eras and periods in common use at the present time. It may be well to note that the kind of sedimentary rock bears no relation whatsoever to its age. Sandstones or any other kind of rock may occur in any geological age.

Geologic Chronology of North America.

(Modified after Pirsson and Schuchert)

Era	Periods.	Advances in Life.	Dominant Life.
Psychozoic	Recent.	Rise of world civilization. The era of mental life.	AGE OF MAN.
	Glacial or Pleistocene.	Periodic glaciation. Extinction of great mammals.	AGE OF MAMMALS AND MODERN PLANTS.
	Tertiary— Pliocene. Miocene. Oligocene. Eocene.	Transformation of man-ape into man. Culmination of mammals. Appearance of higher mammals. Vanishing of archaic mammals.	

Geologic Chronology of North America—Cont.

Era	Periods.	Advances in Life.	Dominant Life.
Mesozoic	Epi-mesozoic interval.	Rise of archaic mammals.	AGE OF REPTILES.
	Cretaceous—Lance.	Extinction of great reptiles.	
	Montanian. Coloràdian.	Extreme specialization of reptiles.	
	Commanchean.	Appearance of flowering plants.	
	Jurassic.	Appearance of birds and flying reptiles.	
	Triassic.	Appearance of dinosaurs.	
Paleozoic	Epi-paleozoic interval.	Extinction of ancient life.	AGE OF AMPHIBIANS AND FERN PLANTS
	Permian.	Appearance of land vertebrates. Appearance of modern insects and ammonites. Periodic glaciation.	
	Pennsylvanian.	Appearance of primitive reptiles and insects.	
	Mississippian—Tennessian.	Appearance of ancient sharks.	
	Waverlian.	Appearance of echinoderms.	
	Devonian.	Appearance of Amphibians. First known land floras.	AGE OF FISHES.
	Silurian.	Appearance of lung-fishes and scorpions	

Geologic Chronology of North America—Cont.

Era	Periods.	Advances in Life.	Dominant Life.
Paleozoic	Ordovician— Cincinnatian.	Appearance of land plants and corals.	AGE OF HIGHER SHELL FISH
	Champlainian.	Appearance of armored fishes.	
	Canadian Ozarkian.	Appearance of nautilids.	
	Cambrian— Croixian.	Appearance of shelled animals.	
	Acadian.	Dominance of trilobites.	
	Waucobian.	First known marine faunas.	
Late Proterozoic	Keweenawan		Dominant life inferred. AGE OF PRIMITIVE MARINE INVERTEBRATES. (Fossils almost unknown. Delineation of base of this age indefinite.)
	Animikian		
	Huronian.		
Early Proterozoic	Ep-algonian interval. Sudburian.		
Archaeozoic	Ep-archaeozoic interval.		AGE OF UNICELLULAR LIFE. Protozoa and protophyta.
	Laurentian.		
	Greenville.		

The unrecoverable beginning of Earth History.

COSMIC HISTORY.

Stratigraphic Distribution of Oil and Gas.

The known oil and gas fields are not confined to rocks of any one particular age. No commercial accumulations have, however, been found in rocks older than the Cambrian; therefore, any area of Proterozoic or Archaeozoic rocks can at once be excluded as a possible oil producer. The most important geological ages from the standpoint of production are given in the following table. Wherever a state is given more than once, the more important production is given in capital letters:

Tertiary:
- CALIFORNIA.
- TEXAS and LOUISIANA.
- MEXICO.

Cretaceous:
- WYOMING.
- COLORADO.
- Texas, Corsicana.
- LOUISIANA, Caddo, Homer.
- California.
- Mexico.

Commanchean, Lower Cretaceous:
- Oklahoma, Medill.
- Wyoming, Big Horn Basin (in part).

Pennsylvanian:
- TEXAS, Electra, Ranger, Burkburnett.
- Wyoming, Lander.
- Pennsylvania, West Virginia, Ohio, Kentucky, Indiana, Illinois, all in part.
- OKLAHOMA-KANSAS.

Mississippian:
- ILLINOIS.
- PENNSYLVANIA.
- WEST VIRGINIA.
- OHIO.
- INDIANA.
- KENTUCKY.

Devonian:
- PENNSYLVANIA.
- WEST VIRGINIA.
- OHIO.
- NEW YORK.
- ONTARIO.

Silurian:

New York.
Ontario.

Ordovician:

OHIO-INDIANA.
Kentucky.
New York.
Ontario.

Cambrian:

New York.
Newfoundland.
New Brunswick.

Tertiary rocks yield over 50 per cent of the world's production of oil. The most important foreign producing fields, such as Galicia, the Dutch East Indies, Peru, Trinidad, Russia and Roumania, are in Tertiary rocks. Paleozoic rocks are important producers in North America only. It will be noted that Jurassic, Triassic, and Permian rocks are non-productive in North America. This is due to the fact that they represent in large part deposition in interior basins under conditions of semi-aridity. As a result they are very poor in organic remains, and because of this fact they are unfavorable to oil.

STATE	AGE OF CONTAINING ROCKS	BASE	QUALITY OF OIL (BEAUMÉ)	TOTAL PRODUCTION INCLUDING 1916	AVERAGE PRODUCTION PER ACRE
Alaska	East – Tertiary; West – Jurassic.	Paraffin	39° to 45.9°	---------	1,000
California	Cretaceous; Tertiary	Asphalt	12° to 35°	922,860,000	30,000
Colorado	Pierre-Cretaceous	Paraffin	38° to 44°	10,850,000	1,000
Illinois	Mississippian-Penna.	Paraffin	28° to 39°	264,270,000	2,500
Indiana	East-Ordovician (Trenton) West- Pennsylvanian	Paraffin	30° to 35°	109,000,000	400
Kansas	Pennsylvanian	Par.-Asph.	27° to 38°	45,600,000	1,500
Kentucky & Tenn.	Mississippian	Paraffin	25° to 43°	11,000,000	300
Louisiana	Cretaceous-Quater.	Paraffin	21° to 41°	117,690,000	4,500
Michigan & Missouri	Carboniferous	Paraffin	30°	80,000	------
New York & Penn.	Devonian-Carbonif.	Paraffin	25° to 50°	774,000,000	1,000
Ohio-East & West	Ordovician-Carbonif.	Paraffin	35° to 47°	448,000,000	1,500
Oklahoma	Pennsylvanian	Paraffin	32° to 41°	685,930,000	10,000
Texas	Pennsylvanian Cretaceous-Quater.	Asph. and Paraffin	15° to 38°	256,000,000	17,000
West Virginia	Devonian-Carbonif.	------	27° to 52°	280,000,000	2,000
Wyoming	Carbonif.; Cretac.	Asph. and Paraffin	18° to 48°	25,790,000	15,000

Figure 9. Chart showing production of oil according to geologic age and quality.

VI. The Arrangement and Structures of Rocks

Structural geology deals with the arrangement and attitude of rocks in the Earth's surface. From the standpoint of the oil geologist it is the most important branch of geological science.

We have already seen that the sedimentary rocks at the time of formation are deposited in parallel layers or strata that are more or less horizontal. We may find them, however, standing on edge and inclined in all possible directions as a result of some disturbance since the time of their deposition.

Dip and Strike.

The attitude or position of a stratum is a geological feature of prime importance and one that must be recorded.

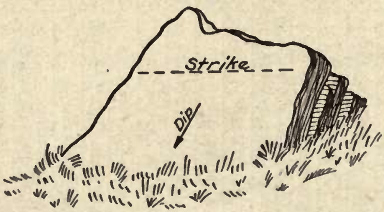


Figure 10. Dip and Strike.

This is done by observing the dip and strike. The dip is the inclination of the bed to a horizontal plane. The strike is the bearing of the line of intersection of a horizontal plane and the plane of the stratum. The directions of dip and strike are at right angles to each other. The strike is always expressed by compass directions, such as North 40° West (N. 40° W.), or South 12° East (S. 12° E.). The dip angle varies of necessity f
for a horizontal bed to 90° for a vertical one. D
strike are frequently recorded on maps by a symbol. Thus, a straight line is drawn in the correct direction of the

strike and at right angles a shorter line is drawn in the direction of dip. The direction of the strike line indicates the true bearing of the strike. The dip line indicates the bearing of the dip but not its amount, consequently it is customary to mark down the value of the dip angle on the symbol.

Outcrops.

In order to work out the structure of rocks and to determine dips and strikes, it is necessary to locate and study outcrops; that is, exposures of bed rock at the earth's surface. When the surface is horizontal, the outcrop of the stratum gives the direction of strike. This is not true, however, in the case of inclined layers of rock that cross rugged country with high hills and deep valleys. Here the bearing of the outcrop and the strike of a stratum may diverge widely, because the outcrop deviates from a straight line when crossing points of different elevation. Thus, if a bed dips upstream, the outcrop travels upstream when crossing a valley; if the bed dips downstream, the outcrop travels downstream. The amount of this deviation or travel is a function of the angle dip and of the depth of the valley. In many cases this enables us to calculate the dip and strike when no direct observation is feasible. Thus, the flatter the angle of dip the greater the travel of outcrop up or down stream; the steeper the angle, the less the travel. Vertical strata show no travel.

Folds.

Frequently we find the outcrops of certain beds repeated in such a way as to suggest that strata of rocks in the earth's crust have been folded in nature much like we fold sheets of paper between our fingers. Such folding is a common characteristic of oil fields.

Three kinds of folds may be recognized:

Anticlines,
Synclines, and
Monoclines (or homoclines).

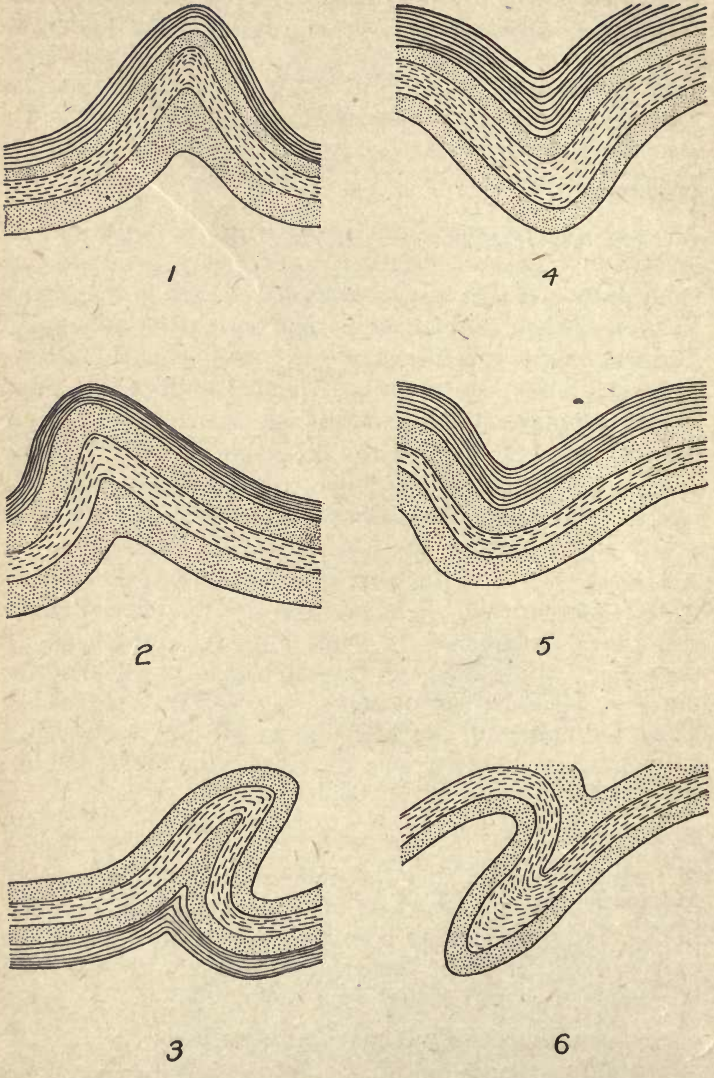


Figure 11. Various types of Folds. 1. Symmetric Anticline. 2. Asymmetric Anticline. 3. Overturned Anticline. 4. Symmetric Syncline. 5. Asymmetric Syncline. 6. Overturned Syncline.

The anticline is an upfold in the strata or an arch. The Syncline is a downfold or a trough. The Monocline is a stepfold, or a flexure in a single direction only. The term homocline has also been applied to a number of formations that dip in one direction only.

Degree of Folding.

Folding exhibits various degrees of intensity. All gradations from very gentle rock waves to intricately twisted and complex crumples are shown. Simple and

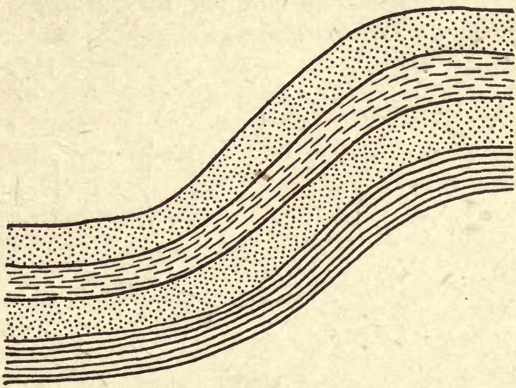


Figure 12. Monocline.

gentle folding is most characteristic of oil regions. Complex, intricate folding is unfavorable in general to oil accumulation. Anticlines and synclines are usually combined in a series of parallel folds of wavelike character, with the anticlines at the crests and the synclines at the troughs. Both occur in a variety of forms. They may be low and broad, or acute and sharply compressed. They may be horizontal, vertical, or inclined in position.

The amount of folding is roughly measured by the difference in elevation of the same layers of rock between the lowest part in the syncline and the highest part in the anticline. This varies from a few feet to several miles. In Wyoming oil fields this is usually large, and varies from several hundred feet to one mile. In Oklahoma and Illinois, this is usually less than two hundred feet.

Nomenclature of Folds.

The sides of the folds are known as limbs. The axis is the direction of elongation. The anticlinal axis is the highest part of the anticline, or its crest. The axis of a syncline is the bottom of the trough. Folds are symmetrical or unsymmetrical, depending on whether or not the dip of the limbs from the axis is equal in opposite directions. Folds are horizontal when the axis is horizontal. Folds with an inclined axis are plunging or pitching folds. Various folds are indicated by the dip and strike symbols in the accompanying figures.

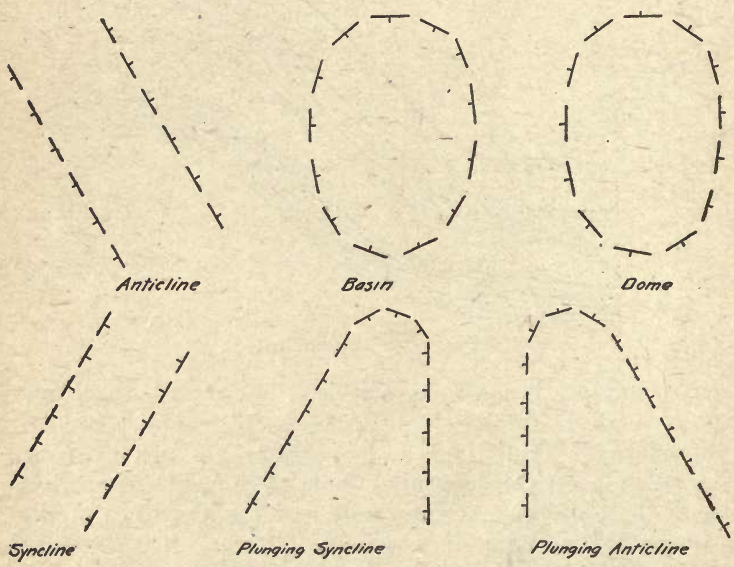


Figure 13. Various structures as represented by their dip and strike symbols.

Composite Folds.

Two types of folds of extreme importance to an oil man are dome folds and basin folds. Both may be conceived of as composite folds, consisting of two folds crossing at right angles. In domes, or quaquaversal folds, the rocks have the attitude of an inverted bowl and dip away in all directions from the center. In Basin, or centroclinal folds, rocks are arranged in the shape of a natural basin and hence dip into the center of the fold.

Domes and Basins also have axes corresponding to the axes of anticlines and synclines. The axis of a dome marks the highest part and the line of elongation of the fold. The highest point on the axis is the apex.

Faults.

In many regions we find that the rocks have been fractured and broken on an extensive scale, and that the broken parts have been displaced with respect to each other. Such displacement on opposite sides of a fracture or fissure, is a fault. The fracture is the fault plane. This is usually inclined. The two sides of the fault are known as the footwall and hanging wall, respectively (see figure 14).

According to the character of the motion we recognize two great classes of faults: normal faults and thrust faults.

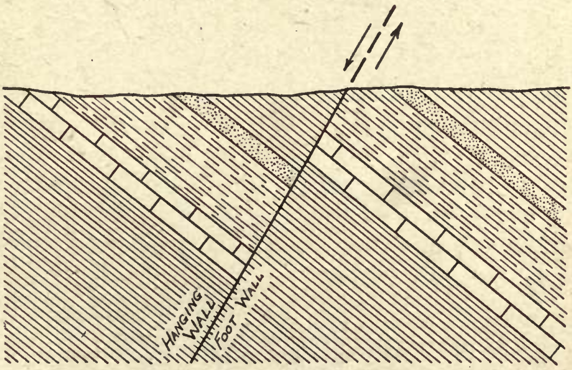


Figure 14. Normal Fault.

Normal Faults.

These usually have steep dipping fault planes and are produced by the tension or stretching of rocks. In these, the hanging wall moves down with respect to the footwall.

Thrust Faults.

The majority of thrust faults have flat, dipping fault planes. They are most common in regions of intricate and complex folding. In these faults the hanging wall moves up over the footwall. They are produced by lateral pressure and the crowding of rocks over each other.

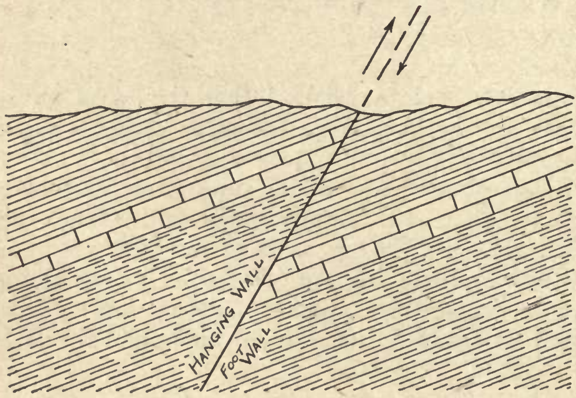


Figure 15. Thrust Fault.

Displacement.

The actual amount of motion in the fault plane is the displacement. This may vary from a fraction of an inch to several miles. Normal faults are most common in oil fields. These usually have displacements of a few hundred feet or less. Complex faulting on a large scale is unfavorable to oil accumulation.

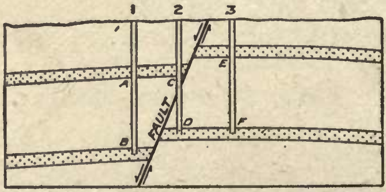


Figure 16. Apparent change in character of rocks due to faulting shown by Well No. 2.
(U. S. Geol. Sur.)

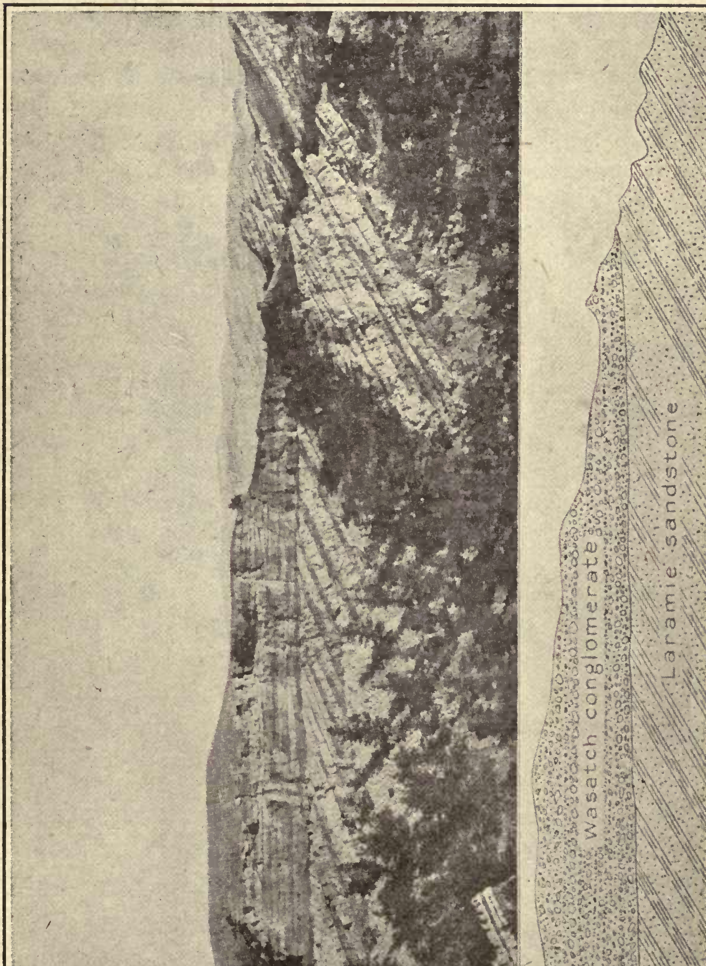


Figure 17. Unconformity in Wyoming. Bighorn Basin. (After U. S. Geol. Sur.)

Unconformities.

The sedimentary rocks are deposited in a regular and systematic order. Each stratum represents a definite time interval; all collectively represent a continuous space of time. The regular succession of rocks may be broken or interrupted. For example, after the deposition of marine strata there may be an emergence of the continent from the ocean, which exposes the recently formed strata to erosion. These may be folded and faulted and eroded into hills and valleys. Subsequently the continent may again be submerged under the ocean and new deposits may be laid down on the dissected surface of the older series. The younger beds, therefore, do not conform to the older rocks below. A surface of contact of this nature is an Unconformity.

The Sedimentary Rocks record Earth history. The rocks above and below the unconformity record periods of time perhaps less extensive than the duration represented by the unconformity. This marks a lost time interval similar to a chapter torn out of a novel. Unconformities may be clearly shown by differences in attitude of rocks indicating that the older series of rocks were tilted and folded and eroded preceding the deposition of the younger series. They are quite important and their influence must be carefully considered in certain oil fields.

VII. Reservoirs of Oil and Gas

Any rock that is capable of containing oil and gas in commercial quantities is known as a "reservoir". The most common types of reservoir rocks are: first, sandstones; second, limestones; and third, shales. These will be discussed briefly.

Sandstones.

Sandstones are the most common type of reservoir rocks. The amount of oil that any sandstone may carry is determined by the number and size of openings it contains, or, in other words, its porosity. This depends on the size and shape of the grains, and on the degree of cementation. The greatest amount of pore space is possessed by the rock that has spherical grains of uniform size; the least amount of pore space, by the sandstone made up of unassorted angular grains. Cement is quite important in determining porosity because it clogs up the interstices between the grains to a greater or less degree. A well-cemented sandstone is hard; a loosely cemented one, soft and friable, that is, it may be crumbled in the hands. Hard, well-cemented sandstones form the reservoir rocks in the Appalachian oil fields, in Illinois, Kansas and Oklahoma. Soft, friable sandstones form the reservoirs in Wyoming, Colorado, and in northern Texas and Louisiana. The oil production from California, Russia, Galicia, Roumania, and Peru comes from unconsolidated, loose beds of sand.

