PETROLEUM EXPLORATION HANDBOOK

A PRACTICAL MANUAL SUMMARIZING THE APPLICATION OF EARTH SCIENCES TO PETROLEUM EXPLORATION

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Chapter 4

PROBABILITY OF SUCCESS IN EXPLORATION

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HISTORY OF EFFORT TO COLLECT DATA

As described in other chapters of this book, many methods have been applied in the search for accumulations of oil and natural gas underground; yet in spite of all the advances made in these methods and in spite of the ever greater accuracy of scientific techniques used for this purpose, there still remains an element of risk of failure. How great this risk is under various conditions of drilling is the theme of the present chapter.

Previous to 1935 no attempt had been made to ascertain the risk involved in wildcat drilling, to find out how many failures, on the average, were drilled for each successful venture. Beginning in that year, we gradually built up a procedure for compiling data on this subject. We soon realized that for reliable comparison of statistics, from year to year or from one region to another, a standard method of reporting would be essential and a standard classification of wells would be requisite. So we evolved a classification which is now used throughout the petroleum industry, and likewise we developed a standard procedure for compiling the necessary data, so that everywhere in the country members of the committee which was appointed to gather the facts would do so in the same way. This committee, known as the Committee on Statistics of Exploratory Drilling, was organized under the auspices of the American Association of Petroleum Geologists, with F. H. Lahee as chairman, in 1945. This committee was successor to a group of geologists who had assisted Lahee during the years 1935 to 1945. After Lahee's retirement from the committee in 1956, Graham B. Moody assumed the chairmanship for one year, to be followed by B. W. Blanpied. Each year, from 1937 to the present time, the chairman has compiled a report from the data furnished him by his committee, a report which has appeared annually in the June number of the *Bulletin of the American Association of Petroleum Geologists* since 1938.

CLASSIFICATION OF WELLS

For proper understanding of the significance of the important facts disclosed by the statistics gathered in this study, the reader must be reasonably familiar with our

classification. All wells drilled specifically for oil or gas may be divided into two groups, or categories: (*A*) *field-development wells* which are drilled *within* the boundaries of known oil or gas reservoirs or which are short (usually one location) step-outs from wells already completed as producers and which are drilled to extend the productive area of the known "pool" or reservoir* and (*B*) wells which are *exploratory* in the

Table 4-1. Classification of Exploratory Wells

Drilling objective	Classification when drilling is started	Classification after completion or abandonment	
		Successful	Unsuccessful
For long extension of partly developed pool	Outpost	Extension well	Dry outpost
For a *new pool* on a structure or in a geological environment already productive—divided into tests drilled			
(1) Within limits of proved area of pool, for new pool			
(*a*) *Above* deepest producing pool	Shallower-pool test	Shallower-pool discovery well	Dry shallower-pool test
(*b*) *Below* deepest producing pool	Deeper-pool test	Deeper-pool discovery well	Dry deeper-pool test
(2) Outside limits of proved area of pool	New-pool wildcat	New-pool discovery wildcat	Dry new-pool wildcat
For a *new field* (on a structure or in an environment never before productive)	New-field wildcat	New-field discovery wildcat	Dry new-field wildcat

sense that they are drilled in search of oil or gas either above or below known reservoirs or at a considerable distance and entirely separate from known producing areas.

These exploratory wells are subdivided into (1) those which are drilled far from any oil-producing or gas-producing area and which, if oil or gas is found, will be the discovery wells of entirely new fields and (2) those which are drilled in association with known producing areas. The wells of group 1 are called *new-field wildcats*. Those of

* In this chapter we use the terms "pool" and "reservoir" as synonymous and as referring to a single interconnected porous rock medium which contains oil or gas in its interstices. A "field" may be one reservoir, or it may include two or more separate reservoirs, all of which, however, are related to the same geologic structure or to the same stratigraphic environment.

group 2 are further divided into (*a*) those located *outside* the known boundaries of partly developed pools and (*b*) those located *within* these known boundaries. The wells under (*a*) may be drilled to explore for new pools (reservoirs) laterally outside the confines of the known reservoir (called *new-pool* wildcats), or they may be wide step-outs intended to extend the known reservoirs (called *outposts* or *extension tests*),