According to the amount of pore space, we speak of "close" or "tight" sands, which mean those of low porosity, and of "open" sands, those of high porosity. The amount of pore space of any sandstone can readily be determined by saturating the dry rock completely with water and noting the amount of water absorbed. The porosity so determined is known as theoretical porosity. This varies from one-half percent in the case of quartzite, to 30 percent in the case of sand. The general average

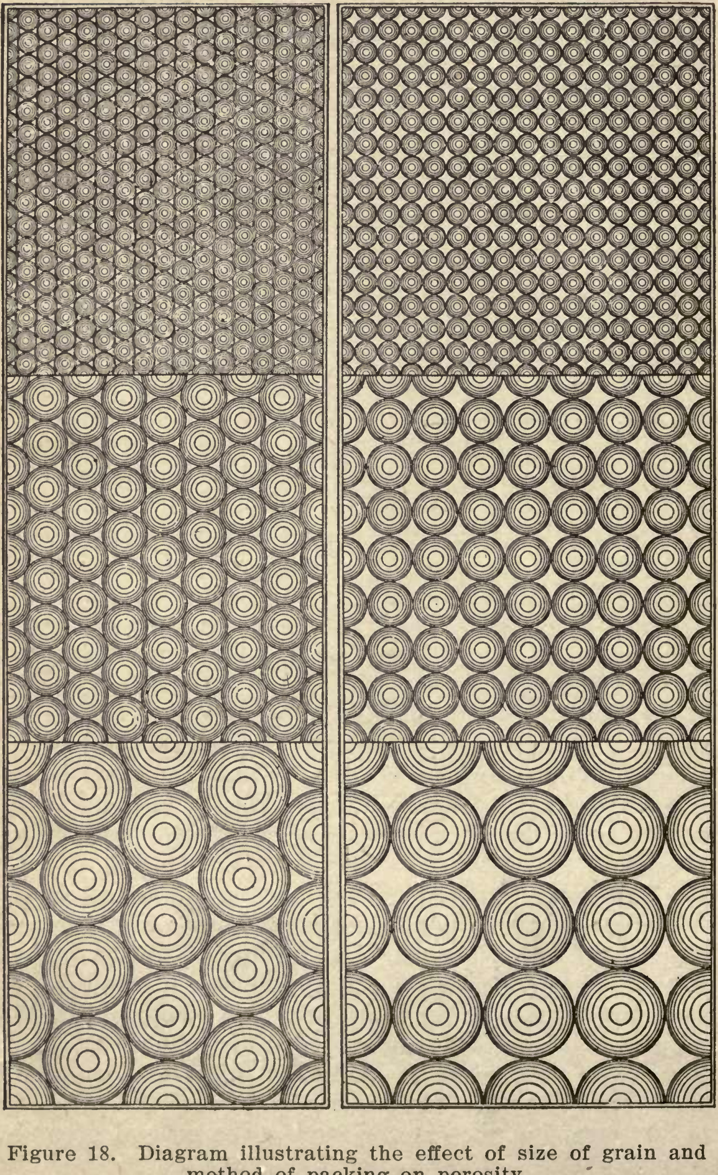


Figure 18. Diagram illustrating the effect of size of grain and method of packing on porosity.

is 10 percent. This is the equivalent of seven hundred seventy-six barrels of oil per acre-foot. This means that a sandstone bed one foot in thickness and extending over one acre, will contain seven hundred seventy-six barrels of oil. We must, however, carry in mind the fact that there is a difference between theoretical and practical porosity. While the theoretical porosity may be 10 percent, the practical porosity is far less, because ordinarily only from 50 percent to 75 percent of the oil in the sand can be recovered. Thus in the Appalachian fields the practical porosity is 4.5 percent, which is equivalent to three hundred fifty barrels of oil per acre-foot. At Glennpool, in Oklahoma, the practical porosity is 6.5 percent, which means that five hundred thirty-five barrels of oil can be extracted for each acre-foot of sand. Extraction is favored by high porosity, by large and connected openings, and by low viscosity of the oil. All of these factors promote ready circulation and easy flow. In the case of unconsolidated sands, even a highly viscous oil may flow readily because of the fact that it will carry the sand along with it. Thus in some of the Russian and Californian fields, more than 50 percent of the material flowing out of the well is sand.

In color oil sands vary decidedly. Usually they are darker in color than the barren sands. Asphalt oils leave yellow to brown stains on the rock and impart to it the odor of petroleum. The paraffin base oils are so light and evaporate so readily that frequently no trace is visible in the outcropping oil sands.

Test for Oil in Sands.

The presence of inspissated hydrocarbons in an outcropping sand can be determined by sampling the outcrop, crushing the rock and treating a tablespoonful of the fragments with ether in a well-corked bottle for half an hour. Any hydrocarbons present will go in solution. If subsequently the liquid be poured off into a white china dish, it will evaporate rapidly and leave behind a ring of oil. This will be greenish amber to pale brown in color in the case of very high-grade paraffin base oils, or dark brown to black in color in the case of asphalt base oils.

Shape of Reservoir.

Certain sandstones occur in well-defined strata that are more or less constant in thickness, and that extend over very large areas. An example of such is the Dakota sandstone which is known to extend over an area of two thousand by one thousand miles. More frequently, sandstones are lenticular in structure. They are limited in areal distribution and thin out or "pinch out" laterally. The entire sandstone bed must not be thought of as being

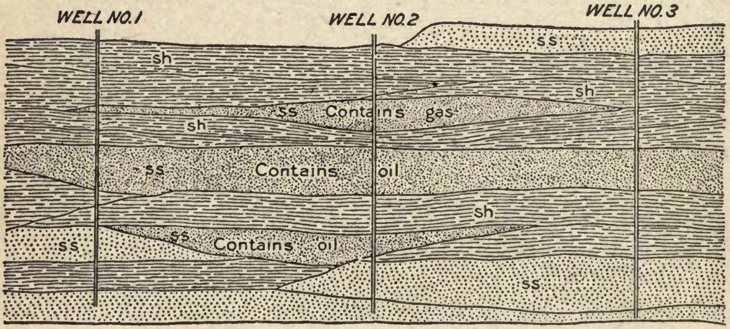


Figure 19. Lenticular sands and their effect on wells. (U. S. Geol. Sur.)

a reservoir. There are certain portions that may be incapable of holding either oil or water because of the fact that they are very tightly cemented, or perhaps made up of excessively fine grains. The reservoir is confined to the porous part of the sandstone where the grains are coarser and consequently the interstitial cavities are larger, or where the cement is poorer and does not completely fill the room between the grains. The accompanying sketch map shows a small area underlain by oil sands. The reservoirs are indicated by shading. It will be noticed that the oil pools are restricted laterally, not by the structure nor by the extent of the sandstone, but by the porous layers capable of acting as reservoirs.

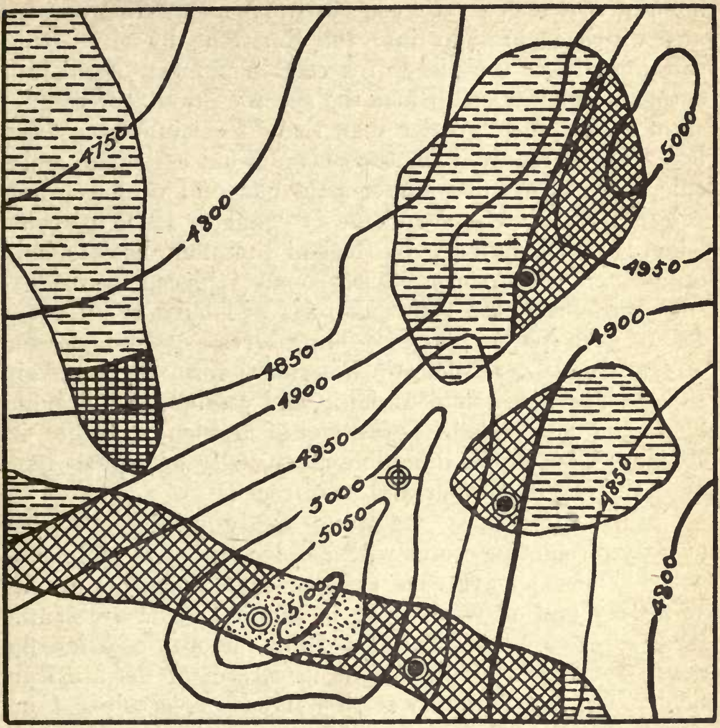


Figure 20. Lenticular layers in oil sands shown by shading. Cross hatching shows oil, dotting gas, broken lines water.

Limestones.

The limestones that we meet with in oil fields represent the fragments of the shells of animals and the skeletons of corals, which have been compacted into rock. Fossils are plainly visible in many limestones. In many others they are very indistinct and may be completely destroyed. Limestones are essentially calcium carbonate. When pure they are ordinarily unfavorable as oil reservoirs. Certain limestones, known as dolomitic limestones, or dolomites, carry varying amounts of magnesium. Such contain oil or gas in a number of prominent fields. While there are differences of opinion as to the origin of the dolomites, it is generally conceded that magnesium carbonate, which is brought into the limestone by circulating solutions, takes the place of a certain number of calcium carbonate molecules. Since the specific gravity of magnesium carbonate is greater than that of calcium carbonate, less space is required for each magnesium carbonate molecule, and as a result we have a shrinkage of volume in the original rock. The shrinkage is equal to 12.30 percent. Thus if one hundred cubic feet of limestone has one-half of its molecules of calcium carbonate replaced by magnesium carbonate, the resulting rock will have 12.30 cubic feet of pore space. These openings serve as receptacles for oil and for gas. Dolomitic limestones form the reservoir rock of the Lima field of Ohio and Indiana, of Spindle Top and other fields in Texas, and of Maiden-i-Napthun in Persia. The oils in limestone are usually of asphalt base and are high in sulphur and in nitrogen.

Pure limestones are quite easily soluble. Consequently circulating water will dissolve out caves and channels. The extensive cave systems of Mammoth Cave in Kentucky and of Wind Cave in South Dakota are familiar examples. Water channels of this sort may occasionally act as reservoirs. This is true in certain of the Mexican fields. Oil will flow very readily in such reservoirs. Consequently wells of great capacity and usually short life may be expected.

Shales.

The older geologists emphasized the importance of rock fractures and fissures as oil containers, and believed these to be far more important than the interstitial cavities between sand grains or the shrinkage cavities in limestones. At the present time this idea is applied to but a few pools. For example, at Florence, Colorado, oil is found in open fissures and fractures in a thick bed of shale. Several other localities, such as West Salt Creek, in Wyoming, and a few areas in Pennsylvania, show a similar type of accumulation. Generally, however, it may be said that such occurrence is unimportant and unreliable.

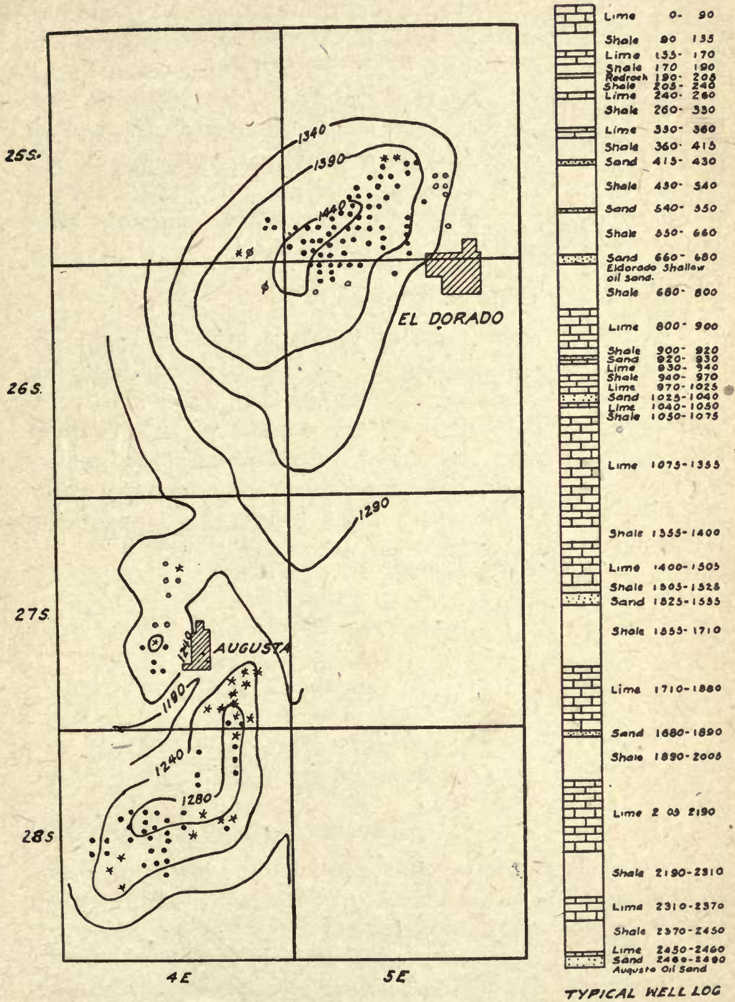


Figure 21. Map of the Augusta and Eldorado pools in Kansas and typical well log.

(After Hager)

Other Rocks.

The above include all important reservoir rocks, although small quantities of both oil and gas occur occasionally in crystalline rocks. At the recently discovered Thrall oil field in Williamson County, Texas, the reservoir rock is a basic igneous rock known as limburgite. It owes its porosity in large part to extensive alteration by circulating underground water. The oil and gas it contains are derived from the surrounding Cretaceous sediments with which this igneous rock is interbedded.

The Enclosing Beds of Reservoirs.

Reservoir rocks must be retained between rocks impervious to the circulation of oil, as, without these, we could expect no commercial accumulation. The most common type of enclosing beds are water-wet, fine-grained rocks, such as clays and shales. Occasionally, the enclosing rocks are similar to the reservoirs, but either so tightly cemented or so excessively fine-grained as to make the movement of oil through them impossible.

VIII. The Laws of Migration and Accumulation of Oil and Gas

In the preceding discussion we concluded that oil and gas are formed by the distillation of plant and animal remains which are buried in the rocks by natural causes at the time of their deposition. Of all sediments, muds are most prolific in organic remains. It seems highly probable, therefore, that by far the greater part of oil and gas was originally formed in shales. Since neither oil nor gas occur in any great quantity in this rock, we are driven to the conclusion that they have migrated from shale and have been concentrated in rocks more suitable as reservoirs.

Causes of Migration.

A number of different causes have probably been active in forcing such migration, chief among which we may mention the following:

1. Differences in specific gravity of gas, oil, and water.
2. Head of ground water.
3. Gas pressure.
4. Rock pressure.
5. Earth movement.
6. Heat gradient.
7. Capillary attraction.

Differences in Specific Gravities.

It is a well-known fact that gas is lighter than oil, and oil lighter than water. Oil and water are not miscible. Oil floats, therefore, on the surface of the water. Consequently, wherever oil and water are mixed in rocks under the earth's surface oil should be on the top, and wherever water moves through rocks, oil must be driven ahead of it. Many phenomena tend to show that ground water is seldom stagnant, but instead is subject to gentle and continuous circulation, and for this reason, many geologists see in the differences of the specific gravities of oil and water the most powerful cause of oil migration.

Head of Ground Water.

The water in the rocks of the earth's crust is known as ground water, or underground water. This water is under pressure which is known theoretically as "head". The head is the factor determining the height to which water will rise. "Head", therefore, causes water to flow, and for the reasons already mentioned, oil and gas are driven ahead of the water through the rocks. In many fields the head of the ground water has been determined and for a large number of cases proved to be equivalent to the pressure on the oil and gas as determined in the wells. Thus for many of the Ohio fields the pressure on the oil is equivalent to the head of water standing at the level of Lake Erie.

Gas Pressure.

The gas associated with oil is frequently under very great pressure. Maxima of fifteen hundred pounds to the square inch have been recorded. This pressure is of necessity exerted in all directions and may to some extent force oil to move through rocks. Gas pressure is of great importance in certain oil fields because it may be sufficiently great to force the oil through the well up to the surface of the earth and so produce flowing wells or gushers. It is probably not a very important cause of oil migration. Gas migrates in all directions far more easily than oil. Gas fields, therefore, are of larger extent than oil fields, and may be entirely distinct from them.

Rock Pressure.

Rocks underneath the earth's surface are under pressure equivalent to the weight of the column of rocks above them. With increasing depth this pressure may be so great that no openings can exist, and that the rocks will flow like wax. Such pressure is hydrostatic, that is, similar to pressure under water, equal in all directions. Rocks under such pressure are said to be in the zone of flowage.

As will be evident, the pressure necessary to bring about this condition will vary with the rocks. Rocks of high crushing strength, such as well-indurated sandstones, require a pressure equivalent to a burial of several miles; clay shales on the other hand, are in a condition of flowage after burial of three hundred feet and perhaps less. The effect of rocks whose pores and openings are saturated with oil or water will be similar to that of a sponge saturated with water and subject to pressure. The liquid and lighter material will be gradually squeezed out and forced towards the surface. Rock pressure is undoubtedly a very potent cause of oil migration, especially in rocks deeply buried. Below four thousand feet it is probably the most important cause of movement.

Earth Movements.

Earth movements, such as folding and faulting and tidal deformations, set up stresses and strains in the interior of the earth which have some stimulating effect on oil migration. Their importance is probably very slight.

Heat Gradient.

As we descend from the earth's surface, we find that the temperature increases at a more or less regular rate of 1° C for every fifty to one hundred feet. This regularly increasing temperature may have a slight stimulating effect on circulation. The general tendency will be to drive the liquids upward. Its importance is probably very slight, because of the great depth required for an effective temperature increase. Thus a burial of one mile is only equivalent to a temperature increase of 50° to 100° C.

Capillary Attraction.

The tendency of liquids to ascend minute openings and pores, such as those in sponges, is a result of capillary attraction. Any opening of tube shape and less than one-half millimeter (one-fiftieth of an inch) in diameter is a capillary opening. Liquids will tend to rise in such tubes against the effects of gravity. The height of such rise will depend upon the nature of the liquid, the size of the tube, and the material of the tube. The effective pressure that forces liquids to ascend such tubes, is capillary pressure. This is a function of the surface tension of the liquid and the attraction between the liquid and the tube. The greater the surface tension the greater the capillary pressure, consequently the greater the tendency to enter microscopic pores. Water has a surface tension three times that of crude oil. Water, therefore, exerts a capillary pressure three times as great as that of crude oil.

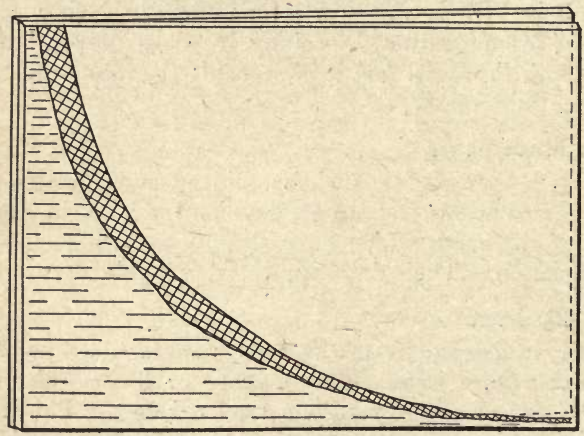


Figure 22. Rise of a Water-Oil emulsion between plates of glass as a result of capillary attraction. Cross-hatched area is oil. Note that on separating, the water has occupied the space of smallest size.

Considering the fact that a mixture of oil and water is disseminated through the rocks of the earth's crust, it will be evident that the differences in surface tension will cause a selective segregation of oil and water. The water, because of its superior surface tension, occupies the pores of smaller diameter; the oil is driven into the opening of larger size. Capillary pressure decreases with rise in temperature. Because of the increase in temperature due to heat gradient, it is virtually negligible in rocks at a depth of several miles.

Conclusions.

All the factors discussed separately, probably played a part in causing oil migration. To some extent, at least, their effects can be differentiated. The original sediments, which consist in greater part of muds with minor layers of sand or perhaps porous limestone, must suffer considerable compacting at the time of their consolidation into rock. The muds especially are subject to a considerable shrinkage of volume, which is mainly the result of rock pressure. The sands and limestones offer greater resistance to pressure and cannot be compacted to the same degree. Their pores will remain open and will serve as reservoirs for the liquid materials squeezed from the clays and mud. Capillary pressure also plays a role and probably the most important one, in affecting a primary concentration of oil and gas in the reservoir rocks. Thus in the progress of time, the oil and gas contained in the shales will be driven out by water because of its greater capillary pressure, and will be forced into the rock with larger pores —the reservoir.

Rock pressure and capillary pressure are chiefly important in collecting oil and gas in reservoir rocks. They will be disseminated through the entire formation, and only under very exceptional conditions can they be concentrated into commercial pools by rock pressure and capillary pressure alone. Oil pools in fissured shale may owe their existence mainly to such concentration.

In the majority of cases the concentration of oil and gas into commercial pools is the result of the differences in the specific gravities of oil, gas and water, and of the movement of the underground water. Oil and gas rise to the surface of the water, and wherever currents exist move ahead on the water surface through the reservoir rocks. A concentration of large quantities of oil and gas may take place where suitable structural conditions exist. The term "trap" is frequently applied to such a condition, and is quite appropriate.

Gas pressure and water pressure due to head are the most important causes of flowing wells, with one or the other dominant, depending upon local conditions.

Conditioning Factors of Oil Migration.

There are a number of conditioning factors upon which the movement of oil and gas are dependent. These are in part due to the characteristics of the reservoir, in part due to the oil, and in part due to local geological conditions. They are shown in tabulated form.

A. Lithological character of the reservoir.

1. Degree of porosity.
2. Size and continuity of pore space.
3. Degree of saturation by water.
4. Proportion of induced to original openings.
5. Composition of reservoir as determining relative adhesion.
6. Effectiveness of cementation.

B. Physical and chemical character of oil.

1. Gravity.
2. Viscosity.
3. Proportion of gas.

C. Geological factors.

1. Structure.
2. Character of enclosing beds.
3. Local heat gradient.
4. Composition of ground water.
5. Depth of burial.
6. Geological history.

The characteristics of the reservoir rock are quite important in determining the relative ease of flow. Ready flow is favored by:

1. High effective porosity.
2. Large and continuous openings or pores.
3. High proportion of induced openings, such as fractures, joints, solution fissures.

4. Presence of water under pressure.
5. Cementation effective enough to hold and support the sand upon removal of oil.

The characteristics of oil also condition its movements. Ready flow is favored by:

1. High degree gravity.
2. Low viscosity.
3. High proportion of gas.

The greater the difference in the specific gravity of oil and water, the more effective gravitative separation will be. The lower the viscosity of the oil, the less the resistance that is offered to movements through the pores of rock.

A number of geological factors influence flow. Thus, steep dips favor flow. Unconformities of the angular type are favorable to migration because of the more rapid concentration of oil from the lower series into the unconformable one above, due to the greater ease of travel along beds than across them. Certain sands are so friable that large quantities of sand are ejected from the wells. Oil flow is favored in these by the presence of strong resistant enclosing beds above and below the reservoir. Locally high heat gradient has the double effect of lowering the surface tension and decreasing the viscosity of oil. On the whole, the effect will be to stimulate circulation. The presence of sulphated ground waters is obnoxious because it results in the production of sulphur compounds in the oil and increases its specific gravity and viscosity. The latter two render the oil less mobile. Depth of burial determines temperature and pressure on the oil, the effect of both of which has already been discussed. The past geological history of an oil field often gives us an explanation of peculiar localization of oil pools. Frequent oscillations in elevation of a district result in changes in the water level and must of necessity stimulate oil movements.

Laws of Oil Accumulation.

The laws of oil accumulation, although relatively simple, were not clearly formulated until 1885. In that year, I. C. White published what is known as the "anticlinal theory". This is probably the most important single concept of oil geology which, in more or less modified form, governs oil accumulation in virtually all oil fields. In oil fields we do not find the sedimentary rocks flat and undisturbed as they were originally deposited, but we find them folded and wrinkled much like the quilt on our bed after a night's sleep. The upfolds or arches are anticlines; the downfolds or troughs are synclines. Experience has shown that the higher parts of the folds, that is, the anticlines, are more likely to carry oil. This is explained as follows:

The sandstones or limestones which act as oil and gas reservoirs are, in most cases, saturated with water. They are overlain and underlain by shale or some other rock which forms a more or less impervious cover. Oil and water, even if vigorously stirred up and shaken in a bottle will not mix, but will separate in two layers according to their weight—the oil on top, the water below. Similarly in the oil sand such a separation will take place. If the sand be completely saturated or filled with water, the oil will rise to the highest part of the reservoir—which is the very top or crest of the anticline. If the sands are only partially saturated, the oil will accumulate on top of the water level along the sides of the folds. If the sands are dry, the oil of necessity will be found in the bottom of the troughs—or, to use the geologic term, in the syncline. In by far the great majority of cases, the oil sands are completely saturated, and the oil accumulates therefore in the crests of the anticlines. These are the conditions met with in the most fields of Wyoming, California, and the Appalachians. Whether or not a sand is saturated can only be determined by drilling.

In many fields noticeable quantities of gas accompany the oil. This, being the lightest constituent present, rises to the top of the oil. The occurrence of gas wells, oil wells, and water wells on the same structure is explained by the fact that the oil sands are penetrated at different elevations; the gas well at the highest; the oil well at an intermediate; and the water well at a lower elevation. The accompanying figure makes this clear.

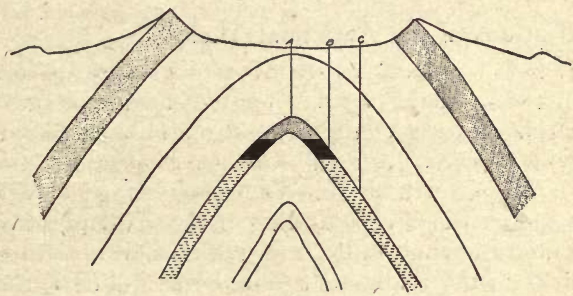


Figure 23. Section illustrating the occurrence of a gas well (A); an oil well (B), and a water well (C) on the same anticline.

There are a number of other structural arrangements of rock that afford suitable traps for oil accumulation. These will be discussed in some detail in the following chapter.

No matter what the structure may be, we must have a porous rock, usually a sandstone, that is capable of acting as a reservoir and that is enclosed in relatively impervious rock, usually shale. The arrangement of rocks must be such that there exists an opportunity for the accumulation of commercial quantities of oil and gas. The most important single factor in the locating of an oil well is, therefore, the geologic structure. The chief value of any geologist is his ability to determine the structure from the distribution and arrangement of the rocks at the surface, and to locate the favorable areas for testing. It may be well to emphasize the fact that a perfect geologic structure is not necessarily an assurance of a producing well. The presence of an oil-pool can only be determined by an actual test. The correct application of geologic principles does not ensure success; it minimizes risks. Under the most favorable geological conditions, drilling in untested and new areas has only about one chance out of three for success. On the other hand, a disregard of geological conditions in drilling a well is practically an assurance of failure.

Modifications of the Anticlinal Theory.

It is to be expected that this theory, since its formulation in 1885, should be subjected to considerable modification. Indeed, occasionally it appeared to be in actual variance with observed facts and was hence considered inapplicable. The growth of our knowledge of geology and a better and clearer understanding of the principles involved in the migration and in the occurrence of oil in nature have forced us to the realization that the accumulation of oils in various fields may occur under different conditions and that the characteristics, both geological and structural, of oil pools may so differ as to render plausible the belief that no single theory can explain all accumulations.

The fact that the characteristic features of oil pools differ in different fields is well expressed in the following words, "in any stated field, oil and gas exist after certain methods of 'habit' which are found to prevail generally throughout that field. This is because, while the substances adhere in their relations to the structures present, there are modifying conditions which cause certain peculiarities to run entirely through the field. In a scientific study of any oil field, for the purpose of determining its possibilities, it is necessary to distinguish the features which it has in common with other fields from those in which it differs from them, and by a process of comparison and inference based on detailed observations and calculations, to draw conclusions as to whether or not the locality is favorable for petroleum".

Oil men should realize the fact that the accumulation of an oil pool is the result of a number of more or less complex features all of which are a function of the general geological and structural characteristics of a given region. The oil pool should not be considered a geological entity independent of the region in which it occurs. The true significance of the productive structure can be properly understood only when we realize the fact that it bears an intimate relationship to, and is actually dependent upon, the geology and structure of the entire surrounding region. Studied from such a viewpoint, we gain the proper perspective and begin to correlate properly and to appreciate the true significance of observed facts. The geological and structural features of a pool in the Gulf Coast region of Texas will not be the same as the characteristics of a pool in Indiana or Wyoming or California. The ability to differentiate and recognize the importance of these characteristics marks the successful geologist. A great percentage of the unsuccessful ventures in drilling prospect wells is due to failure to realize these differences. The oil man or geologist may have had a wide experience in one field and become quite successful because the features of the geology and structure that lead to the accumulation of oil in this field are clearly recognized by him. When confronted with radically different geological conditions he has the tendency to apply the same familiar standards and judge accordingly, in most cases with fatal results. Indeed, much of the prejudice of the practical driller against geology is due to his unfortunate experience with some geologist who failed to understand and to apply correctly geologic principles. The failure represents not the failure of the science, but the faulty and imperfect application by a human being. The principles of geology are but tools, and the results accomplished by their use depend on the ability and genius of the man using them.

IX. Maps and Their Uses

Nearly every report on an oil field, whether a government report or one made for private interests, includes a map of some sort. This is not surprising because a great amount of information can be shown on a map in a condensed form and in such a way as to summarize clearly the important features of the region. Three kinds of maps are most frequently used. These are topographic maps, geologic maps, and structural maps.

Topographic Maps.

Topographic maps are intended to show the configuration or relief of the earth's surface, the distribution of the hills, valleys, mountains, streams, roads and similar features. The United States Geological Survey has completed over twenty-five hundred topographic maps scattered through every state of the union, each of which covers an area of from about two hundred to about three thousand square miles. These maps show the earth's relief by means of contour lines, which are lines drawn through points of equal elevation at a definitely stated interval, known as the contour interval, above sea level. On the government maps these contour lines are drawn in brown. Each fifth line is drawn heavy and has inserted at frequent intervals its elevation above sea level. The contour interval depends on the ruggedness of the country. In the western states it is usually fifty feet. Water is always drawn in blue, while the work of man—culture, as it is called—such as roads, buildings, railroads, and land divisions, is indicated in black. The spacing of contours indicate the slope. A long, gentle slope has few contours widely spaced; a steep slope has contours closely crowded. The accompanying figure shows an ideal sketch of a landscape and the corresponding contour map.

The relief features of the earth's surface are determined by the geological structure. Much useful information can therefore be obtained from a careful study of the topography or the topographic map. Crystalline rocks are very resistant to erosion. They usually form rough, irregular, and steep slopes. The topography is characterized by general ruggedness. Sedimentary rocks give a more varied topography. The well cemented sandstones and conglomerates and the limestones usually form the

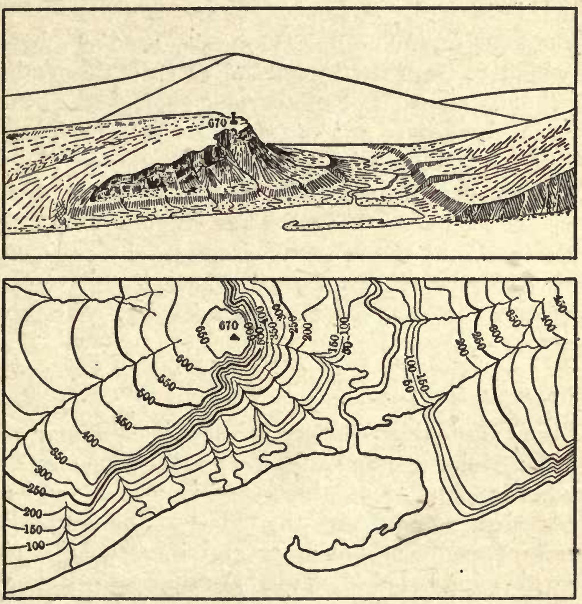


Figure 24. Ideal landscape and its contour map. (U. S. Geol. Sur.)

steeper slopes and the elevations; shales form the gentle slopes and the valleys. Horizontal sedimentary rocks produce a decided similarity in surface features over the whole area, so much so that almost any square mile of the area of the map may be substituted for any other without producing any marked change. Occasional buttes and mesas may remain as elevations. The streams have a characteristic, treelike or dendritic shape. Inclined sedimentary rocks produce a topography characterized by a linear arrangement parallel to the strike of the rocks. The hard layers form more or less parallel hogbacks, the softer layers the valleys between. The main streams usually cross hard and soft layers alike. The tributaries are confined to the softer layers and are arranged in a roughly parallel manner.

Geologic Maps.

The topographic map is frequently used as a base map upon which is recorded by means of suitable symbols or colors, the distribution of the various geological formations at the earth's surface. The structure of the rocks determines this distribution; conversely, therefore, the structure may be determined from the distribution of formations as shown by the map. Thus in dome folds we find the older rocks in the center surrounded by progressively younger rocks as we go outward. In a basin we find the younger rocks in the center surrounded by rocks progressively older.

Columnar Section.

Every geological report includes a columnar section intended for the purpose of interpreting the map. This is an arrangement of all the formations in a vertical column according to age, with the oldest at the bottom. The thickness of each rock member and its lithologic character are also indicated. Thus limestones are shown by masonry pattern; sandstones, by dots; and shales by closely crowded parallel lines. Intermediate rock types, such as calcareous shales, are shown by a combination of two such patterns. Certain beds of rock are located with great accuracy in the columnar section because they can be readily recognized, and hence are of value as "index beds" or "key horizons".

Structure Sections.

Most maps are accompanied by a structure section. This is a drawing of a vertical section through the earth's

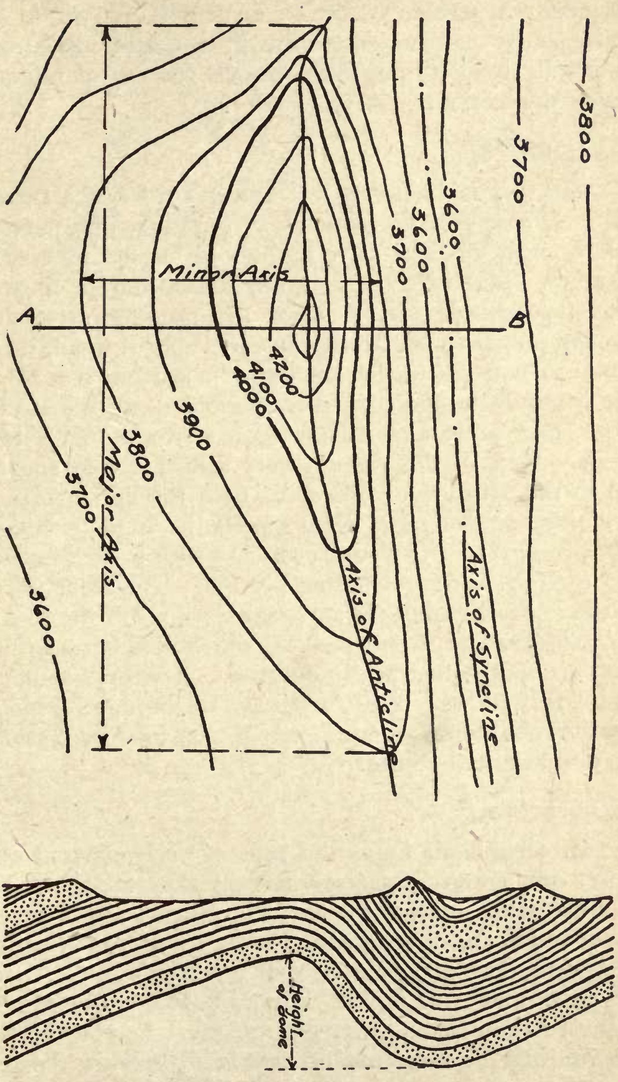


Figure 25. Map and section of ideal dome.

surface and shows the various rock formations in their true attitude. A structure section is usually drawn to scale, consequently we can determine by a direct measurement the depth down to any bed of rock for any point on the line of the section.

Structure Map.

Most of the maps of oil and gas fields are structure maps. These show the attitude or structure of a particular bed of rock, such as an oil sand, by means of structure contours. These are lines similar to the contour lines used on a topographic map. They are not, however, drawn through points on the earth's surface—but instead, through points of equal elevation on top of a certain bed of rock. The contours indicate by their arrangement the structure of the rock layer and its elevation above sea level for all points. Maps of this sort are very useful as they show at a glance the attitude of the rocks over the entire area covered, and at the same time enable us to determine the depth from the earth's surface to any rock layer whose position is given in the columnar section. The structure contours are drawn from the surface exposures of the rock and their observed dips and strikes, which enable us to calculate the depth to the rock in question. A structure map can be drawn with very great accuracy in the developed fields because reliable information can be obtained by a study of the well-logs and records.

Isochore Lines.

In certain oil fields the beds of rock exposed at the earth's surface are not absolutely parallel to the oil sand. As a result the normal distance between a certain layer of surface rock and the oil sand gradually diminishes in one direction. The rate of approach for two layers of rock is subject to much variation. It may be a few feet per mile or several hundred. This feature must be considered in interpreting the structure of any field, because the structure of the oil sand may not coincide with the structure of the surface rock. Hence, the area which appears to be

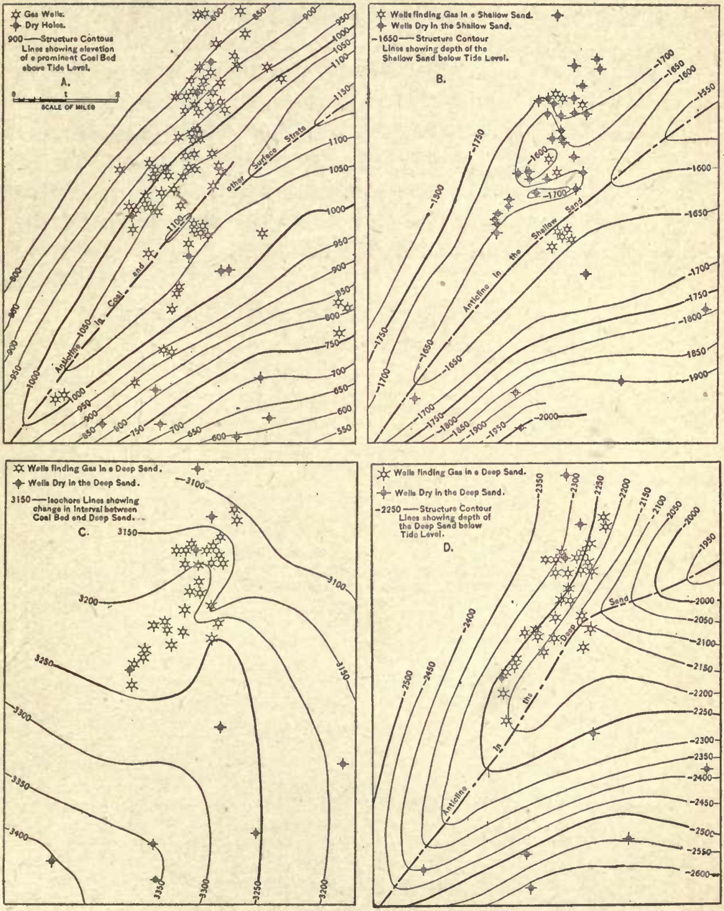


Illustration of an anticlinal gas field in Pennsylvania in which several sands are productive. A shows lay and dip of surface strata, with positions of all wells; B shows lay and dip of a shallow sand, with positions of wells drilled to it, C is a convergence map used in calculating the lay of the deep sand for D; D shows lay and dip of a deep sand, with positions of wells drilled to it.

Figure 26. The application of convergence maps.
(After Clapp)

favorable as judged from surface exposures may in reality be unfavorable in the productive horizon. For this reason it is necessary to determine the rate of approach of a certain keybed at the surface and the oil sand, and to construct a "convergence sheet", that is, a map which shows for all points the actual vertical distance between the keybed and the oil sand. This is done by means of isochore lines—that is, lines of equal distance which are drawn a definite interval apart. The convergence sheet—or isochore map—can then be superimposed upon the structure map of the key horizon and from the two, the structure map of the oil sand can be drawn.

X. Oil Structures

Structure.

Any arrangement of the rocks of such a nature as to form a trap suitable for the accumulation of commercial quantities of oil, is known as a "structure". Such may occur in a great variety of forms and in considerable complexity.

Classification of Oil Fields on Basis of Structure.

Experience has shown that the various oil fields have certain geological structures that are characteristic and distinctive, and that vary decidedly from field to field. The following classification of American oil fields is based on structure:

I. Fields with Folded Structure.
- The Appalachian field.
- Illinois.
- Oklahoma-Kansas.
- North Texas.
- North Louisiana.
- California.
- Wyoming.
- Colorado.

II. Fields with Monoclinal Dip (Homoclines).
- Ohio-Indiana.
- California (minor importance).
- Wyoming (minor importance).

III. Fields on Domes.
- Wyoming.
- Ohio.
- Louisiana-Texas (Gulf Coast).
- Mexico.

IV. Fields on Faults.
- California (of minor importance).
- Wyoming (of minor importance).

V. Fields on Unconformities.
- California
- Wyoming (of very minor importance).
- Oklahoma (Healdton ?)
- Quebec and Ontario.
- Northern New York.

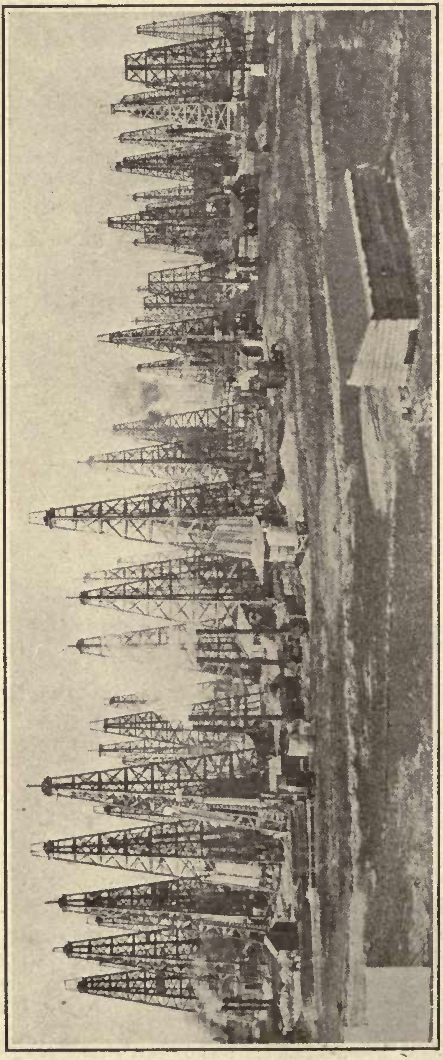


Figure 27. Spindle Top Field, Beaumont, Texas.
(After Ries)

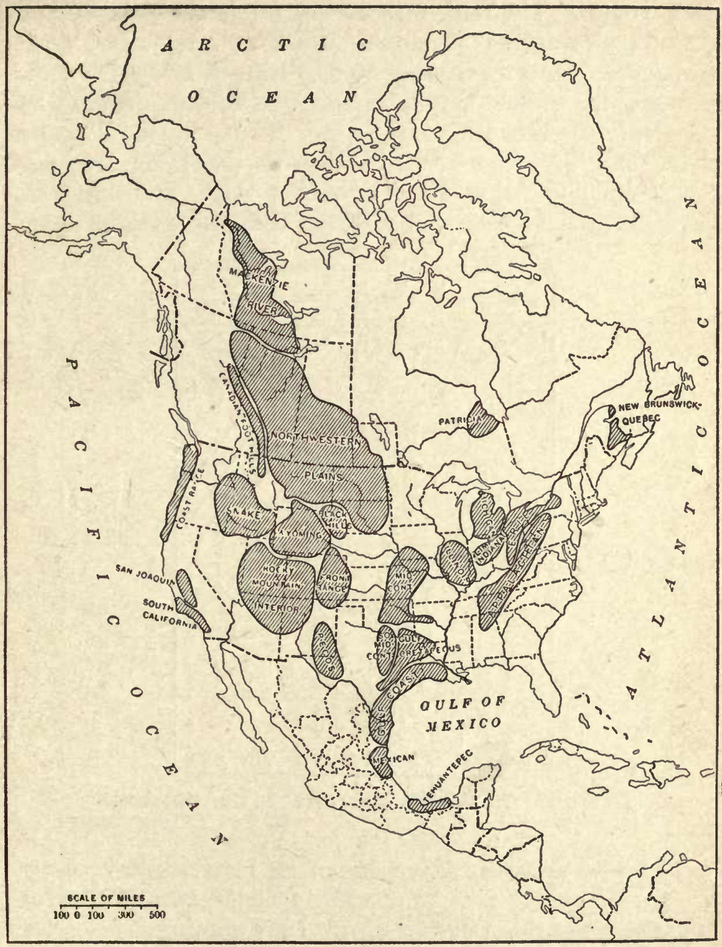


Figure 28. The oil fields of the United States.
(After Johnson & Huntley)

Fields with Folded Structure.

By far the greater part of the oil fields of the world are in regions characterized by folding. This is true of virtually all important foreign fields, such as those of Russia, Galicia, Roumania, India, Persia, Peru, and the Dutch

East Indies. The folds may consist of closely crowded and rapidly alternating anticlines and synclines, or of large isolated anticlines standing some distance away from the general area of folding. The degree of folding differs very decidedly in the different fields. Thus, in the Eastern fields and in Oklahoma and Kansas the folds are very gentle and show dips of a few degrees only. In sóme cases the dips of the beds are so flat that they can only be deter-

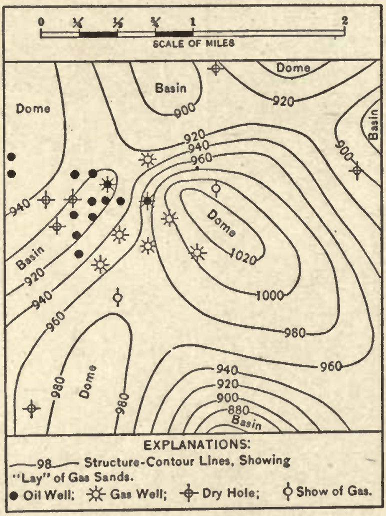


Figure 29. Oil Pool in structural basin, Oklahoma. (After Clapp)

mined with accuracy by means of an instrumental survey. In the Wyoming fields and also in Colorado and California, the rocks show steeper dips. In Wyoming dips of 45° are common. Vertical and even overturned dips occur in California.

The oil and gas pools may occur in all possible structural relationships on the folds. The location depends to a large part on the amount of water present in the reservoir rocks. In the majority of cases these are completely saturated, the oil and gas therefore occupy the crest of the

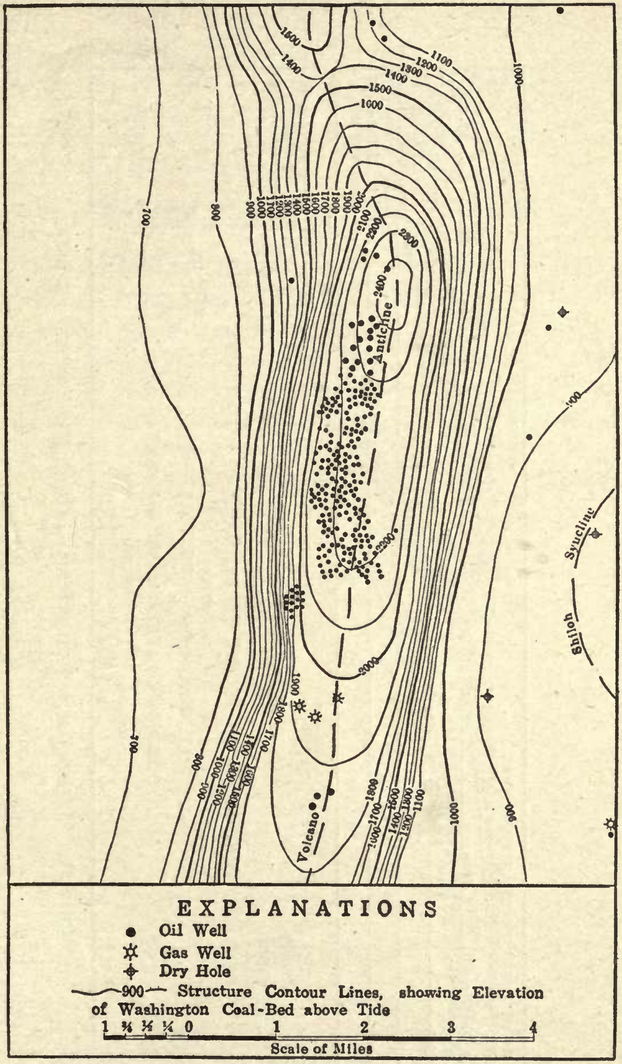


Figure 30. Oil field on the Volcano Springs anticline, W. Va. (After Clapp)

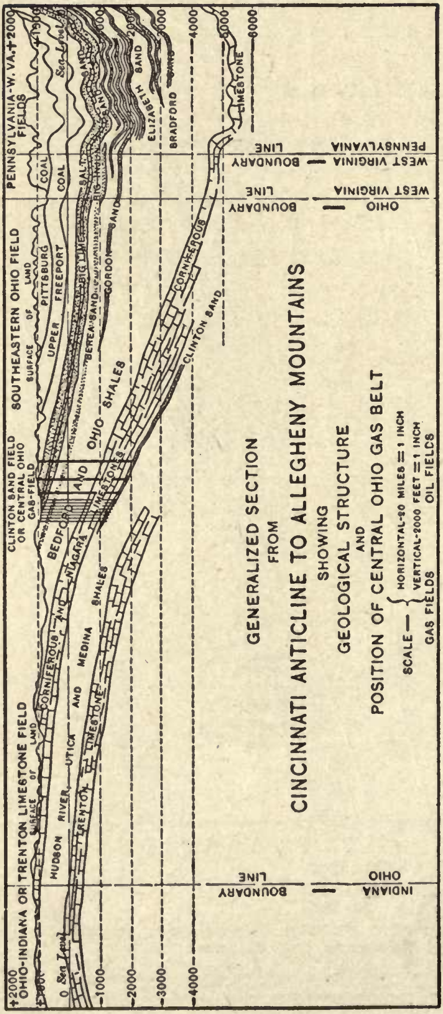


Figure 31. Idealized structure section through the Eastern oil fields.

anticline. This is true of all fields in Wyoming, and probably in Colorado, and in the greater number of fields in Oklahoma, Kansas, and California. Partial saturation means the location of pools on the limbs of the folds just above the water level. Dry reservoirs mean accumulation in the bottom of the syncline.