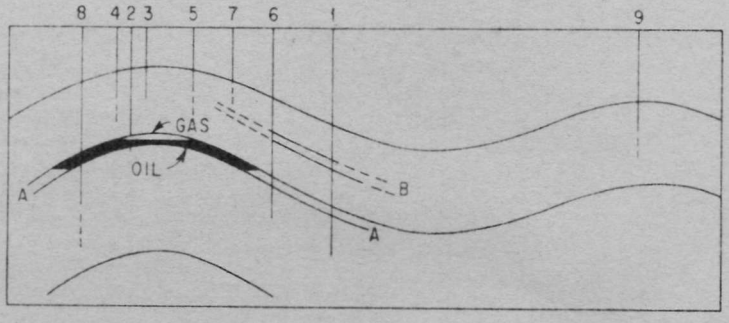

FIGURE 4-1. Diagrammatic illustration of different classes of hole drilled for oil and/or gas. 1. Dry new-field wildcat. 2. New-field wildcat producer. Discovery well of oil field in sand *A*. 3,4. Field-development wells, drilled after completion of 2. 5. Outpost, several locations from 3. 6. New-pool wildcat, outside of productive part of sand *A*, looking for a new pool on the same structure. Both 1 and 6 encountered a water-bearing sand *B* above the main pay *A*. 7. Shallower-pool test drilled in search of oil or gas near pinch-out edge of sand *B* which was absent in 5. 8. Deeper-pool test, drilled in search of possible production in unknown sand or sands below pay sand *A*. 9. New-field wildcat drilled on separate structure from that on which oil was discovered by well 2.

and the holes of subgroup (*b*) may be drilled to search for a new reservoir either stratigraphically *above* the known reservoir (called *shallower-pool tests*) or stratigraphically *below* the known reservoir (called *deeper-pool tests*). This classification is summarized in Table 4-1 and is diagrammatically illustrated in Figure 4-1.

RISKS OF FAILURE IN DRILLING

In the drilling of a well for oil or gas there is always risk of failure, and here we mean failure to find a permeable medium (sandstone, limestone, or other rock material) containing fluid hydrocarbons under sufficient pressure and in sufficient quantity to give promise that, when completed, the well will be a commercial success. The various methods, geological and geophysical, aimed at finding the more favorable geologic structures or environments on which to drill cannot yet surely determine whether or not these hydrocarbons are present or in what quantity they may be present. Only the drill can discover these facts and then usually only after the application of various technical tests made on the prospective reservoir after it has been penetrated by the drill. These statements apply especially to the new-field wildcats, far removed from known underground conditions, but they also apply to all other classes of exploratory hole and even, though to a considerably less degree, to field-development wells.

Through the accumulation of analogous data from year to year, we are now able to ascertain approximately what the average risk of failure is in drilling the various classes of hole for oil or gas. Tables 4-2 to 4-5 record the number of failures and the number of successes as reported at the close of the year when the hole was abandoned as a failure (a dry hole) or was completed as a producer. This we call the "year of completion." Each table covers 15 years. The largest percentage of failures is

recorded for new-field wildcats (Table 4-2) where, for the 15-year period, only 11.2 per cent of the holes drilled were called successful, or, stated in other words, there was only one success in every 8.9 holes drilled. Taking all five classes of exploratory hole into consideration (Table 4-3), in the 15-year period 19.7 per cent were successful, or

Table 4-2. New-field Wildcats Drilled

Year	Oil producers	Gas producers	Total producers	Dry holes	Total holes	Per cent success
1943	298	115	413	2,573	2,986	13.8
1944	247	94	341	2,752	3,093	11.0
1945	232	119	351	2,685	3,036	11.6
1946	236	97	333	2,800	3,133	10.6
1947	274	120	394	3,086	3,480	11.3
1948	366	135	501	3,795	4,296	11.7
1949	364	142	506	3,943	4,449	11.4
1950	462	130	592	4,698	5,290	11.2
1951	515	169	684	5,505	6,189	11.0
1952	555	185	740	5,957	6,697	11.1
1953	581	193	774	6,151	6,925	11.2
1954	639	263	902	6,478	7,380	12.2
1955	659	258	917	7,186	8,103	11.3
1956	628	240	868	7,841	8,709	10.0
1957	589	283	872	7,142	8,014	10.9
Total	6,645	2,543	9,188	72,592	81,780	11.23