The accompanying maps show various types of accumulation.

The larger anticlines, which may extend fifty miles or more, like the Shoshone anticline in the Wind River Basin in Wyoming, usually are not simple folds, but undulate along the crest or axis. Thus they have higher points separated by saddles. The high dome-like bulges are called "structural highs," the saddles are called "structural lows". On the Shoshone anticline there are four well-defined structural highs which carry producing oil pools. These are

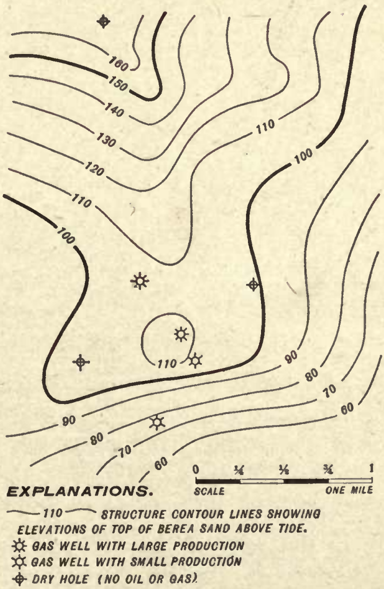


Figure 32. Gas on structural terrace in Ohio.
(After Clapp)

known collectively as the Lander Oil Fields. The Salt Creek Oil Field and the Teapot Dome in Wyoming represent structural highs on the so-called Salt Creek anticline which has a north and south extent of perhaps fifty miles.

Fields with Monoclinal Dip.

All fields in which the rocks show a general dip in one direction only will be considered under this heading. In general such a structure is unfavorable to oil accumulation. There are rare exceptions which may be summarized as follows:

Accumulations as a result of:

1. Change in rate of dip.
2. Change in direction of dip.
3. Lenticular structure.
4. Asphalt sealed sands.

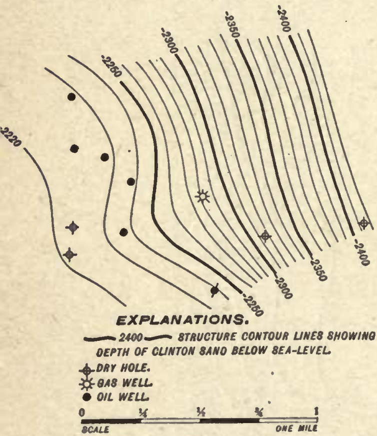


Figure 33. Oil accumulation due to change of dip. Ohio. (After Clapp)

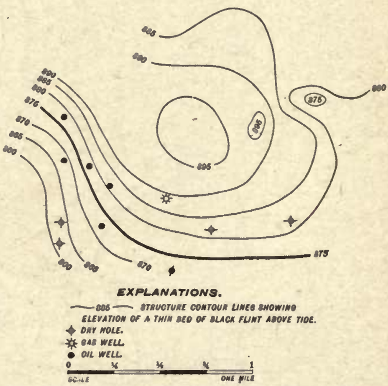


Figure 34. Surface structure on same area as in Figure 33. (After Clapp)

Structural Terrace.

A change in the rate of the dip sufficient to cause a noticeable flattening of the rocks produces a structure which is known as a "structural terrace" or as an "arrested anticline". The change in dip may be sufficient to retain oil and gas in commercial quantities. Terraces of this nature have been quite productive in the Ohio fields and elsewhere, but have not been tested out in Wyoming with the possible exception of the Big Muddy field, which may be considered to be a big terrace. In many cases an actual trap for oil and gas exists, in others, the oil is escaping on the updip side of the terrace. In the latter case there may be an accumulation because of the slow motion of the oil through the terrace and the relatively rapid addition of oil from the downdip side.

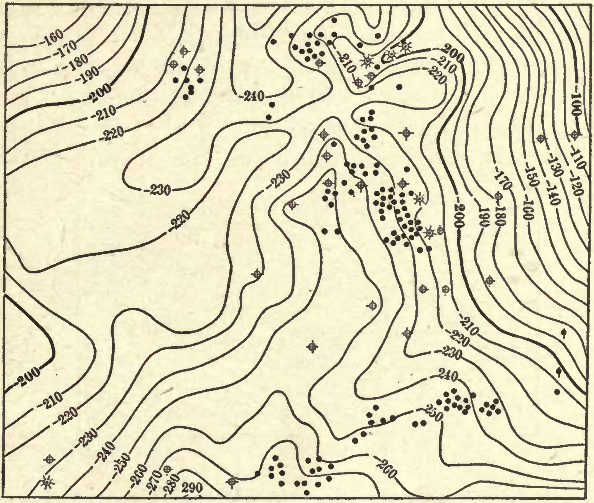


Figure 35. Oil accumulation on a structural ravine. Ohio. (U. S. Geol. Sur.)

Structural Ravines and Valleys.

A change in the direction of the dip may produce a sort of transverse wrinkle in the rocks which looks like a valley or ravine on the earth's surface. Folds of this sort are usually diagonal to the general slope of the rocks and die out gradually by flattening in the direction of their axes. They may entrap oil or retard its passage for a sufficiently long time to make a commercial accumulation possible. Many examples of such structures are known from the Ohio, Oklahoma and Pennsylvania fields.

Lenticular Structure.

In the preceding pages attention was called to the fact that many sandstones possess a lenticular structure, that is, they disappear by thinning in various directions. A lenticular sand of this nature enclosed in impervious beds and not actually outcropping would form an ideal reservoir for oil and gas. The gas sands of eastern Ohio are of this nature.

Asphalt Sealed Sands.

Oil-bearing sands that outcrop at the earth's surface usually give oil and gas seeps. Because of this fact they are frequently drilled down the dip in the hope of striking an oil pool. This is not justified unless there is evidence of the existence of a terrace or structural ravine. Certain heavy oils may carry so much base, especially in the form

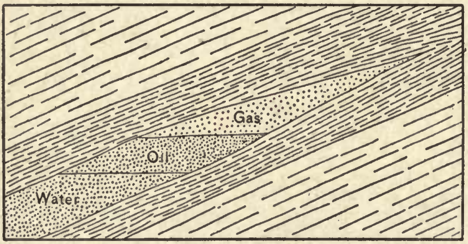


Figure 36. Accumulations in lenticular sands.

of asphalt, that this may clog up all the pores in the sand in the outcrop and so form an effective seal on the remaining oil. Such accumulations are reported from the Island of Trinidad. They are very rare, however, and need not be expected in the light Wyoming and Colorado oils, as these do not carry enough heavy base to seal a sand. A number of outcropping oil sands have been drilled down-dip, both in Colorado and Wyoming, but with disappointing results in every case.

Fields on Domes.

Some of the world's most productive oil fields are located on dome structures. Among the best known of

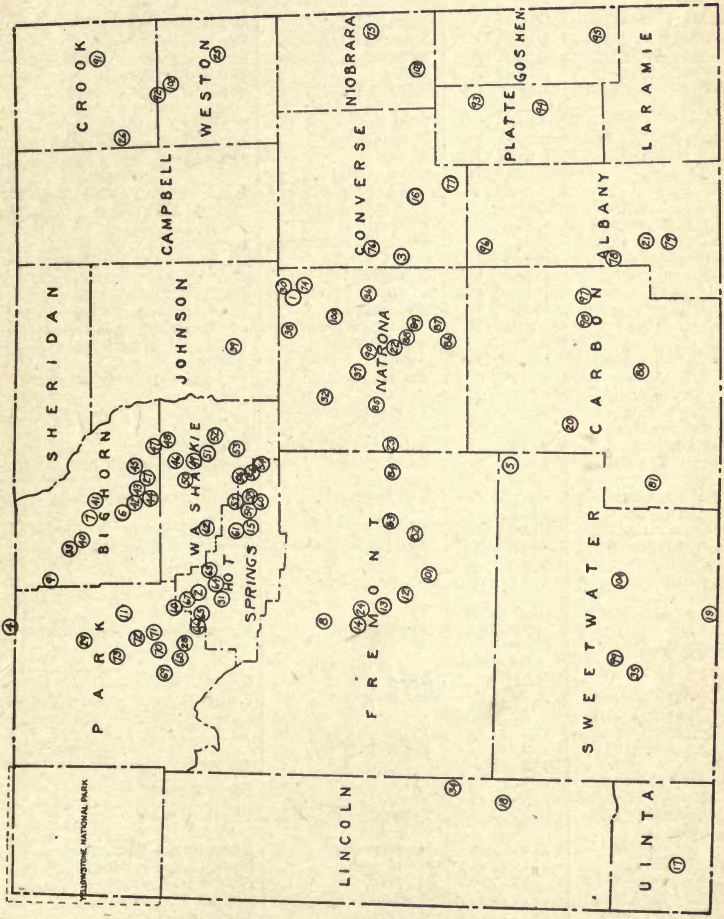


Fig. 37. Sketch map of Wyoming showing oil districts.

Oil Structures in Wyoming.

No. on Map Name	Produces	Formation at Surface	Formation Producing or Possible Producer
1—Salt Creek	Light Oil	Niobrara	Wall Creek
2—Grass Creek	Light Oil	Niobrara	Wall Creek
3—Big Muddy	Light Oil	Pierre	Shannon and Wall Creek
4—Elk Basin	Light Oil	Cody	Wall Creek
5—Lost Soldier	Light Oil	Niobrara	Wall Creek
6—Basin	Light Oil and Gas	Frontier	Mowry
7—Greybull	Light Oil	Frontier	Mowry and Dakota
8—Pilot Butte	Light Oil	Cody	Niobrara
9—Byron	Light Oil and Gas	Cody (Niobrara)	Wall Creek and Dakota and Morrison
10—Little Buffalo Basin	Gas	Pierre	Wall Creek
11—Oregon Basin	Gas	Cody (Niobrara)	Rusty Beds, Cloverly
12—Dallas	Heavy Oil	Chugwater	Embar and Tensleep
13—Lander	Heavy Oil	Chugwater	Embar and Tensleep
14—Sage Creek	Heavy Oil	Chugwater	Embar and Tensleep
15—Thermopolis	Heavy Oil	Chugwater	Embar and Tensleep
16—Douglas	Light Oil	White River Tertiary	Cretaceous sands and Basal White River.
17—Spring Valley	Light Oil	Aspen	Aspen
18—La Barge	....	Tertiary	Aspen (Mowry Shale)
19—Vermillion	....	....	....
20—Rawlins	....	Various	Embar ?
21—Laramie Plains	....	Pierre	Frontier
22—Oil Mountain	....	Sundance	Embar—Tensleep
23—Rattlesnake Mountains	....	Various	Embar—Tensleep
24—Washakie	....	....	....
25—Newcastle	Light Oil	Benton	Sandstone in Benton
26—Moorcroft	Light Oil	Benton—Dakota	Benton—Dakota
27—Bonanza	Light Oil	Mowry	Dakota
28—Sunshine	....	Mowry	Dakota
29—Cody or Shoshone	Light Oil and Gas	Frontier	Mowry—Thermopolis—Cloverly
30—Shannon	Heavy Paraffin Oil	Pierre	Shannon
31—Cottonwood	....	Mowry	Dakota
32—Cottonwood Creek	....	....	....
33—Alkali Butte	....	Mowry and lower	Dakota
34—Dry Piney	....	....	....
35—Rock Springs	....	....	....
36—Wheeler	....	Pierre	Wall Creek
37—Powder River Jct.	....	Mesaverde	Shannon—Frontier
38—Tisdale	....	Sundance	Embar—Tensleep
39—Kaycee	....	Morrison	Embar—Tensleep
40—Sheep Mtn.	....	Madison	Basal Paleozoic
41—Shell Creek	....	Morrison	Embar—Tensleep
42—Dry Creek	....	Cody	Frontier
43—Mercer	....	Sundance	Embar—Tensleep
44—Manderson	....	Cody	Frontier—Cloverly
45—Paintrock	....	Sundance	Embar—Tensleep
46—Nowood	....	Chugwater	Embar—Tensleep
47—Ziesman	....	Tensleep	Madison
48—Brokenback	....	Tensleep	Madison
49—Sherard	Oil and Gas	Frontier	Mowry—Cloverly

Oil Structures in Wyoming—Cont.

No. on Map Name	Produces	Formation at Surface	Formation Producing or Possible Producer
50—Well Area	....	Cody	Frontier—Cloverly
51—Tensleep	....	Mowry	Mowry—Cloverly
52—Bud Kimball	....	Chugwater	Embar—Tensleep
53—Mahogany Butte	....	Madison	?
54—Lysite Mtn.	....	Mowry	Cloverly
55—Black Mtn.	....	Mowry	Cloverly
56—Lake Creek	....	Frontier	Mowry—Cloverly
57—Zimmerman Butte	....	Cody	Frontier—Cloverly
58—Blue Spring	....	Thermopolis	Cloverly
59—Red Spring	....	Embar	Tensleep—Madison
60—Wildhorse Butte	....	Chugwater	Embar—Tensleep
61—Lucerne	....	Morrison	Embar—Tensleep
62—Neiber	....	Fort Union	Eagle—Frontier
63—Sand Draw	....	Cody	Frontier—Cloverly
64—Waugh	....	Cody	Frontier—Cloverly
65—Wagonhound	....	Cody	Frontier—Cloverly
66—Enos Creek	....	Cody	Frontier—Cloverly
67—Little Grass Creek	....	Cody	Frontier—Cloverly
68—Gooseberry	....	Cody	Frontier—Cloverly
69—Fourbear	....	Frontier	Mowry—Cloverly
70—Pitchfork	....	Mowry	Mowry—Cloverly
71—Spring Creek	....	Mowry	Mowry—Cloverly
72—Frost Ridge	....	Mesaverde	Frontier
73—Half Moon	....	Frontier	Mowry—Cloverly
74—Teapot	....	Pierre	Frontier
75—North Lusk	....	Morrison	Embar (Minnelusa)
76—Coal Creek	....	Mesaverde	Frontier
77—Poison Lake	....	Casper	Casper
78—Diamond	....	Pierre	Frontier
79—Big Hollow	....	....	....
80—Saratoga	....	....	....
81—Muddy Creek	....	Wasatch	Wasatch
82—Big Sand Draw	....	Pierre	Frontier
83—Rock Springs	....	Fort Union	Frontier
84—Dutton	....	Chugwater	Embar—Tensleep
85—Wallace Creek	....	Fort Union	Eagle—Frontier
86—Alcova	....	Tensleep	Madison ?
87—Bates Hole	....	Benton	Dakota
88—Goose Egg	....	Chugwater	Embar—Tensleep
89—Iron Creek	....	Frontier	Dakota
90—Pine Dome	Gas	Sundance	Embar—Tensleep
91—Sundance	....	....	....
92—Thornton	....	Benton	Dakota
93—Platte River	....	....	....
94—Wheatland	....	....	....
95—Meridian	....	....	....
96—Toltec	....	....	....
97—Medicine Bow	....	....	....
98—Simpson Ridge	....	....	....
99—Baxter	....	....	....
100—Castle Creek	....	Pierre	Frontier
101—Sweetwater	....	....	....
102—Upton	....	Benton	Dakota
103—South Lusk	....	Tertiary	?
104—Bitter Creek	....	....	....

these are the Gulf Coast fields of Texas, Louisiana, and Mexico; the Lima field of Ohio; and the greater part of the Wyoming fields.

Three types of domes may be recognized. These are Structural Domes, Saline Domes, and Volcanic Necks.

Structural Domes.

Dome structures which are the simple result of folding or arching of the rock of the earth's crust are "Structural Domes".

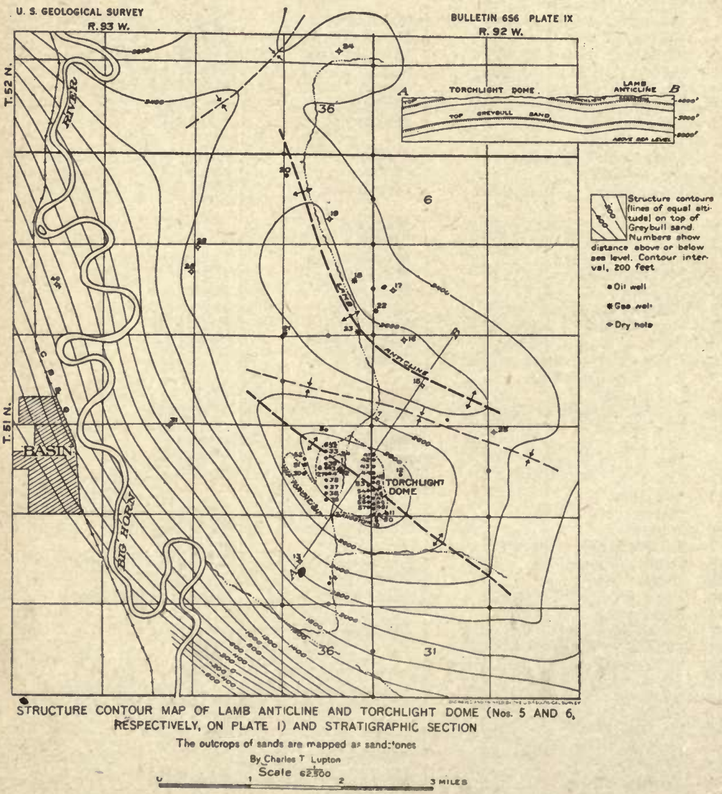


Figure 38. Structure map of Basin Oil Fields.

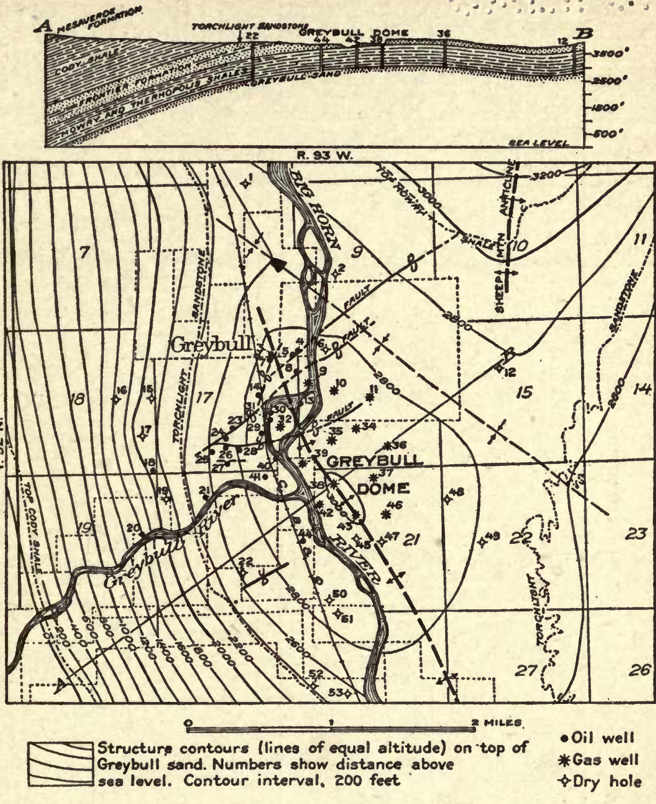


Figure 39. Greybull Oil Field.
(U. S. Geol. Sur.)

Wyoming, because of its complex geological structure, has a great number of such domes. Most of these are really "structural highs" on well-defined anticlines. Because of the great interest in these structures at the present time, they will be discussed in some detail. Figure 25 shows a structural section of an ideal dome and also its structural contour map. On the map the structure is shown by contours one hundred feet apart. A number of terms are defined on the figure such as major and minor axes of dome, and height of dome. The contours are

SECTIONS SHOWING OCCURRENCE OF OIL AND GAS IN SOME OF THE ROCKY MOUNTAIN FIELDS.

(Modified After Hares.)

[Correlations approximate and sections incomplete. o., Oil; g., gas; +, seeps or small production of oil or gas.]

System	Spring Valley and Labarge.	Big Horn Basin.	Lander.	Central Wyoming.
				White River. +
Tertiary.	Wasatch. +o.	Wasatch.	Wind River	Wind River. +?
	Evanston.	Fort Union.	Absent or concealed	Fort Union.
Tertiary (?)		Lance or Ilo.		Lance.
Cretaceous. Montana.	Adaville.	Meeteetse.		Lewis.
		Mesaverde, or Gebo Eagle.	Mesaverde	Mesaverde. Teapot. + Parkman.
	Hilliard.	Cody. Pierre Basin.	Mancos.	Steele. Shannon. o.
Colorado.				Niobrara.
				Carlile.
	Frontier. o.	Frontier. o. Torchlight. Peay (o.g.)		Frontier. Wall Creek. o. + Peay. +
	Aspen. o.	Mowry. o.	(+o.)	Mowry.
		Thermopolis. g.		Thermopolis.
	Bear River. o.	Cloverly. g. Greybull	Dakota.	Dakota. +
Cretaceous (?)	Beckwith.		Lower Cretaceous(?)	Lower Cretaceous Shale. Conglomerate +
		Morrison. g.	Morrison.	Morrison. +
Jurassic	Twin Creek.	Sundance	Sundance.	Sundance. +
Triassic.		Chugwater	Chugwater. +o.	Chugwater. +
Permian.		Embar +	Embar. o.	Embar. g.
Pennsylvanian.		Tensleep	Tensleep. o.	Tensleep. +
				Amsden.

SECTIONS SHOWING OCCURRENCE OF OIL AND GAS IN SOME OF THE ROCKY MOUNTAIN FIELDS.

(Modified After Hares.)

[Correlations approximate and sections incomplete. o., Oil; g., gas; +, seeps or small production of oil or gas.]

System	Douglas.	Black Hills	Boulder, Colo.	Florence, Colo.
Tertiary.	White River. o.g.			
	Fort Union.			
Tertiary (?)	Lance.			Laramie (?)
Cretaceous. Montana.	Fox Hills.	Fox Hills.	Fox Hills.	Trinidad. ?.
	Pierre. Parkman (?) Shannon ? +	Pierre. +	Pierre. Hygiene. o.g. (o.)	Pierre. (o.)
Cretaceous. Colorado.	Niobrara.	Niobrara.	Niobrara. o.	Niobrara.
	Benton. + o.g. Wall Creek ?	Carlile. +	Benton. o.?	Carlile. +
		Greenhorn.		Greenhorn.
		Graneros.		Graneros.
	Mowry. (o.?)	Mowry. o.		
	"Cloverly." o. +	Dakota. +	Dakota. +	"Dakota" +
		Fuson. +		
		Lakota.		
Cretaceous (?)	Morrison.	Morrison.	Morrison.	Morrison. +
Jurassic	Sundance.	Sundance.		
Triassic.	Chugwater.	Spearfish.		
Permian.		Minnekahta.	Lykins.	
		Opeche.		
Pennsylvanian.	Forelle (?). Satanka ? + Casper. +	Minnelusa. o.	Lyons.	
		Pahasapa. +	Fountain.	
		Englewood.		

SECTIONS SHOWING OCCURRENCE OF OIL AND GAS IN SOME OF THE ROCKY MOUNTAIN FIELDS.

(Modified After Hares.)

[Correlations approximate and sections incomplete. o., Oil; g., gas; +, seeps or small production of oil or gas.]

System		Western Colo.	San Juan, Utah.	Grand Co., Utah.
Tertiary.		Green River +		Green River. +
		Wasatch o.g.		Wasatch. +
Tertiary (?)				
Cretaceous.	Montana.	Mesaverde. o.g.		Mesaverde.
		Mancos. +		Mancos. +
	Colorado.			
		Dakota. +		Dakota.
Cretaceous (?)		Flaming Gorge		McElmo. +
Jurassic		White Cliff.	La Plata.	La Plata.
Triassic.			Dolores.	Pecos Valley, N. M.
Permian.			Moencopie.	Red Beds.
Pennsylvanian.			Goodridge. o.	Delaware. o.g.

closely crowded on one side, indicating a steep slope as is well brought out in the section.

Wyoming.

The accompanying sketch map of Wyoming shows the location of a number of structures through the state. The accompanying table summarizes such data as is available for a number of these. The rock formation at the surface and the possible oil horizons are indicated. In order to understand the table there is given a columnar section of the geologic formation of the Rocky Mountains. Oil and gas have been produced in commercial quantities only from the Cretaceous and the Carboniferous rocks. The most important production comes from the Wall Creek sandstone of the Frontier formation, followed in order by the Shannon sandstone of the Pierre formation, by a sand in the Mowry shale, the Rusty Beds in the Thermopolis shale, the Greybull sand in the Dakota, and possibly a stray sand near the base of the Niobrara. Gas under heavy pressure occurs in the Morrison formation. The oil from the Cretaceous rocks is a very high grade light paraffin base oil. The Carboniferous oil comes from the Embar and the Tensleep sandstones, and is a heavy black asphalt base oil of minor importance.

Of the Wyoming fields the most important producers are: Salt Creek, Grass Creek, Big Muddy, Lance Creek, Rock River, Elk Basin, Lander, Greybull, Basin, Pilot Butte, Lost Soldier, Douglas, and Byron. Wells of commercial capacity are reported from many other fields, including Thermopolis, Big Hollow, Notches, Osage, and Sherard. Gas has been encountered in large quantities in Oregon Basin, Little Buffalo Basin, Hidden Dome, near Worland, Pine Dome, Big Sand Draw, and Garland. Sketch maps of several of the more prominent fields are given.

Colorado.

The Colorado fields are in part located in regions of folded rocks, in part on monoclines, and in part on simple domes. Colorado is the oldest producing oil state in the

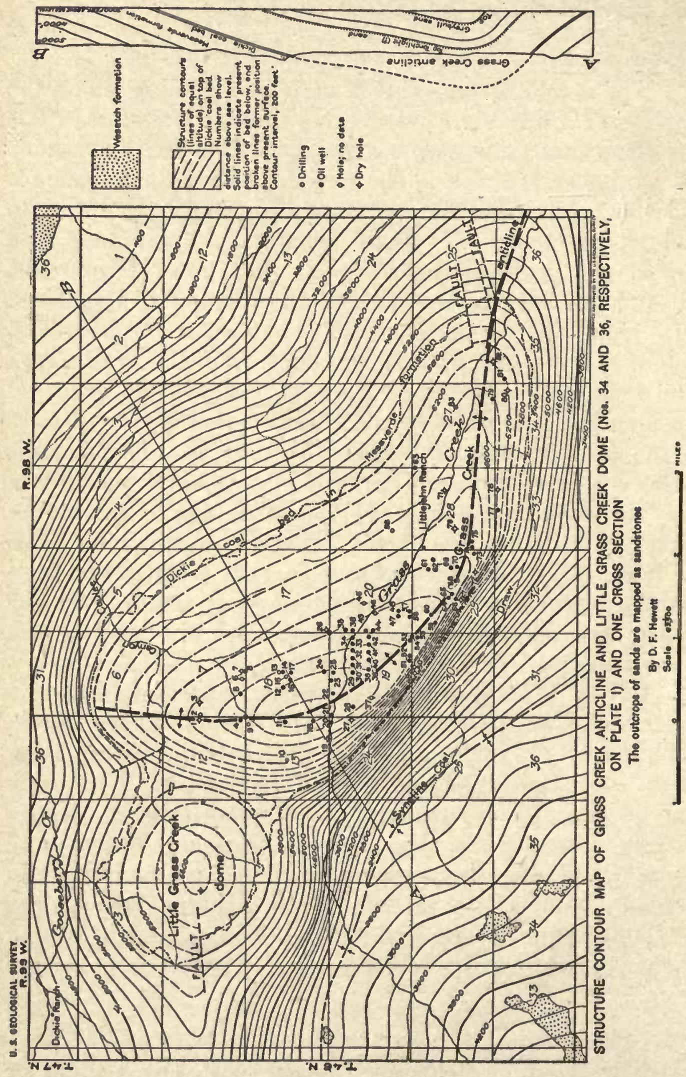


Figure 40. Grass Creek Oil Field.

Rockies. The first oil was produced in 1862 in the Florence District from an oil spring, since which time a small production has been maintained. The first well was drilled in 1876. This field is unusual in that the accumulation takes place in fissured shales and in open joints and is apparently independent of folding. The production of this district is declining rapidly.

The Boulder District was the scene of great excitement a few years ago. The production has always been small and has never exceeded one hundred thousand barrels in any one year. The accumulation here has taken place in a plunging anticline. The field is practically exhausted.

De Beque and Rangely.

A number of wells have been drilled near De Beque and Rangely in the northwestern part of the state. These have been unsuccessful although a small production of high grade oil could undoubtedly have been secured had it been desired. No attempt to secure this was made at that time because of the low value of crude oil. These wells obtained small flows of oil or gas in the basal part of the White River formation, the top of the Wasatch, the top of the Mesaverde, from sands in the Mancos shale, and from the Dakota sandstone. Favorable structures in these formations merit careful investigation, and, other geological conditions being favorable, promise to yield small capacity wells of high grade oil.

Eastern and Southeastern Colorado.

The foothills region is in general rather unfavorable to oil accumulation because of the absence of minor folds parallel to the main uplift of the Front Range. No large producing fields need be expected here, although small fields located structurally like Boulder and Florence may be discovered.

The Plains region is for the greater part of its area unfavorable because the Pierre shale, which with the underlying and interbedded sands is the most promising oil carrier, lies so deep as to be out of reach of the drills, or

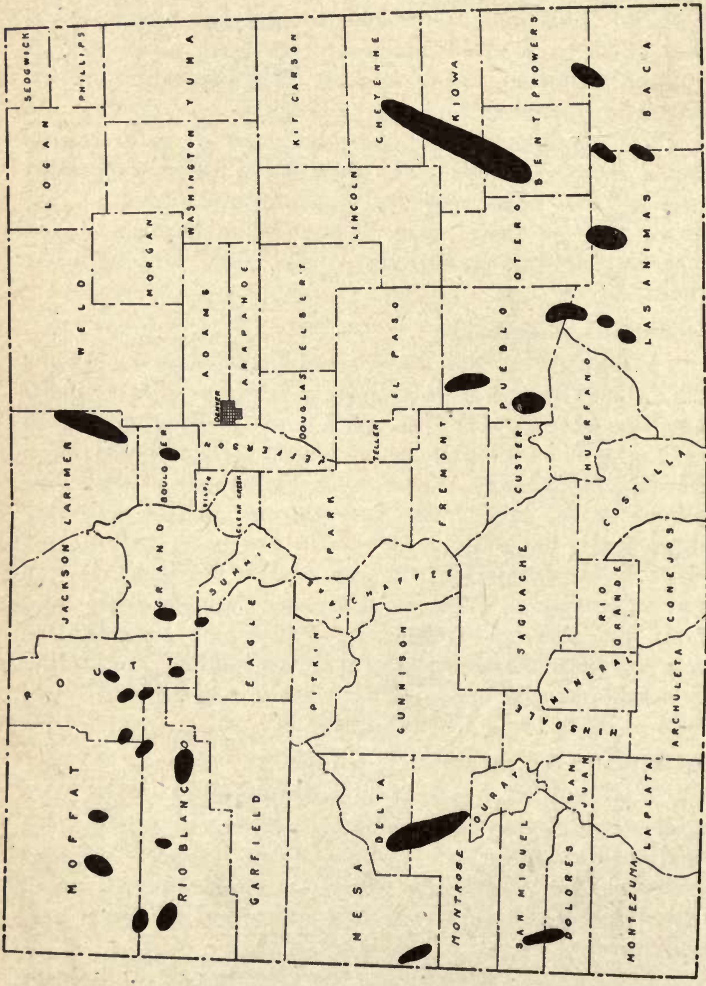


Figure 41. Sketch map of Colorado showing in black areas worth prospecting for oil.

is covered by unconformable Tertiary formations which completely mask the structure of the underlying rocks.

Much interest has been aroused in the southeastern part of the state, especially in Kiowa, Otero, Baca, Las Animas, Bent, Pueblo, and Cheyenne Counties. These undoubtedly deserve careful investigation, especially as these Counties contain good structures. In this part of the state as well as elsewhere, the Cretaceous formations are undoubtedly the most promising and should receive the most attention. The nearness to the Oklahoma line is frequently cited as proof of the likelihood and even the certainty of the existence of large oil pools. As a matter of fact the northwestern part of Oklahoma does not contain any important oil or gas fields. All of these are restricted to the eastern half of the state. A number of wells have been drilled in the western half of Oklahoma without success. The geological formations in this part are also distinctly unfavorable to oil. For these reasons the State Geologist of Oklahoma concludes that "the prospects for future development in this general region (northwestern Oklahoma), as evidenced by formational characteristics and by past drilling records, are not of the brightest." We may safely conclude, therefore, that the Carboniferous sands are no more promising in southeastern Colorado than in northwestern Oklahoma. Any attempts to drill for these Carboniferous sands should only be undertaken by those abundantly able to bear the financial burden and with the full knowledge that the chances for success are less promising than could be desired.

On the whole Colorado is less favorably situated with respect to oil than Wyoming. The section of the Cretaceous rocks is not as favorable because of the virtual absence of sands capable of acting as reservoirs. In addition, the structure of the Cretaceous rocks is relatively simple, consequently the possibilities of structural arrangements favorable to oil accumulation are far less than in Wyoming where the geological structure of the Cretaceous rocks is much more complex. Large fields need not be expected in Colorado. The possibilities are bright of finding a few

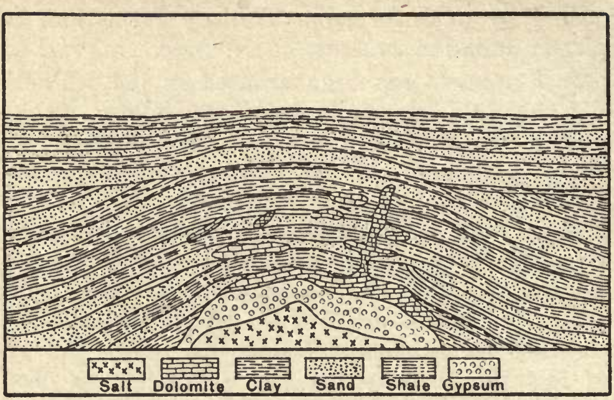


Figure 42. Section of saline dome.
(After Hager)

scattered fields with wells of small capacity that yield a high grade oil.

New Mexico.

There has been a great deal of interest in the oil possibilities of New Mexico during the past year (1919), and a great deal of exploratory work has been undertaken in this State. This is due to the stimulating high prices for crude oil and its products as well as the phenomenal development of the North Texas oil fields around Ranger, Burkburnett and Wichita Falls. Wildcat wells are being drilled at the present moment in various parts of the Pecos Valley, in the Tularosa basin, in the San Juan region, near Albuquerque, near Magdalena, near Columbus, etc. Small production of heavy oil is reported from the Seven Lakes district, northeast of Gallup and from the southern part of the Pecos Valley near Artesia.

Pecos Valley.

The greatest activity is in the Pecos Valley, which is located in the eastern part of the State, to the east of the front ranges of the Rockies. This district is, therefore, a transition from the Plains region with its nearly horizontal rocks, to the Rocky Mountains, characterized by decided well developed folding. The Pecos Valley and the adjacent part of the Pan Handle of Texas is characterized by flat dips generally easterly, broken by a great number of very gentle folds. The geological conditions and the structure here are in many respects similar to those in the Mid-Continent oil fields, of which this area may be considered to be a possible westward extension. The surface formations are usually red beds of Triassic to Permian age. The topography shows a decided tendency to conform to the structure. Production is expected in the Pennsylvanian and possibly Mississippian formations. Huge gas flows have been encountered in wells drilled at Amarillo, Texas, one of which is reported to have the largest capacity of any gas well in the Mid-Continent field. Small flows of oil are reported from wells near Artesia and Roswell. Encouraging shows of oil and gas are reported from Tucumcari. Several wells drilled on the Anton Chico Grant, northwest of Santa Rosa, were somewhat disconcerting. These were drilled into granite and failed to encounter the Carboniferous formations in which production was expected. As is naturally to be expected, a great deal of the drilling is done ill-advisedly and consequently with very slight chance of success. On the whole, however, enough work has been done to prove the generally petroliferous character of the Carboniferous formations. One discouraging feature is the scarcity of capable reservoir rocks in them. Wherever these are present, a proper structure is sufficiently promising to warrant drilling.

San Juan Basin.

The San Juan Basin is located in the northwestern part of the State. The greater part of this basin lies in the adjacent portions of Utah and Colorado. The basin itself is a synclinal depression practically surrounded by towering mountain ranges. From the standpoint of structure and geology this district is a part of the Rocky Mountain oil fields. The formation of interest as a possible oil producer, is the Cretaceous. This is in some respects similar to the Cretaceous farther north in Colorado and Wyoming. It differs in that the marine shales (known as the

Mancos) are very much thinner and seem to lack capable reservoir sands. The upper part of the Cretaceous (the Mesaverde formation) comprises a thick series of alternating sandstones and shales and thick coal beds. The sandstones are the dominant members of this series and are so abundant as to hinder an effective concentration of oil. Shows and seeps of oil in these sands are quite common throughout the entire area. It is very improbable that large production will ever be encountered in this formation, but the chances of getting small wells on pronounced structures in this general area must be considered promising. A number of wells yielding small production have been brought in in Utah and several in the Seven Lakes district in New Mexico. The whole area is seriously handicapped by the absence of railway connections and it is unlikely that any development here can be profitable under present conditions because of transportation difficulties, the general high cost of operation, and the small production met with to date.

Lima, Ohio.

The Lima field of Ohio is located on a huge dome fold that extends over the entire state and which is known as the Cincinnati anticline. The dips of the fold are so gentle as to be unapparent to the eye. The Trenton limestone of the Ordovician age is the oil reservoir and formerly was a very important producer. Folds as broad and of such large extent are frequently called ge-anticline.

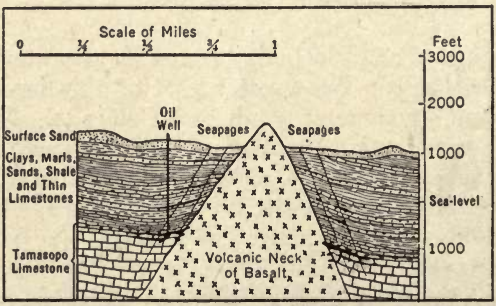


Figure 43. Idealized section of Mexican oil structure of volcanic neck type.

(After Clapp)

Saline Domes.

The oil fields of the Gulf Coast of Texas and Louisiana are characterized by deposits of salt and by salt springs. They are usually of rather limited extent, and appear occasionally as slight elevations above the plains. The first of these domes discovered, was the Spindle Top field at Beaumont. This covered a surface area of only three hundred acres but produced the largest gusher of the United States—known as the Lucas well—which had an initial capacity of seventy-five thousand barrels per day.

The salt usually occurs in the center of the dome and at a considerable distance under the surface. There is a tendency for the saline domes to be arranged in two sets in parallel straight lines intersecting at nearly ninety degrees. This has led geologists to the belief that the domes are located at the intersection of major faults or lines of weaknesses along which the circulation of underground water is stimulated. At the intersection of two such faults, salt is crystallized out, making room for itself by bowing up the overlying rocks and producing the dome.

Others have explained the domes as the result of the deposition of salt around mineral springs simultaneously with the deposition of the enclosing sediments on the ocean bottom. After elevation the sediments were compacted and settled down around the core of salt and thus produced the dome.

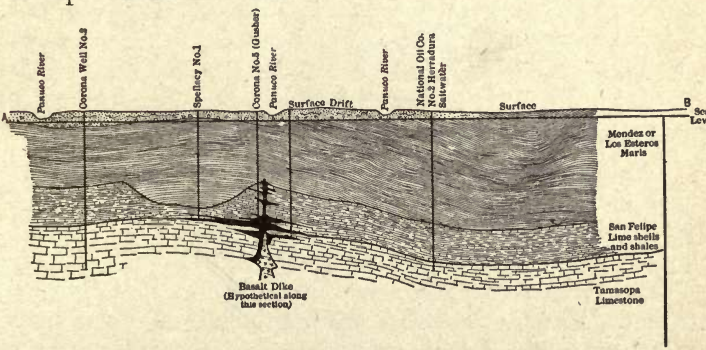


Figure 44. Section through Mexican oil field.
(After Johnson and Huntley)

Volcanic Domes.

The most productive wells in the world occur in Mexico in fields that owe their presence to intrusion of igneous rocks as necks or plugs. The igneous rock in forcing its way through the practically horizontal sediments has arched them slightly, has fractured and shattered them, and thus has produced both a reservoir and a suitable structure.

The structure resembles to some extent a funnel. This is the result of arching or bowing up of the sediments all around and for some distance away from the igneous rock at the time of intrusion, followed by a dragging downward of the edges of the sediments at the very contact due to shrinkage of igneous rock on cooling. A characteristic volcanic dome is shown in Figure 43. The volcanic domes similar to the Saline domes are apparently localized in intersecting straight lines which represent lines of weakness in the earth's crust.

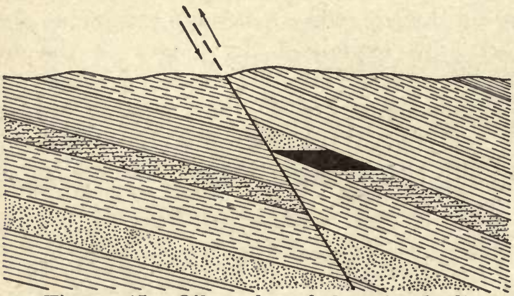


Figure 45. Oil pool sealed in by fault.

Fields on Faults.

Faults have in some instances exerted a beneficial effect in bringing about a concentration of oil. This is due to the fact that they carry finely ground up rock of claylike appearance known as gouge, which is impervious to water circulation, and hence may serve as a seal on an oil sand. Large production has been obtained under such conditions in the Los Angeles field in California as well as elsewhere.

In southwestern Wyoming a huge north and south fault exists known as the Absaroka fault, along which there are a number of oil springs and seeps. A small production has been obtained from sands sealed by minor faults in the Douglas field of Wyoming.

In the case of faulted strata, only one side affords the right conditions for accumulation. This depends on the inclination of the fault plane and the strata. The accompanying figure indicates why on one side of the fault we obtain a water well, on the opposite side, gas or oil.

Fields on Unconformities.

The gas fields of northern New York which are located in the Potsdam sandstone, occur at an uncon-

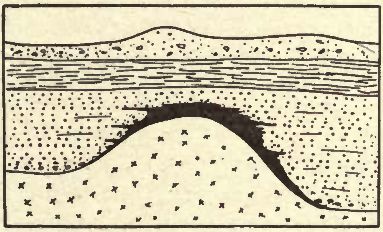


Figure 46. Gas pool at unconformity. New York. (After Clapp)

formity below this formation. The gas is concentrated in commercial pools on the top of the old hills left in the older erosion surface below the unconformity (see figure 46). In a similar manner commercial gas accumulations occur in Quebec and northern Ontario.

Small oil pools in the Brenning Basin near Douglas, Wyoming, owe their existence to an unconformity. Here the oil bearing Cretaceous rocks have a homoclinal structure with northeasterly dips of about 20° to 24°. Tertiary rocks have been deposited across their beveled edges. The Tertiary clays are impervious enough in some cases to seal the underlying Cretaceous sands, and so cause a small accumulation. It will be evident, however, that by far the greater part of the oil originally present in the Cretaceous rocks in this field must have been dissipated at the earth's surface during the time that these rocks were tilted and eroded down to the flat surface on which the younger Tertiaries rest. All wells in this field are of very limited capacity and short life.

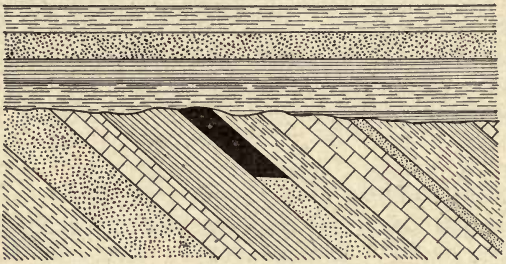


Figure 47. Oil pool on an unconformity. Wyoming.

Summary.

By far the great majority of oil fields occur on folded rocks. Anticlines and domes are the most favorable structures and should be the first to receive attention. In regions of monoclinal dip, that is, wherever the strata are inclined in one direction only, accumulation may take place on a structural terrace or structural ravine, or perhaps in a lenticular sand. Wherever igneous rock has been intruded in the shape of volcanic necks or plugs, there may have been sufficient structural disturbance to cause favorable conditions for oil accumulation. This is true only under exceptional conditions. The same holds for faults which may serve to seal in small oil or gas pools. Most eccentric of all accumulation and probably the least reliable, are the gas and oil pools on unconformities.

In the majority of oil fields, pools may be expected to occur in a number of these structures. Every type of accumulation is known in California with the exception of that around volcanic necks. In Oklahoma, pools are located on anticlines, domes, structural terraces, and lenticular sands. Certain of the oil-bearing sands of Pennsylvania, Kentucky, and Oklahoma are dry. Oil pools are, therefore, localized in the synclines and basins in some of the pools in these fields.

XI. Popular Fallacies in Oil Geology

Not all Rocks Carry Oil.

One of the erroneous statements frequently made is that "all rocks carry oil"; consequently, that all that is necessary to warrant drilling is a favorable geologic structure. This is by no means true. The crystalline rocks are nowhere producing commercial quantities of either oil or gas. As a matter of fact there is no probability of ever obtaining a production except from the sedimentary rocks. Neither do all sedimentary rocks carry oil and gas. The rocks deposited in deserts or by mountain torrents are formed under such conditions that life forms cannot flourish. Consequently they do not contain the raw materials necessary for the production of oil or gas. The marine sediments, especially those deposited near the shore, are the most favorable because here life of all kinds is abundant. As a matter of fact probably every marine rock analyzed with sufficient care will yield at least a trace of oil. Such sedimentary rocks are usually dull colored—gray, black, brown, or dark green. The bright colored sediments, especially the bright red ones, are distinctly unfavorable as oil producers. There is no reason, however, for condemning marine sediments above or below red beds. These may be productive, as are the Embar and Tensleep formations below the Chugwater Red Beds of Wyoming.

Again it is well to realize the fact that commercial production can be expected only where suitable reservoirs and enclosing beds exist. We must have sands or sandstones open in part, or perhaps porous limestones, imbedded in shales or other impervious rock. In the case of producing fields, shales are usually three or more times as thick as the sands. In Wyoming, the shales are from six to ten times as thick as the sandstones. A series of marine rocks, essentially sands, is so porous that oil and gas are disseminated in small quantities throughout the whole formation and are not concentrated sufficiently to be of value. A number of sands may occur, all of which appear to be favorable for oil production in a certain field. Nevertheless, only one or two of these may afford commercial pools. The results of a thorough test are the most valuable guide in determining the oil possibilities of the sand in other structures in the same field, and should be carefully considered in making future locations.

Drill Deep.

Very frequently the statement is made that all that is necessary to secure oil is to drill deep enough, and the failure to obtain oil in a well is explained as lack of depth. This is possibly true in the case of an individual well correctly located on a structure, but as generally applied, the statement is fallacious. To drill without the knowledge that the well is actually on a favorable structure and that in depth we may hope to strike a favorable reservoir, is a waste of money and time. Whenever this argument is presented it is well to call to mind the fact that if depth were the only requisite to a producing well, the investor would probably prefer to sink wells in his own back yard, where markets and transportation facilities are at hand.

"Favorable Indications."