Table 4-3. Total Exploratory Holes Drilled

Year	Oil producers	Gas producers	Total producers	Dry holes	Total holes	Per cent success
1943	529	178	707	3,291	3,998	17.7
1944	709	235	944	3,852	4,796	19.7
1945	840	374	1,214	4,399	5,613	21.6
1946	762	375	1,137	4,615	5,752	19.8
1947	981	397	1,378	5,397	6,775	20.4
1948	1,098	365	1,463	6,550	8,013	18.3
1949	1,406	424	1,830	7,228	9,058	20.2
1950	1,583	431	2,014	8,292	11,306	17.8
1951	1,763	454	2,217	9,539	11,756	18.8
1952	1,776	559	2,335	10,090	12,425	18.8
1953	1,981	699	2,680	10,633	13,313	20.1
1954	1,985	723	2,708	10,389	13,097	20.7
1955	2,236	869	3,105	11,832	14,937	20.8
1956	2,274	822	3,096	13,077	16,173	19.1
1957	1,945	865	2,810	11,897	14,707	19.1
Total	21,868	7,770	29,638	121,081	150,719	19.7

one success in every 5.09 drilled. Table 4-4 lists the data for *all* wells drilled for oil or gas, both field-development and exploratory. Here, in the 15 years, 64 per cent were successful, or one success in every 1.56 drilled. Finally, in Table 4-5, we show the data for field-development wells, excluding all types of exploratory hole. Even here, in the 15 years, there is shown to have been only 78.9 per cent success, or one success

Table 4-4. All Holes Drilled for Oil and/or Gas*

Year	Oil producers	Gas producers	Total producers	Dry holes	Total holes	Per cent success
1943	9,887	2 390	12,277	6,364	18,641	65.9
1944	13,502	3,078	16,580	7,153	23,733	69.9
1945	13,944	3,192	17,136	7,346	24,482	70.0
1946	16,087	3,562	19,649	8,496	28,145	69.8
1947	17,613	3,720	21,333	9,751	31,084	68.6
1948	22,197	3,312	25,509	11,939	37,448	68.1
1949	21,415	3,499	24,914	12,898	37,812	65.9
1950	23,775	3,480	27,255	14,918	42,173	64.6
1951	23,532	3,542	27,074	17,497	44,571	60.7
1952	23,371	3,693	27,064	18,211	45,275	59.8
1953	25,251	4,232	29,483	18,759	48,242	61.1
1954	28,063	4,219	32,282	19,137	51,419	62.8
1955	30,474	4,169	36,643	20,564	57,207	64.1
1956	30,641	4,495	35,136	22,254	57,390	61.2
1957	27,364	4,475	31,839	20,156	51,995	61.2
Total	327,116	55,058	382,174	215,443	597,617	64.0

* Excluding water-disposal wells and fluid-injection wells. These figures were taken from *World Oil*, Feb. 15, 1958, p. 139.

Table 4-5. Field-development Wells*

Year	Oil producers	Gas producers	Total producers	Dry holes	Total holes	Per cent success
1943	9,358	2,212	11,570	3,073	14,643	79.1
1944	12,793	2,843	15,636	3,301	18,937	82.5
1945	13,104	2,818	15,922	2,947	18,869	84.4
1946	15,325	3,187	18,512	3,881	22,393	82.8
1947	16,632	3,323	19,955	4,354	24,309	82.1
1948	21,099	2,947	24,046	5,389	29,435	81.6
1949	20,009	3,075	23,084	5,670	28,754	80.3
1950	22,192	3,049	25,241	6,626	31,867	79.2
1951	21,769	3,088	24,857	7,958	32,815	75.8
1952	21,595	3,134	24,729	8,121	32,850	75.2
1953	23,270	3,533	26,803	8,126	34,929	76.8
1954	26,078	3,496	29,574	8,748	38,322	77.2
1955	28,238	3,300	31,538	8,732	40,325	78.2
1956	28,367	3,673	32,040	9,177	41,217	77.9
1957	25,420	3,610	29,030	8,263	37,293	77.8
Total	305,249	47,288	352,537	94,366	446,903	78.9

* Excluding water-disposal wells and fluid-injection wells.

in every 1.27 drilled. These statistics impressively demonstrate how large is the factor of probable failure, or, to put it in another way, how small are the chances of success, when drilling for oil or gas.