A great many popular misconceptions center about the so-called "favorable indications". Among these we may include the following:

1. Oil and gas seeps at the surface.
2. The presence of salt water.
3. The presence of oil residue in rocks at the surface.
4. The presence of "oil shale".
5. Traces of gas and oil in wells.

Seeps.

Wherever oil and gas escape from rocks at the earth's surface we have a "seep". The quantities that escape may be, and usually are, very slight. The presence of such seeps is frequently cited as a proof of the existence of oil pools under the surface. This is not necessarily their true significance. They only prove that the formation does carry oil, and that it would be *worth drilling provided a suitable structure* could be found. Only from this standpoint are oil seeps "favorable indications". Seeps are most common along the outcrops of the reservoir rocks. This rock, therefore, could not be considered a possible producer at the point of the seep. Some distance away, however, there may be an anticline or dome which carries this reservoir rock at a drillable distance under the surface. Under such conditions, the fact that a seep is known to

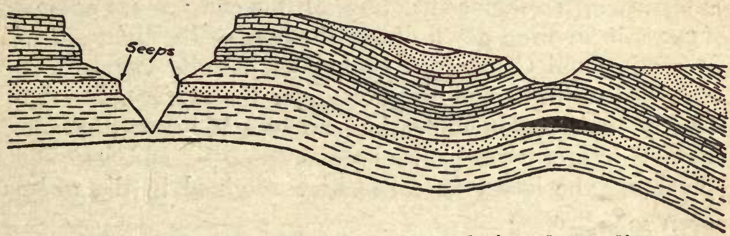


Figure 48. Oil seeps and accumulation down dip.

exist some distance away in the outcrop, is an encouraging feature. Seeps occur under a great variety of conditions. In very many cases these are such as to preclude all probability of the presence of commercial pools. A seep may then indicate that the oil is being dissipated and not being retained. Seeps are only of value as proving the petroliferous character of a formation. In themselves they are no justification whatever for drilling a well or locating an oil claim.

Salt Water.

The salt water so commonly met with in oil wells represents the ocean water which was originally included in the pores and openings in the sediments at the time of their deposition on the ocean floor. Water so occluded and retained is also known as connate water.

The frequent association of brine with oil has led to the popular belief that salt water invariably indicates the presence of oil. This is by no means true. Brines may or may not be accompanied by oil. The presence of salt water is, therefore, of no particular diagnostic value.

Residual Deposits.

Asphalt or paraffin in the surface outcrop of rocks has practically the same significance as have oil and gas seeps. They prove that the formations are petroliferous, but do not indicate that an oil pool is located beneath them. Drilling down dip from the outcrop in such rocks has only a bare chance for success in the case of asphalt base oils. Unless there is a favorable structural condition, such as a terrace or lenticular structure, all the chances are against success in drilling down dip in the case of the light oils of Wyoming and Colorado. Asphalt or paraffin met with in a drilled well at some distance under the surface, is a distinctly unfavorable indication, because it proves that the lighter hydrocarbons have been evaporated and lost and that only the heavy base has been retained in the rocks.

"Oil Shales."

Oil shales are clay rocks rich in bituminous material which, on destructive distillation, yield oil and gas. Considerable heat is necessary to obtain the oil. Probably by far the greater part is not present as oil but as an organic residue which breaks up into oil when heated. This is corroborated by the fact that shales which carry as much as eighty gallons of oil to the ton, are not in the least greasy and do not show visible oil. The oil shale of the Green River formation covers large areas in northwestern Colorado, southwestern Wyoming, and northeastern Utah. The shales are at the earth's surface exposed to erosion, and have probably no significance whatever as far as possible oil fields are concerned.

Oil and Gas Showings in Wells.

Oil and gas in small quantities may be disseminated through all marine shales, and may be localized occasionally in small porous streaks under conditions where no commercial quantities could be expected. A showing of small quantities of either oil or gas in a well is, therefore, not a necessary proof of the existence of, or of approach to, an oil pool.

Summary.

"Indications" so far mentioned are only of value in proving the fact that a certain formation carries oil. They do not indicate commercial accumulation under the surface. Drilling should be undertaken only on a favorable geological structure in rocks proved petroliferous. The following table of "indications" (modified after Craig), shows under what conditions a formation may prove a favorable or an unfavorable one to prospect, provided a suitable geological structure exists.

Indications of Oil.

(After Craig)

Favorable			Unfavorable	
Always	Usually	Sometimes	Usually	Always
Shows of oil and strong gas in thin beds in shales.	Shows of filtered oil and gas.	Shows of oil and little gas.	Evidence of true marine conditions.	Shows of oil in thick porous beds with much water.
	Evidence of shore conditions.	Beds of gypsum and rock salt.	Gas shows and water in porous beds in shale.	Hot water and no oil or gas.
	Shows of gas under thick shales.	Sulphuretted Hydrogen and hot water.	Partially evaporated oil deep down.	
	Paraffin and asphalt in surface.			

Divining Rod.

Belief that an oil pool can be located by means of the divining rod, a forked willow twig or by instruments of various sorts is a survival of the superstition of the middle ages fostered by the charlatan. There is no scientific basis for such belief.

XII. Prospecting and Developing Oil Lands

Prospecting for oil consists of two distinct operations; namely, the prospecting for areas of suitable rocks, and the locating of favorable structures.

Prospecting for Areas of Petroliferous Rocks.

In the preceding chapter "Popular Fallacies in Oil Geology", the so-called "Indications" of oil were discussed in some detail. These include oil and gas seeps and springs, the occurrence of salt water, the presence of residual bases such as asphalt and paraffin at the earth's surface, and oil and gas "showings" in wells. None of these prove the existence of oil pools; they are simply evidences of the fact that the rock formations carry petroleum. Other points have to be considered, and their effect may be such as to make an oil and gas seep a distinctly discouraging feature.

Characteristics of the Formation.

The problems of oil accumulation are intimately connected with the problem of its origin. Oil is derived from organic material, both plant and animal remains, which are buried in the finer sediments, the muds, clays and oozes at the time of their deposition. Because of the fine and dense character of these sediments and of the presence of salt water, the organic remains were protected from rapid decomposition and suffered only a sort of selective putrefaction which subsequently resulted in the formation of oil. This change was in part due to increasing pressure and temperature, and in part due to the action of bacteria. All important oil accumulations are the result of the chemical or bacterial alteration of organic remains. By far the greater part of oil is formed in the fine grained sediments, those that ultimately form shales, and, to a lesser extent, sandstones.

The lithological characteristics of the formations within reach of the drill are, therefore, of the utmost importance. We must know that these rocks were originally petroliferous, that is, carried the raw materials from which oil and gas could be produced. Marine strata, especially those showing evidence of shallow water or near shore conditions at the time of their deposition, are the most favorable. No important accumulations need be expected in rocks of strictly continental origin.

Lithological Characteristics of Possible Reservoirs.

Another feature of importance to be considered is the presence of suitable reservoir rocks within or near this formation and so spaced and enclosed as to be capable of retaining the oil concentrated in them. Without such reservoirs it will be impossible to concentrate the oil into a commercial pool. In possibly 95 per cent of the producing fields sandstones or sands are the reservoirs. In any new structure or new field it is of the utmost importance to determine the following features if possible:

A. Are the sandstones saturated with water? This will determine the position of the pool in the structure. In dry sand the oil would be in the syncline or basin. In a saturated sand the oil would be near the crest of the dome or on the axis of the anticline.

B. Are the sands lenticular or continuous? Lenses of sand may too small in area to catch sufficient oil. Widely distributed and continuous sandstone beds offer a large collecting surface to the migrating oil, a condition which is distinctly favorable. The shape of the sandstone beds is in many fields the factor determining the accumulation.

C. Are the sandstones porous or tightly cemented? An open and friable sandstone has the pore space available to carry oil. Tight sandstones may not be worthy of consideration as possible reservoirs. Frequently there are local differences in the degree of cementation, and a sand open and porous in one spot may be tightly cemented in another. A realization of this fact may make it possible to avoid the areas of induration. Frequently this is impossible, but the knowledge that this feature prevails is of the utmost importance to the driller.

D. Another feature to be considered is the position of the sand with respect to the petroliferous formation. The most effective migration of oil is probably in a vertical direction upward. A sand resting directly upon the petroleum producing formation would therefore be in a much better position than a reservoir sand below the series. This is well shown in Wyoming by the Wall Creek sand, which rests directly upon the marine shales of Benton age. These shales are compact and close grained sediments quite rich in organic matter, and represent the most important source of the Wyoming oils. At the base of these shales we have the Muddy and the Greybull sands. While these carry oil and gas locally, they are nowhere as productive as the Wall Creek above.

The presence of more than one sandstone or reservoir rock is an encouraging feature. It is of interest to know that the sandstones must be much subordinate in quantity to the finer sediments, and that whenever the sands dominate, the likelihood of concentration of oil is decreased. It is also well to realize the fact that in the same structure certain sandstones may carry nothing but water, while others may carry oil or gas or a mixture of both. The relative positions of water and oil sands are indefinite. The water horizons may be above or below the producing sand or may be interbedded in a number of such.

Locating Structures.

After a favorable series of rocks has been located it is desirable to prospect them for "structures". This necessitates the careful study of the dips and strikes and of the distribution of the rock formations at the earth's surface. The latter is of very great value because the distribution of the formations at the surface is dependent upon their structure.

Type of Structures.

There are two general types of structures tending to the accumulation of commercial oil pools. These are:

1. Trap Structures.
2. Retardation Structures.

The first structures are those that effectively trap the oil while migrating through the rocks and prevent further migration as long as these structural conditions exist. The second type of structures are such that there is a continual flow of oil through them. The access of new oil, however, is greater than the loss, so that the commercial accumulation is the result of the retardation of the oil migration. The structures of the first class hold an oil pool more or less indefinitely. The oil pool may disappear as the result of a subsequent structural disturbance such as igneous intrusions, complex folding, regional metamorphism or exposure of the reservoir rocks at the surface by erosion. The oil pool in the second class of structure will tend to disappear as soon as all available oil is effectively concentrated along the channel or direction of access. From that time on there will be a gradual dissipation of the accumulated oil.

Trap Structures.

Trap structures carry the majority of the important accumulations of oil. They are not confined to any particular region or field but are of commercial importance in every producing region. The following are examples of such structures:

1. Domes.
   (a) Structural Domes.
   (b) Saline Dome.
   (c) Volcanic Domes.
2. Structural highs on an anticline.
3. Anticline sealed by faults.
4. Fissured rocks.
5. Lenticular sands.

It is well to realize that such a classification is not hard and inflexible and that the accumulations of the oil in such a structure may be dissipated because of the presence of some interfering feature such as fractures and faults.

Retardation Structures.

The commercial importance of this class of structures is not nearly so great as that of the first class. In many fields their presence is of no commercial significance. Effective accumulations of oil in them are restricted and limited to certain fields. All these possess the common characteristics of very low dips and slight structural disturbances. The producing regions of North Central Texas, of Oklahoma and of Ohio, are examples of fields in which these structures frequently carry oil pools. Even in these regions we must not lose sight of the fact that trap structures are the much more likely to yield production. The following are examples of structures of retardation:

1. Structural terraces.
2. Changes in the rate of dip.
3. Structural valleys and ravines.
4. Anticlinal noses.
5. Asphalt sealed sands.

Structures and Oil Pools.

It is well to realize that the presence of a structure does not necessarily indicate the presence of an oil pool.

The following features must be considered in determining the likelihood of obtaining production from any structure:

1. Characteristics of the formation.
2. The lithological character of possible reservoirs.
3. Structural characteristics.
4. Geological history of the area investigated.

Topographic Features.

The different formations yield more or less characteristic and distinctive erosion forms which may enable us to recognize them at a considerable distance. This feature is well shown by the Mesozoic rocks of the Bighorn Basin of Wyoming. From the oil man's standpoint, here the more important formations are those included between the Dakota and the Mesaverde in the columnar section on page 98. The Dakota sandstone usually gives a high ridge with a sharp serrated crest covered with pine trees.

The Mowry shale forms another hogback much higher than the Dakota, marked with horizontal gray bands and characterized by smoother slopes and crest. Part way down the dip slope of the Mowry hogback is a minor hogback of sandstone which usually consists of two or three well defined small ridges. This is the Frontier formation and contains the most important oil sands of the state. The Cody shale forms a flat featureless valley, broken occasionally by a development of bad lands in the rocks near its base (Niobrara). The Mesaverde forms a high prominent hogback characterized by very thick massive ledges of buff sandstones and by occasional coal beds. These topographic expressions show almost at a glance the distribution of the formations and hence the structure of a field.

Folded areas usually follow mountain ranges and are restricted to a narrow belt along the foot of each range. The longer axis of the folds is usually parallel to the trend of the mountain's uplift. The folds are unsymmetrical in most cases, with their steeper dips on the mountain sides.

Choice of Structure.

In new and unproven territory it is logical to test the most promising geological structure first. If possible this should be a dome, preferably one standing in an isolated position away from other folds, so that a large underground drainage area may be tributary to it. Next favorable to a dome is a "structural high" on an anticline. This is followed in order by a horizontal anticline, a structural terrace, and finally by faulted structures and unconformities.

Structural Characteristics.

Structural characteristics are of prime importance in determining possibilities of accumulation. The following characteristics of the structure should be investigated.

A. Trap structures or retardation structures.

A structure of the trap type is the most favorable and is equally so no matter what field it happens to be located in. Structures of retardation, however, would not merit consideration in those oil fields where we have strong folding and prominent well defined structures, like those of the Rocky Mountains and California. In these fields, dips up to the vertical occur and the circulation of water proceeds so readily that the retardation in flow due to a terrace or structural ravine is usually insufficient to hold the oil in large enough quantities to merit exploitation. It is well to regard such structures with suspicion in all fields except those with very low dips.

B. Surface and sub-surface structures.

Very frequently it happens that a structure shown at the surface disappears in depth. In other cases it may become accentuated. This is due to the fact that the strata are not absolutely parallel but converge more or less rapidly. This may be due to the fact that the sedimentary formations are lenticular, or it may be due to the fact that they are unconformable to each other. Thus, the underlying rocks which carry the oil may have been folded previous to the deposition of the surface rocks. Subsequent to the deposition of the latter, the rocks may have been folded once more along the same general axis, thereby intensifying the fold in the lower formation. In the Northern part of the Gulf Coastal Plains, as at Homer, Louisiana, Corsicana, Texas, and also in the North Central Texas fields, as at Burkburnett and Desdemona, there are only very slight structural disturbances in the rocks at the surface but a much accentuated folding in the oil sands below.

In other regions the relationship of the surface formations to the underlying oil producer may be such that an apparently favorable structure in them is of no value. Thus, the structures in the Tertiary formations of the Rocky Mountain region ordinarily afford no clue as to the attitude of the Cretaceous or older rocks below.

Relation to Other Structural Features.

The oil structure, while favorable in form, may be so located as to preclude any expectation of large production. Thus, for example, in the Kansas oil fields the general dip of the formations is westward and the important drainage direction from which the oil comes is from the West. A structure that is located immediately to the east of another structure has, therefore, a somewhat unfavorable position, because the drainage from the west will be interrupted by the latter structure, and, if this be large enough, it may trap and hold all the available oil.

Geologic History.

Certain features of geologic history influence productivity of an oil field. The date of folding or of formation of the structure is of considerable significance. If the folding followed closely the period of the deposition of the rocks it will be much more favorable than if a long period of time had previously elapsed. In the latter case there will be less tendency for a concentration of the oil. In the first case it might be concentrated as quickly as formed. The conditions following the deposition of the sediments are the conditions under which the formation of oil must have taken place. A great deal of volcanic and igneous activity with its attendant structural disturbance tend to dissipate the oil. A limited amount of igneous intrusions would hasten distillation with a probable formation of a heavy black oil. Much structural disturbance would have the tendency to convert the oil into gas. The degree of metamorphism determines the likelihood of finding petroleum. Excessive metamorphism is unfavorable. Metamorphism is a function of both age and pressure and consequently of structural disturbance. The greater the structural disturbance and the greater the age, the more pronounced the metamorphism. David White has suggested that since the nature of the coals associated with oil-bearing rocks depends upon the stage of the metamorphism to which it has been subjected, the coals may serve as a criterion to measure its intensity. It has been found that the percentage of carbon in coal increases with the amount of intensity of the metamorphism to which it has been subjected. When the percentage of carbon in coal exceeds 65 per cent no production need be expected. Most of the important accumulations of oil occur in regions where the percentage of carbon in coal is less than 55 per cent. It is well to carry in mind the fact that this generalization applies only to the formation in which the coal itself occurs and cannot be applied to much younger and overlying rocks.

Summary.

From the theoretic considerations discussed above, it will be apparent that the following features will favor maximum accumulation of oil:

1. Comparatively recent age of formations.
2. Slight folding, very closely following the period of deposition.
3. Rock originally rich in organic remains.

Great geologic age, excessive and intense folding, tend to the carbonization of the oil and to the production of gas. Rocks rich in fossils are not necessarily rocks rich in organic remains. The shells of clams and oysters may accumulate in tremendous quantities without any accompanying preservation of the fleshy part of these animals. The presence of fossils, therefore, does not prove the presence of oil.

Locating a Test Well.

The location of the test well is of the utmost importance. In nearly all cases this should be located near the highest point of the structure. In most oil fields the reservoir rocks are saturated; the highest part of the fold should, therefore, be productive. In case a well so located strikes water, the structure is probably nonproductive. Should the well strike gas, a second well should be drilled down dip on the flank of the fold where the oil would be expected. A dry hole in the apex of an anticline, where an examination of the drillings from the reservoir rock

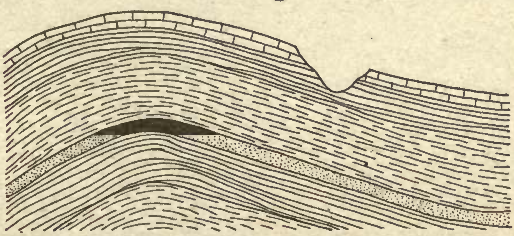


Figure 49. Dome left as structural mountain.

proves this to be porous and open, indicates a dry sand or at least only a partially saturated one. Therefore the next test well should be located down on the flanks of the fold or on the syncline.

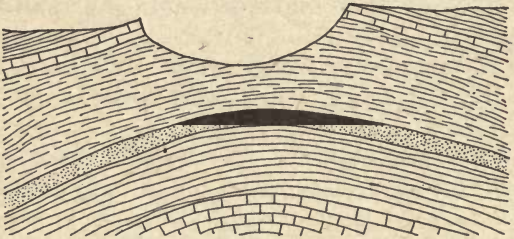


Figure 50. Eroded dome.

To locate the highest point on a particular structure is not as simple as it would appear to be. The dome or anticline may be left as an elevation due to the presence of a resistant layer of rock. The highest point of this elevation may represent the apex of the structure. This is frequently the case in Oklahoma. Wyoming oil domes are usually so eroded as to show a central basin surrounded by encircling hogbacks of the harder rocks. Consequently here the surface elevation has no significance. The lowest point in the surface may actually represent the highest point in the structure. An instrumental survey may be needed to determine the axis or apex of low, flat-dipping structures that cover large areas.

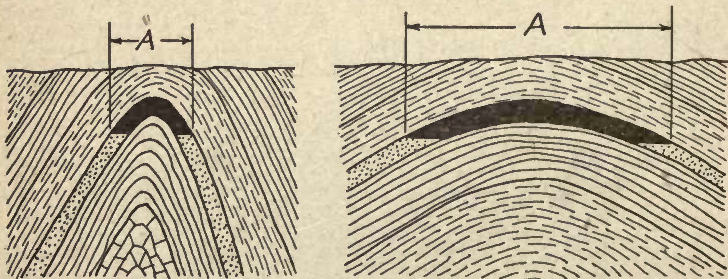


Figure 51. Sections to show the relationship existing between width of producing area and dip of rocks.

In structures with steep dips the productive surface area is of limited extent, and the correct location of test wells is of paramount importance. The axis of an unsymmetrical anticline shifts in the direction of minimum dip with descent. A test well must, therefore, be located away from the surface axis on the side of least dip. Its location must be carefully determined in order to ensure its striking the oil sand at the top of the fold.

Economic Considerations.

It is of course self evident that certain economic considerations are of the utmost importance in determining the advisability of drilling a particular structure. Indeed, these may be more important than geologic considerations and may make inadvisable the development of an area otherwise favorable. Those individuals and corporations using the nicest of judgment in balancing these two sets of considerations against each other achieve the greatest success in the petroleum industry.

The economic considerations may be grouped under the following headings:

1. Depth of drilling.
2. Possible value of production.
3. Accessibility.
4. Transportation facilities.
5. Operating requirements.
6. Legal status of lands.

Depth of Drilling.

The post of operation increases rapidly with increasing depth. Whenever the depth exceeds 3,000 feet, the cost of operation increases at a startling rate. The writer doubts that a 3,000 foot wild-cat well can be drilled in the Rockies for less than 100,000 dollars. In North Central Texas a similar hole could perhaps be drilled for one-half this amount. In the Gulf Coastal Plains, by using a rotary, the cost can probably be reduced to 30,000 dollars. Each additional thousand feet will approximately double the cost of the well. Excessive depth to possible oil sands may make a structure unattractive.

Possible Value of Production.

Seeps, outcrops of sands at the surface, records of other wells or other geologic features, may indicate the nature of the production to be expected. Probabilities may be in favor of gas or black oil or light paraffin oil. It may also be possible to form a conclusion as to the approximate magnitude of the probable yield. Such conclusions are always dangerous especially in wild cat areas, and should only be received with credulence when made by geologists of wide experience and when backed by all the observed facts in the area under investigation. It is not possible to foretell the exact amount of the production to be expected from any well. Such forecasts are in a class with the request of a newcomer in the oil game, who asked drilling contractors to submit bids on the cost of drilling a hundred-barrel well.

Accessibility.

Accessibility to labor markets, to supplies needed in drilling and development, to fuel and water, determine in part the cost of operations. Many areas may be so far distant from markets and supply houses that a great deal of expensive and little used machinery and tools must be kept on hand to provide for possible emergencies that may never arise.

Transportation Facilities.

To some extent transportation facilities and accessibility go hand in hand. The presence of railroad lines facilitates and cheapens costs. Many of the western areas favorable from the geological standpoint are without adequate railroad facilities. Transportation costs become exorbitant, when all materials, supplies and fuel must be handled by auto or team over poor roads, possibly fifty to one hundred miles from the railroad. In many cases roads must be built and maintained and even the water needed for drilling must be hauled many miles. Under such conditions development is seriously handicapped, not only because of the high cost of drilling, but also because of the exorbitant cost of marketing the oil produced.

Operating Requirements.

The requirements of drilling and operating and the royalties stipulated by the leases may be of such a nature as to destroy the attractiveness of a promising acreage. Legitimate concerns will not sign contracts to drill twenty wells on a wild-cat structure; neither will they pay 40 per cent royalty. Demands such as these may be met on paper by promoters of stock sales propositions. Property owners should realize the fact that one-eigth royalty is the accepted standard established as the basis of a fair working agreement between the producer and the property owner. High royalties quickly destroy the margin of profit to the producer. The incentive is to speed up production and to abandon the property before it is really exhausted. Thus, the result is an economic loss to the nation and potentially a financial loss to the operating company and the land owner. The drilling of wells and the production of oil is a legitimate place of business activity. Experience has established principles of conduct and conditions of operation which cannot be violated without incurring the danger of bankruptcy.

Legal Status of Land.

Operators should assure themselves that the title to the land is clear and valid. All conflicting titles, no matter how flimsy, should be cleared up and settled preceding development. After discovery of oil in commercial quantities, these can probably not be settled except by expensive and perhaps drawn-out litigation.

Title of much of the prospective oil land in the West comes direct from the government in the form of oil placer claims. In many cases a number of different claimants have located the same acreage. In these cases it requires the nicest of legal acumen to determine the valid title. It appears to be the concensus of opinion that the claimant first discovering oil in commerical quantities has best title.

Much of the land is homestead land taken up by the agricultural claimant under a specific waiver of mineral rights which are expressly reserved to the Government subject to future legislation. Leases from the homesteader appear, therefore, to be invalid. Oil placer claims are frequently filed over such homesteads with or without the consent of the homesteader. Their status is doubtful, although the title may be the best obtainable under the conditions.

Much of the Government land in the West is located on areas withdrawn from entry as oil land. The largest of these areas are located in Wyoming and California. Their disposition is subject to future legislation such as the "oil land leasing bill" now before Congress. According to the features of this bill, the land would be leased directly from the Government on a royalty basis, subject to certain limitations as to the area of land so obtainable.

Producing Problems.

It has been well stated by Hager that the problem of the producer consists of three distinct and separate parts. First, he must work out the best method of production for his property; second, the best method of defending it against drainage by neighboring producers; and third, the most effective method of draining adjacent properties. These ideas must be constantly carried in mind because oil reservoirs are more or less continuous sheets that underlie large areas, and a few favorably located wells will in the course of time seriously affect and even destroy the possibilities of production in adjacent properties.

Objects of Production.

Maximum profit with least expense is the chief object of most producers. This does not imply the production of the greatest quantity of oil possible from a given area because the element of time must be considered. Thus it is possible to speed up production so as to secure a large annual production for a short time. A rapid return of the capital invested and a high profit is the result. More

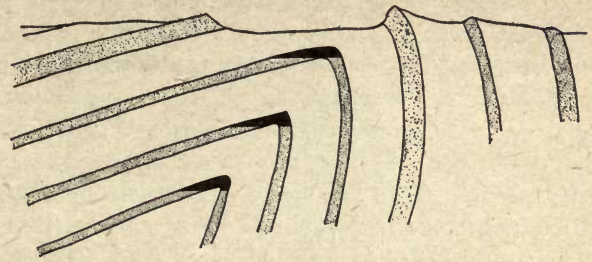


Figure 52. Section of an unsymmetric anticline, illustrating the shift of the crest of the fold with increasing depth.

economic and less wasteful methods would yield a smaller annual production spread over a proportionately greater period of years, so that eventually a much larger quantity of oil would be obtained from the same area. The return of the money invested is slower in this case and the annual profits are much smaller. In most oil fields the methods adopted are strictly those of the first class. Every attempt is made to produce as much oil as possible in the least time from a given plot of ground.

Spacing of Wells.

The rate of production depends mainly on the location and spacing of wells. Best practice means drilling one well for every five to ten acres. The spacing best suited to a particular area can be determined by a consideration of the following points:

1. The amount of oil available.
2. The rate of flow or circulation of oil.
3. The methods adopted by neighboring producers.

Amount of Oil Available.

The amount of oil available can be determined from the following:

(a) The number of oil sands in reach of the drill.
(b) Their aggregate thickness.
(c) Their degree of saturation.

The number of oil sands and their aggregate thickness is determined by a study of the columnar section and of well records. The degree of saturation depends on the field. The average is about ten per cent by volume; this means a potential production of about five hundred barrels per acre foot. The saturation of Wyoming sands is probably greater than this because of their open porous structure. Calculations should be based only on that part of the area actually underlain by the oil pool. The greater the quantity of oil present, the closer the wells may be spaced without injury to the field.

Flow of Oil.

The relative ease of flow is dependent on

(a) The character of the reservoir rock.
(b) The viscosity and specific gravity of the oil.
(c) The steepness of the dip.
(d) The pressure on the oil.

Ready circulation is favored by a reservoir that is open and contains pores that are large, continuous, and connected. A reservoir of low porosity with small, tortuous and disconnected openings retards the flow of oil and necessitates a closer spacing of wells. Viscous oils flow with difficulty. Other conditions being the same, wells should be spaced closer in fields producing a heavy asphalt oil and farther apart in those fields that produce a high grade paraffin base oil. The steepness of the dip determines the gradient of flow. It is evident, therefore, that steep dips are conducive to easy and rapid flow. Flat dips retard flow. The steeper the dip the less number of wells are required to drain a given area. The methods adopted in the drilling of adjacent properties must influence every drilling campaign. These call for defensive methods and are discussed under that heading.

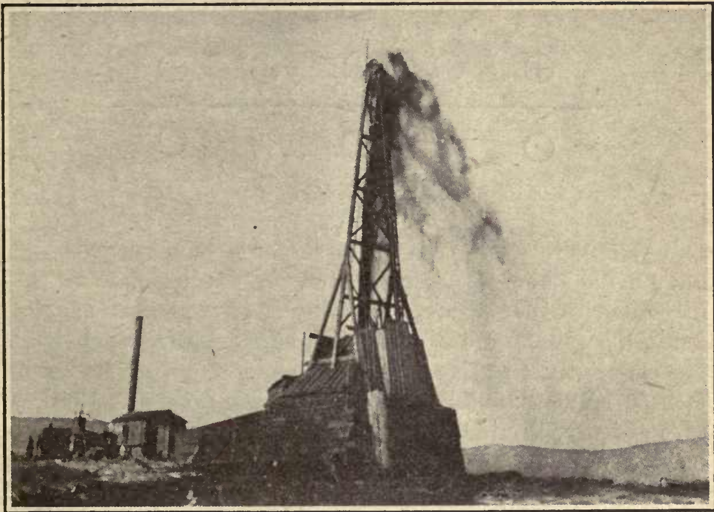


Figure 53. Flowing well, Salt Creek Field.
(U. S. Geol. Sur.)

Defensive and Offensive Methods.

"A good offensive is the best defensive". This is true in oil production as well as in warfare. For this reason both methods may be considered simultaneously.

Every well drains oil from an area the shape and size of which depends on

(a) The ease of flow of the oil.
(b) The dip of the oil reservoir.
(c) The location of other wells.
(d) The extent of the pool.

With horizontal or nearly horizontal reservoirs the area drained by a single well will be nearly circular in outline with the well located at the center. Ready and easy flow of oil increases the size of the area. This has been mentioned under "Spacing of Oil Wells". In steeply dipping reservoirs the area drained assumes an elliptical shape, with the longer diameter in the direction of the dip. The well is not located at the center of the ellipse

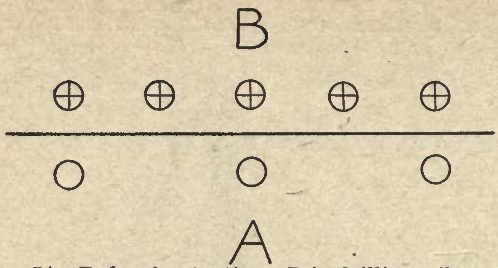


Figure 54. Defensive tactics. B is drilling offset wells.

but on the down-dip side, because of readier flow in this direction. Other producing wells, if located near enough, limit the area for drainage by another well. Such wells are especially effective if located along the dip; less so if located along the strike. The drainage area of a well is, of necessity, limited by the extent of the pool. Wells located at the edges of pools must derive their oil from areas very much restricted as compared to wells on inside locations. Their capacity is, therefore, much smaller.

Offsetting.

As is evident from this discussion, the drainage area of any well follows natural laws and not artificial boundaries. Oil wells located directly on the line between two properties will drain areas of both. Indeed, they may be so situated that the greater part of their drainage area lies in the adjacent property instead of the one in which the well is located. This is true if the well is placed down-dip from the adjacent property. It will be apparent that a tract of land may be surrounded by oil wells on all sides and be completely drained without ever having a producing well drilled on it. To defend a property against drainage by adjacent wells, "offset" wells are drilled. These are wells directly across the boundary line from the producing well. Their spacing and that of subsequent wells is shown on figure 54. The most effective offset wells are those located down the dip of the formation, or down the pitch of the axis from a producing well. In addition to drilling offset wells, it is also desirable to drill wells of larger diameter, because the larger the well the greater the producing capacity. It is also possible to speed up production from the line wells, which will result in a gain in oil production at the expense of the adjacent property.

XIII. Oil Shales and Their Utilization

The constantly increasing consumption of crude oil in the United States is a cause of serious concern. This is due to the fact that the older oil fields are being exhausted rapidly, and that no new oil fields of great importance have been discovered in the last few years in spite of very vigorous prospecting campaigns. At the present rate of consumption all the known oil fields of the United States will be exhausted within the next twenty years. For these reasons there is much interest in "oil shales" as a possible source of petroleum.

Oil Shales.

Oil shales are shales, that is, muds or clays consolidated into rocks, from which oil and gas can be produced by destructive distillation. These shales do not actually carry oil or gas as such. They contain organic materials such as partially altered plant remains which are broken up into oil and gas when subjected to heat. That by far the greater part of the oil is not present as such is proved by the fact that even the richest shales are not greasy or oily in appearance, and that oil seeps are virtually unknown in them.

Location.

Probably the most extensive and richest deposits of oil shale occur in northwestern Colorado, southwestern Wyoming, and northeastern Utah. The area covered is shown on the accompanying map.

Oil Content.

It is estimated that the oil shale in Colorado alone carries ten times as much oil as all the oil fields in the United States have produced since 1859. The areas in Wyoming and Utah that are underlain by oil shale are as large as those in Colorado, and those in Utah are undoubtedly just as rich.

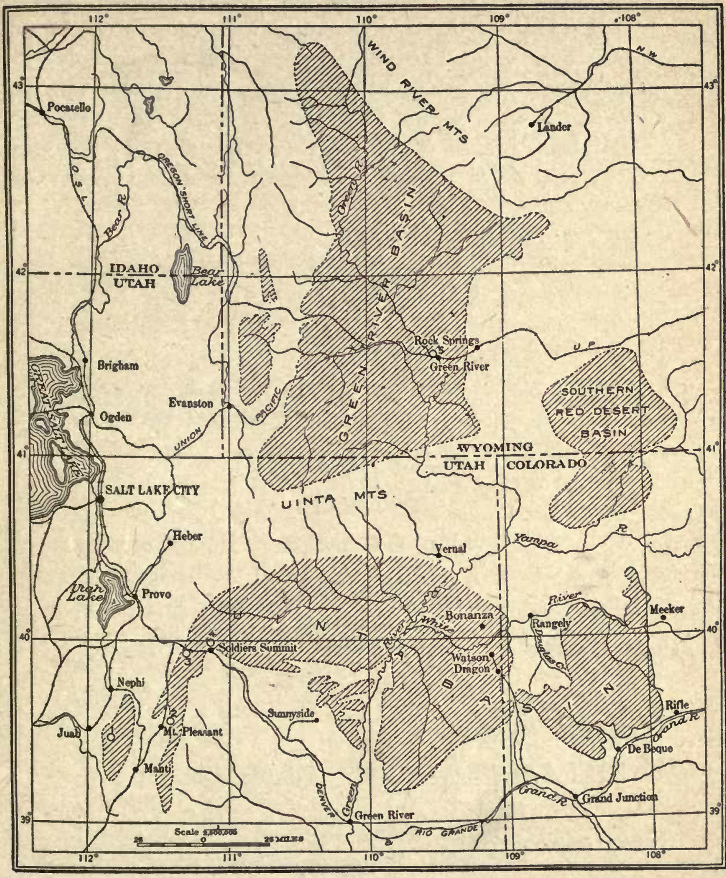


Figure 55. Map showing Colorado and Utah oil shales.
(U. S. Geol. Sur.)

Green River Formation.

The oil-bearing shale is confined to the middle part of the Green River formation. This is of Tertiary age. In the Colorado shale area, this lies at the earth's surface. In Utah and Wyoming, the Green River shale is covered for a greater part by younger rocks.

The Green River formation is essentially shale.

"It exhibits on the weathered outcrop a more or less white color, but closer examination reveals an alternation of gray, bluish gray, and white bands. The shale that yields the most oil when subjected to distillation is that which weathers into massive benches of grayish-blue color but which is dark brown to

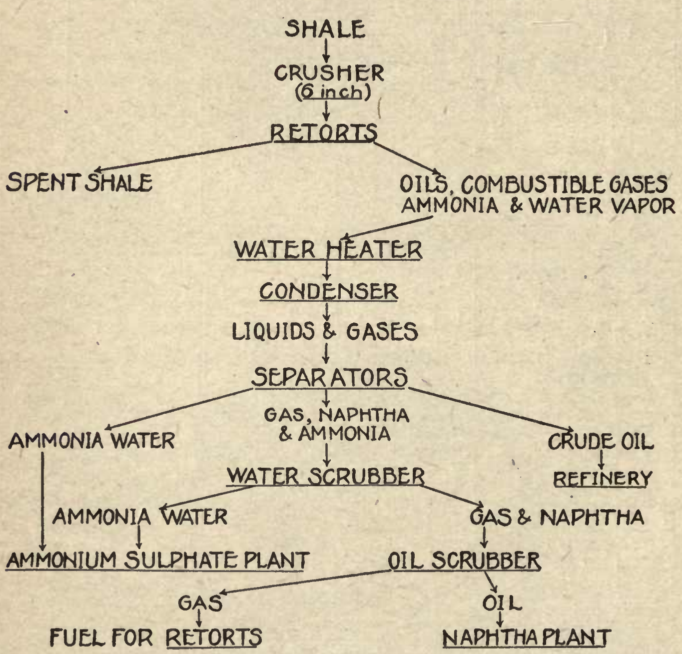


Figure 56. Outline of treatment of oil shale.

black on a freshly broken surface. After this tough rich shale, which appears to be without bedding planes or laminations, is heated and the oil driven off it crumbles easily and exhibits true shale structure. Where thin benches of rich shale are interbedded with lean or barren shale, the former, being resistant, weathers to projecting ledges. Some of the very rich beds show a vitreous luster similar to that of coal. The massive shale is exceedingly tough, resists erosion to a remarkable degree, and as it weathers to a bluish-white surface and will burn when ignited the ranchers of some parts of the region refer to it as 'white rock that will burn.' When freshly broken, the shale gives off an odor of petroleum. All gradations exist between this hard, tough, massive rock and the papery shale which weathers to curly forms. The papery shale is in a few places black, but usually light brown, and the thin plates of weathered shale are remarkably flexible, a characteristic which distinguishes it from ordinary carbonaceous shale. Weathering affects the papery shale to a distance of more than twenty feet back from the outcrop, but, except along joint planes, the hard, massive shale shows little evidence of weathering for more than a quarter of an inch from the exposed surface. Oil has been distilled from the papery shale as well as from the hard, massive variety, although in smaller quantity. The hard, rich shale that crops out as projecting ledges and weathers to a gray or grayish-blue color is dark brown to black on the unweathered surface, and in all probability weathering does not affect the oil-yielding capacity of the shale to any considerable depths."

The whole formation varies from two thousand to about twenty-six hundred feet in thickness. Not all of the formation is valuable as oil shale. This occurs in layers from a fraction of an inch up to twenty feet in thickness.

Distillation Tests.

The shale yields in addition to oil and gas, large quantities of ammonium sulphate. This is quite valuable as a fertilizer. The accompanying table shows the results of distillation tests of a number of different shale beds in the Green River formation.

Analyses of Shale Oils and Oil Shales.

	1	2	3	4	5	6	7	8	9
Distillation Tests—									
Gasoline	10.0	12.0	12.0	6.0	11.0	7.0	10.5	9.0	9.0
Kerosene	28.5	32.0	49.0	35.0	35.5	39.0	42.5	35.5	38.5
Residuum	61.5	56.0	39.0	59.0	53.5	54.0	47.0	51.5	52.5
Specific Gravity at 60° F.									
Crude	0.8937	0.8850	0.9138	0.9290	0.9327	0.8946	0.8838	0.9126	0.9126
Gasoline	0.7947	0.7769	0.8090	0.7974	0.8202	0.7849	0.7568	0.7838	0.7605
Kerosene	0.8602	0.8466	0.8260	0.8742	0.8876	0.8722	0.8524	0.8682	0.8538
Residuum	0.9695	0.9643	0.9884	0.9894	1.0160	0.9684	0.9368	0.9695	0.9628
Asphalt, percent.	1.35	0.82	2.82	4.10	3.62	2.49	0.47	1.40	1.03
Paraffin, percent.	7.70	6.93	2.22	3.72	1.63	4.56	4.70	9.21	4.00
Sulphur, percent.	0.54	1.06	......	......	......	0.73	1.42	0.41	0.69
Nitrogen, percent.	1.848	0.887	2.198	1.549	1.643	1.267	1.849	1.820	2.135
Analyses of Shale—									
Proximate									
Moisture	1.05	1.05	......	......	......	3.18	0.45	0.43	0.85
Volatile Matter	33.55	45.04	......	......	......	19.55	32.90	39.85	51.60
Ash	65.43	45.73	......	......	......	79.00	62.65	59.95	46.23
Ultimate—									
Sulphur	0.27	1.07	......	......	......	1.08	0.55	0.30	0.95
Hydrogen	1.80	5.19	......	......	......	1.75	2.76	2.24	4.32
Carbon	13.37	36.76	......	......	......	8.34	22.48	18.87	36.40
Nitrogen	0.39	0.39	......	......	......	0.46	0.54	0.46	1.22
Oxygen	18.74	10.86	......	......	......	9.37	11.02	18.18	10.88
Yield of Shale, gallons ton	16.8	86.8	11.3	22.88	6.27	8.4	40.6	28.0	65.3

The fractional cut of shale oil given in most analyses under the heading of "gasoline" or "motor fuel" is not gasoline suitable for the ordinary internal combustion engine. It is a very complex distillate and only a small fraction of it can be refined into commercial gasoline.

"The following figures* are based on the results of one hundred and thirty-two analyses published by the United States Geological Survey, forty-two analyses made in the laboratories of the Colorado School of Mines, and thirty-one analyses from other sources. Fifty-four of the analyses are on Colorado shales, fifty-two on Utah shales, forty-five on Wyoming shales, and fifty-four on Nevada shales.

No. of Analyses	Constituent	Unit	Average
205	Shale Oil	Gallons per Ton	38.0
205	Shale Oil	Specific Gravity	.890
163	Ammonium Sulphate	Pounds per Ton	9.4
64	Gas	Cubic Feet per Ton	3800.
26	Water	Gallons per Ton	4.8
26	Spent Shale	Pounds per Ton	1200.
26	Sulphur	Percent	.80
16	Heating Value	B. t. u.	4500.
6	Carbon	Percent	22.5

"Shale distillations with steam yield a few more gallons of oil a ton than dry distillations, and the specific gravity of the oil is between .03 and .04 greater. Steam distillations also increase the quantity of ammonium sulphate between two and three times the value obtained by the dry distillation. The values given in the table above were obtained by dry distillation. In the laboratory distillations, the yield of gas is almost doubled if the retort is surrounded by magnesia insulation, and the final temperature is thus increased a few hundred degrees."

Shale Oil.

"Shale oils vary considerably in color, specific gravity, and viscosity, and in their content of sulphur, asphalt, and paraffin. They invariably contain a larger percentage of unsaturated hydrocarbons than petroleum. This is quite a disadvantage in their utilization for gasoline, but improvement in motors and methods of refining may largely overcome this handicap. Experiments in cracking the heavier distillates from shale oil show that it is possible in this way to increase the yield of gasoline. The follow-

* Quoted from article by C. W. Botkin.

ing summary is made from data obtained by analysis and distillation of twenty-two different samples of crude shale oil".

	Specific Gravity	Average
Initial boiling point	....	65°C
Gasoline, to 150°C	.750 — .850	11.7%
Kerosene, to 300°C	.820 — .900	38%
Heavy oil, residue	.900 — 1.02	45%
Unsaturated hydrocarbons in kerosene	....	63%
Unsaturated hydrocarbons in crude shale oil	....	80%
Asphalt in crude shale oil	....	2.5%
Paraffin in crude shale oil	....	5.0%
Sulphur in crude shale oil	....	.75%
Nitrogen in crude shale oil	....	1.2%

Black Shale.

"It may be interesting to compare with this table the results of the distillation of black shale from eastern United States, where extensive beds of this shale are known to occur directly below the coal measures. Analyses are by the United States Geological Survey".

State—	Number of Samples	Average Gallons Oil Per Ton
Indiana	7	10
Illinois	2	14
Kentucky	3	5.1
Ohio	4	7.1
Pennsylvania	7	27.6
Tennessee	13	5.2
West Virginia	5	1.4

Canadian Shales.

"Oil shales in Canada are quite widespread in distribution and have been investigated in considerable detail by the Canadian Department of Mines. The most important deposits occur in New Brunswick. The figures below are compiled from publications by the Canadian Department of Mines and the United States Geological Survey, respectively:

Average Analyses of Oil Shales.

	Canadian	U. S.
Number of samples..........	44	132
Gallons Oil Per Ton..........	34.9	19.2
Specific Gravity of Oil.......	0.903	0.918
Degree Beaumé of Oil.......	25	25.2
Pounds Ammonium Sulphate Per Ton	51.3	16.0

"The greater richness of the Canadian Shales is forcibly brought out in this table. The discrepancy in the Ammonium Sulphate content is especially important because it represents the most valuable constituent of oil shale".

Other Foreign Countries.

"Oil shale has been retorted on a commercial scale in France and New South Wales for a number of years, but at the present time this industry is declining".

Scotland.

"The following table cited from a paper by Egloff, gives the products and yields of 3,500,000 tons of shale treated in Scotland in 1916".

Products Marketed from Scottish Oil Shales, 1916. Total Tons Shale, 3,500,000.

	Gallons	Per Cent of Oil Yield	Spec. Gravity	Degree Beaumé
Crude Oil	80,500,000	......	0.91	23.8
Motor Spirits	600,000	0.7	0.74	59.2
Naphtha	4,840,000	5.1	0.78	49.5
Burning Oil	22,000,000	28.5	0.82	40.7
Gas or Fuel Oil............	13,000,000	16.2	0.86	32.8
Lubricating Oils	11,000,000	13.7	0.90	25.5
Paraffin Wax (tons)........	27,500	1.0	110°-132°	...
Coke (tons)	84,000	3.0	...	...
Ammonium Sulphate (tons).	59,400	1.41% per ton shale		
Ammonia (tons)	16,000	0.44% per ton shale		

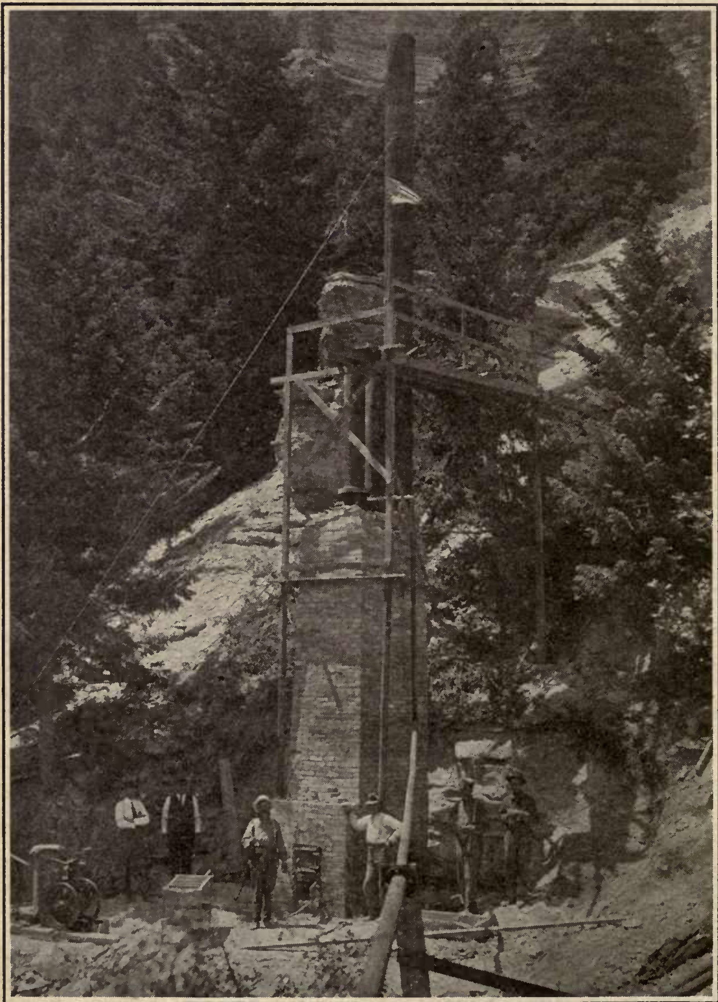


Figure 57. Experimental oil shale retort erected to test Colorado shale.

(Courtesy D. & R. G. R. R.)

Methods of Treatment.

The first commercial plants for the utilization of oil shale were erected in Scotland in 1848. Since that time they have been in continued and successful operation. The development of the industry has been carried out with much skill. The methods of treatment evolved and the machinery employed are the results of many years of practical experience and of the application of the best scientific and technical talent procurable. It is not surprising, therefore, to find the Scottish Shale Oil Industry flourishing and highly successful.

Scottish Oil Shale Plants.

A Scottish shale oil plant is quite elaborate and consists really of two separate plants; a crude oil works and a refinery.

Crude Oil Works.

The crude oil plants are usually located at the mine, as it is cheaper to treat the shale there than to transport it for any great distance. The crude oil from several plants goes to a single, centrally located refinery. The crude oil works consist of retorts, oil condensers, scrubbers, a naphtha plant, and an ammonium sulphate plant.

Retorts.

Forty-four to sixty-six retorts are arranged in batteries or "benches". In these the shale is heated and distilled. The two most common retorts used are known as the Henderson and the Pumpherston or Bryson type. The retorts in either case consist of two parts—the upper and shorter part is cast iron; the lower part, firebrick. They are jacketed by flues and heated to a temperature of about 1,000° C. near the bottom of the brick part. The temperature decreases gradually to about 670° C. in the metal part. Sufficient dry gas is yielded in the distillation of the

Scottish shales to furnish all the fuel required. In neither of these furnaces is the shale column permitted to remain at rest, because of the danger of melting the shale and clogging the retort. The Henderson retort has toothed rollers at the bottom which support the shale column and

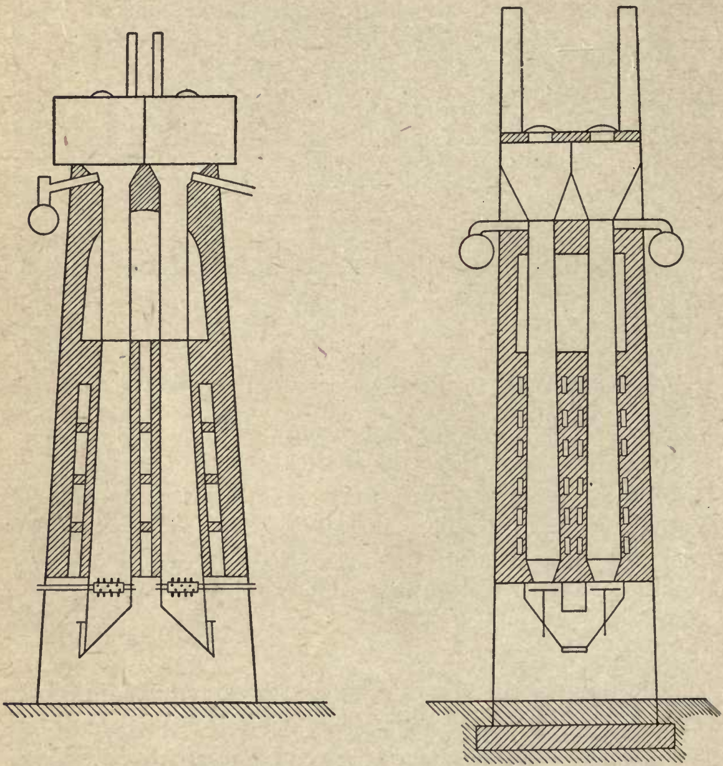


Figure 58. Oil shale retorts. Henderson type at left, Pumpherston type at right.

which are rotated to maintain a downward movement and to discharge the spent shales at the bottom. In the Bryson type, the shale is supported by a table provided with a revolving arm which keeps the shale column in motion and removes the shale by revolving at regular intervals. In

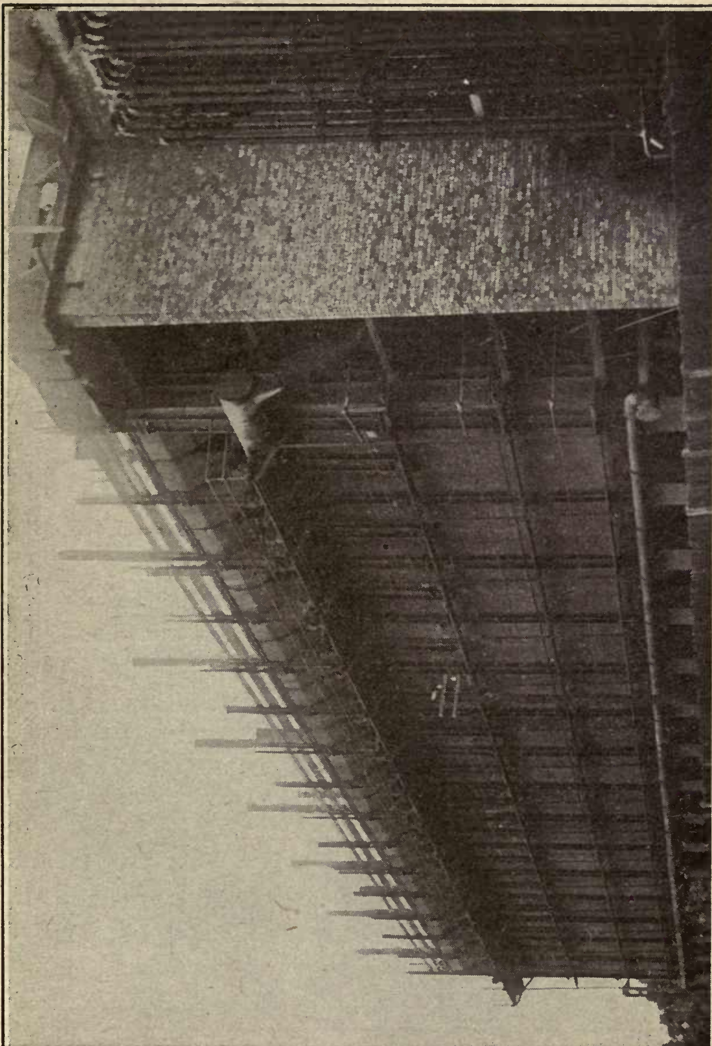


Figure 59. Bench of oil shale retorts, Pumpherston, Scotland.
(Courtesy Canada Dept. of Mines)

nearly every distillation process steam is introduced into the shale at the bottom of the furnace. This assists in the easy and complete removal of the oil obtained, combines with the nitrogen in the shale to form ammonia, and also combines with the carbon to form gases, such as carbon monoxide and carbon dioxide.

Condensers and Separators.

The oil and the gases that are driven off, as a result of the distillation, escape through outlet pipes near the top of the iron section of the retorts and are conducted into the condensers. These are huge racks or coils of four

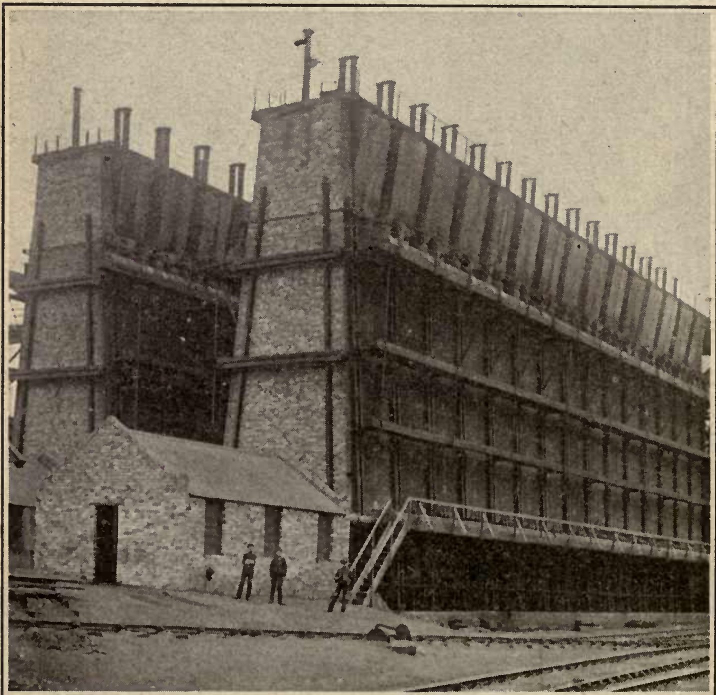


Figure 60. Bench of shale retorts, Broxburn, Scotland. (Courtesy Canada Dept. of Mines)

inch iron pipe similar in shape to steam heat radiators. The gases are cooled to air temperature in these and the oil and water is condensed and drawn off into separators. The greater part of the ammonia is condensed with the water. The ammonia water goes from the separator to the ammonium sulphate plant; the crude oil is sent to the refinery.

Scrubbers.

The uncondensable gases coming from the separators still contain valuable quantities of ammonia and of naphtha. These are washed out in so-called "scrubbing towers"; the ammonia in a "water scrubber"; the naphtha in an "oil scrubber". Both are tall towers in which the gases are washed with a fine spray of water or of oil, respectively. The washed gases eventually obtained are used as fuel to heat the retorts.

Shale Oil Refineries.

"Shale oil refineries consist of (a) stills for distilling the crude oil and refining the fractions; (b) agitators and settling tanks, in which the oils are treated with sulphuric acid and caustic soda for the separation of the tarry matters; (c) paraffin-house, where the heavy oil obtained from the crude oil is cooled and pressed for the separation of the paraffin wax; (d) paraffin refinery, where the wax is refined; (e) stock tanks for the finished products; (f) shipping department, where the barrels are made and the products are shipped to the consumers; (g) candle-house, where the paraffin is made into candles for the trade; and sometimes (h) a sulphuric acid manufactory, where the sulphuric acid required for refining and the production of ammonium sulphate is made. There are also, of course, shops, sawmills, offices, and laboratories. All are arranged with due regard to convenience, cheapness, and safety from fire."

The various refining operations cannot be described in detail here. For a full discussion of these, the more

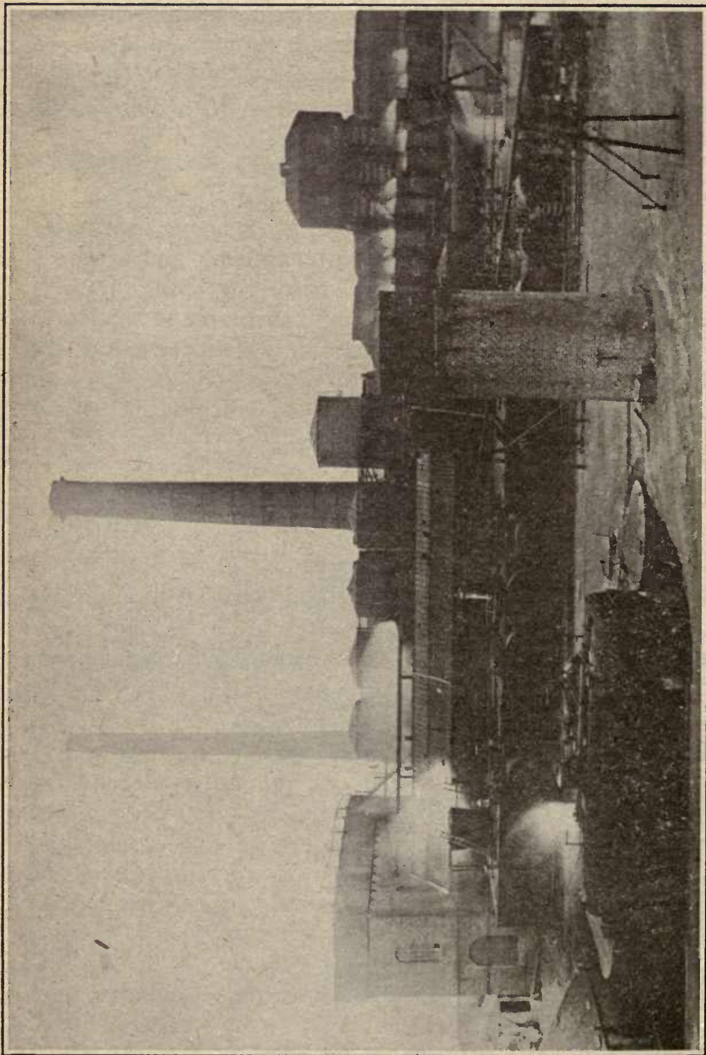


Figure 61. Shale oil refinery, Broxburn, Scotland.
(Courtesy Canada, Dept. of Mines)

elaborate technical treatises should be consulted.* The following products are yielded:

1. Permanent gases; used as fuel.
2. Shale naphtha, gasoline, motor spirits, and illuminating oil.
3. Lamp oils of high quality.
4. Intermediate oils; used for the manufacture of gas of high illuminating power.
5. Lubricating oils; these do not decrease in viscosity as rapidly as other mineral oils.
6. Paraffin; candles, waterproofing, and insulating.
7. Still grease; very heavy distillate, used for grease making.
8. Still coke; used for fuel.
9. Ammonium sulphate; used for fertilizer.
10. Fuel oils; tars, residues, and dregs unfit for other purposes.

Future of Western Oil Shales.

There has been a great deal of newspaper advertising and propaganda in connection with oil shale enterprises. A number of companies have been organized as stock selling propositions, rather than to assist in the development and upbuilding of a permanent industry. The oil shale industry is a business for the future. Under present conditions, it cannot hope to compete with the petroleum industry. The energy and money of the people interested in oil shale should be devoted to the encouragement of scientific investigations and technical research. This alone can furnish a sound basis upon which there can be a healthy development of the Oil Shale Industry.

Very little is definitely known of such features as the quantity of oil yield, the quality of oil yield, the propor-

* Bacon and Hamor, "The American Petroleum Industry," Vol. II.

tion of gas, the proportion of by-products as influenced by the type of furnace used, by the temperature of distillation, by the rate of distillation, and by the pressure of water or steam. For Scotch practice, some of the above data are available, but the differences in labor conditions, in transportation and marketing facilities, and other economic considerations make it improbable that the Scottish practice can be followed successfully in the exploitation of American Oil Shales. The data enumerated above must be studied in the light of American conditions and requirements.

Considering the present lack of knowledge of the fundamentals of oil shale refining, it must be apparent that estimates on the cost of commercial shale plants, on the cost of treatment per ton of shale, on the value of the products yielded, and on the possible profit per ton cannot be more than an expression of personal opinion, and had probably be best designated as a guess. The oil shale industry must develop as a large scale manufacturing enterprise, similar to the manufacture of shoes. In the shoe industry, the salient factors necessary to design, build, equip, and manage a plant have been established by continuous practice and research; in the oil shale industry, they are as yet unknown. They can be determined by technical and scientific investigations more accurately and much more cheaply than by the construction of plants designed on a basis of personal opinion and preconceived notions.

The following important facts regarding the oil shale situation are worth emphasizing:

1. There are no plants operating commercially in the United States at this time. (January, 1920.)

2. The cost of installation of a commercial plant is problematical. Estimates range from $1,000,000 to $5,000,000.

3. Nothing definite is known about the costs of oil shale operations, or the possible profits to be derived therefrom.

4. Shale oil cannot be refined in the ordinary petroleum refinery. Shale oil is an exceedingly complex mixture, much more difficult and more costly to refine than petroleum.

5. The development of the Oil Shale Industry on a commercially important scale will require many years. In the immediate future, it cannot hope to compete with the petroleum industry.

XIV. Oil Investments

In the purchase of oil stocks one of two purposes may actuate the buyer—either speculation or investment. As a matter of fact, the element of risk is so large in the average oil stock that many people refuse to consider their purchase a really legitimate investment. This is especially true when compared with an investment in railroad or similar bonds or real estate, all of which have a fixed value determined by the annual income derived from them. Oil property, on the other hand, has not a fixed but a continually decreasing value. Annual dividends paid on oil stocks are not true income on the capital invested, but include repayments of the capital in small installments. The value of an oil stock, similar to that of a mining stock, is determined by the sum total of the dividends and the length of time necessary to obtain them. Oil is a "wasting asset which is always in process of distribution." When the oil is gone the payments of annual dividends cease.

Dividends on Oil Stocks.

One of the most important ideas to carry in mind with respect to oil investments is the fact that annual dividends include repayments of the original investment. Any oil property should repay the capital within three to five years; subsequent payments, therefore, represent dividends only. When this fact is impressed on the mind of the investor, the high annual dividends paid on oil stocks will lose much of their attractiveness. An oil stock yielding twenty-six per cent annual dividends must continue to produce at the same rate for nearly five years in order to assure repayment of the initial investment and a return of six per cent profit. Many oil pools are completely drained within that time.

Types of Oil Investments.

Oil investments fall under one of three heads:

(a) Investment in stocks of producing concerns.

(b) Investment in stocks of concerns that intend to develop territory in proven fields.

(c) Prospecting or "Wildcatting" ventures in territory not productive.

These are ranked according to the safety of the investment, other things being equal.

Wildcatting.

Prospecting new and as yet unproductive territory is to be classed mainly under the head of speculation. By far the majority of small oil companies are organized for this purpose. Prospecting ventures, if successful, result in fabulous profits, and consequently are especially attractive. It is well to carry in mind the fact that while there are still many opportunities of finding new fields, the chances are preponderantly against success. The field manager of one of the larger producing companies in America is authority for the statement that in wildcatting only one well in thirty-seven proves a producer. The element of risk can be greatly reduced by distributing the investment over a number of wildcat areas. The investor should, however, satisfy himself that the properties in question have been investigated by a reliable and thoroughly competent geologist, and that their drilling has been recommended.

Geology in Wildcatting.

The following editorial from "The Mining American" is timely and to the point:

> "We find that the scramble for oil lands has, in some instances, been carried to irrational limits. Companies have been formed upon holdings in which, from the geologist's viewpoint, no oil could possibly be

stored. Expenditure of money in locating, validating, and drilling of such lands is positively reckless and it is done without—or contrary to—the advice of competent experts. Doings of this sort have naught but failure ahead and they lower the public's faith in the state and in the industry.

"Would that some way might be devised and put into effect to prevent such fiascos. There are enough really good oil structures in Wyoming to go 'round among legitimate promoters. Why will men not limit their holdings and expenditures to them?

"We have heretofore dwelt upon the advisability of employing petroleum geologists when wildcatting. The finding of oil was formerly a wild gamble. Nowadays it need not be. During the exploitation of the older American fields, the ratio of productive wells to all wells drilled was very, very small; but science has studied petroleum's genesis and occurrence, and theories have been evolved and tested in practice by skilled, educated men until the factor of uncertainty in drilling for natural oil has been radically reduced and is becoming smaller all the time.

"This is one of our latest technical branches. It is thoroughly recognized by every large, successful oil company. A few years ago, during the wildcatting of fields in Kansas and Oklahoma, success in bringing in oil wells was considerably less than one per cent. Now, with scientific guidance available, the average is around sixty-eight per cent—and it would be still higher if it were not that some concerns still consider it economy to curtail the geologist's fee or salary. False economy!"

The wild and irrational scramble to get into the oil game is also well illustrated in the number of new oil companies organized. The statement has been made on good authority that the combined capitalization of the companies operating in Wyoming and in Colorado, or organized for that purpose within the past two years, is so great that the petroleum production of the entire United States for 1917 is only sufficient to pay three per cent interest on the capital, without providing in any way for the ultimate return of the money invested.

Producing Companies.

Risks can be eliminated largely in investments in the stock of companies which have a definite production established. In this particular case we can determine the following points:

1. Productive capacity.
2. Cost of production and maintenance.
3. The value of the oil.
4. Location and market facilities.
5. Financial status of the Company.

Productive Capacity.

The productive capacity of a particular tract of ground can be determined from the area actually oil-bearing, and the number and thickness of the oil sands and their degree of effective saturation. Wells actually drilled on the property or on surrounding properties, studied in connection with the structure map of the field, will give much of the information needed. Producing wells on adjacent properties and on similar structures indicate the length of life and the rate of decline in production to be expected on the area in question.

Cost of Maintenance and Production.

Under cost of maintenance and production we include the drilling of wells, cost of pumps, pipe lines, storage tanks, power plants, wages, and similar expenditures. Again, the experience in adjacent properties, if available, furnishes valuable information, such as the cost of drilling wells and of maintaining them in good condition, and the number of wells necessary to maintain production at a definite figure.

Value of Oil.

The value of oil is subject to extreme variation. This is shown by the diagram in figure 2, page 3. For purposes of estimating the value of property, the minimum price paid for oil should be used.

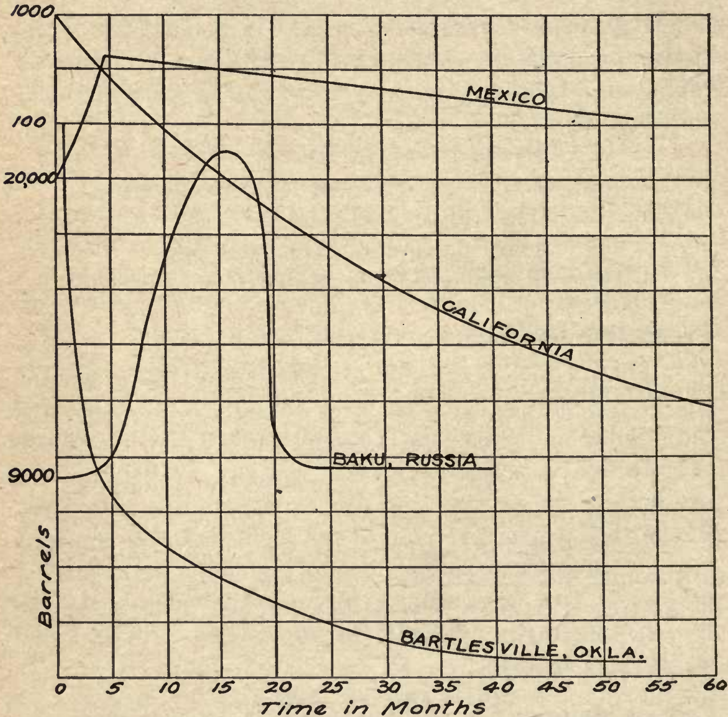


Figure 62. Typical curves showing decline in production of typical wells. Figures at left show initial daily production in barrels.

Location.

Market facilities, accessibility to railroads or pipe lines, and to refineries are features worthy of serious consideration. An unfavorable location with respect to these features may make an otherwise promising tract unattractive to the investor. Very few oil companies rely on production from a single field alone, but have areas scattered over a number of different structures and perhaps different states. This distribution of risk makes their stock more attractive to the investor, and, in many cases, puts it in a class with high class industrial stocks as far as security is concerned.

Financial Status of the Company.

Investment in the stock of oil companies is not advisable unless the investor has absolute confidence in the honesty and integrity of the management, and in its financial and technical ability.

Hammond's Don'ts.

In this connection I cannot do better than to quote John Hays Hammond's rules for investors in Mining Stocks, as with the substitution of the word Oil for Mine these are applicable and to the point:

First—Don't invest your money in an *oil property* simply because of the fact that a friend of yours became rich through a fortunate investment made in *oil stocks.*

Second—Don't, on the other hand, be deterred from investing in an *oil property* because another less fortunate friend became bankrupt through some other *oil investment.*

Third—Don't allow any insinuating, slick, dishonest, not to employ the short and uglier word, promoter, or so called stock broker, to overcome your natural modesty and convince you that, because you have been successful in your own line of business, you yourself are competent to determine the value of an *oil property.* Many men of business ability in their own lines have made trips of self-deception to see for themselves that which existed only in their imaginations. "Shoemaker, stick to your last".

Fourth—Don't be influenced in your desire to purchase *oil stocks* by a *bottle of oil* that the property has produced, even though you yourself have seen the *oil* actually on the ground. This is similar to specimen rock in a mine, which is not a criterion of the average grade of the ore upon which the success of the mine depends. I remember the story of old John Cashweiler, a well-known mining capitalist of his day, when he was asked his opinion on the value of a property from which very rich specimens of ore were shown him. "You might as well show me the hair from the tail of a horse", said Cashweiler, "and then ask me how fast the horse can trot."

Fifth—Do not buy stock in an *oil property* because it has produced a profit of millions of dollars in the past, for the property is obviously so much poorer for the millions already abstracted.

Sixth—Do not buy stock in an *oil company* simply because of the fact that its property adjoins another *oil property* of great value. That may be interesting, but it is not conclusive as to the value of the property in question.

Seventh—Do not buy stock in an *oil property* solely because it is in a far-off country, even though distance lends enchantment to the view.

Eighth—Above all, don't buy shares in an *oil property* unless you have the unqualifiedly favorable report made by an *oil expert* of known integrity, ability, and experience, and one who has made a success in investment of money for his clients. An engineer may have the best obtainable technical training, supplemented by considerable practical experience, and yet lack the certain qualifications in his professional make-up that determine success or failure.

Ninth—Don't buy stock in an *oil property* unless you are sure that the board of directors are honest and competent, because good management is just as essential to success in *oil production* as it is in other enterprises.

Tenth—In short, don't abandon all your good common sense just because the investment happens to be one in *oil* and not in some other class of industrial securities.

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