One of the striking facts brought out by these tables is the relatively small variation in the indicated percentages of success from year to year when examined separately under each group. These variations are shown in Figure 4-2. This relative consistency through this period must mean only one thing, that improvements in the

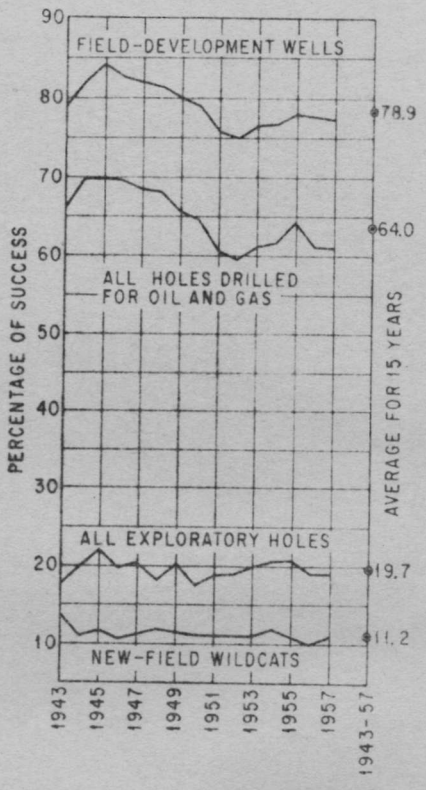

FIGURE 4-2. Curves showing percentage success of different classes of hole drilled for oil and/or gas during period from 1943 to 1957, inclusive.

Table 4-6. Average Depths of Exploratory Holes, Feet

Year	For all classes of exploratory hole	For new-field wildcats
1943	4,189	4,416
1944	4,217	4,217
1945	4,103	4,403
1946	3,854	4,007
1947	3,896	4,198
1948	4,086	4,362
1949	3,842	4,082
1950	3,898	4,181
1951	4,197	4,516
1952	4,476	4,852
1953	4,560	4,889
1954	4,549	4,808
1955	4,631	4,810
1956	4,574	4,823
1957	4,701	4,873
1943–1947	4,031	4,245
1948–1952	4,125	4,438
1953–1957	4,605	4,839
1943–1957	4,338	4,593

techniques of finding have been approximately balanced by the increasing difficulty of locating commercial underground accumulations of oil and gas, and this increasing difficulty is dependent mainly on the greater depths of drilling required to find new reserves and on the fact that the more obvious geologic structures have already been drilled. The increase in the average depth of drilling in exploratory holes is recorded in Table 4-6. Especially significant is this increase by 5-year periods.

Definition of Successful

When referring to a new-field wildcat as "successful" at the close of the year of completion, we mean that, as far as can be ascertained at that time, by examination of cores, by drill-stem tests, and by determinations of potential flow of the hydrocarbons, the well will prove to be commercial in the sense that its production when marketed will repay its costs of drilling, completing, and producing, although possibly with no additional returns to repay all the other costs which entered into the leasing, exploring, and overhead that preceded its drilling. However, if we wait a few weeks or a few months after the close of the year of completion, we find that some of these supposedly successful wells turn out to be failures, which are therefore abandoned. A careful study of these results reveals the fact that, on the average, not *one in nine*, but only *one in every ten* new-field wildcats can actually be rated as successful.

ESTIMATED RESERVES DISCOVERED BY WILDCAT DRILLING

Each successful new-field wildcat generally initiates the drilling of adjacent field-development wells, and these, after several years of development history, are usually sufficient to permit a fair estimate of the total ultimate recoverable reserves of oil and gas in the field. By a detailed investigation of such reserves, and by crediting them to the wells which discovered the fields, we can determine how many fields of certain selected sizes were discovered each year. For this purpose we use letter symbols, as follows:

Symbol	Barrels of liquid hydrocarbons	Cubic feet of natural gas
A	50 million or more	300 billion or more
B	25–50 million	150–300 billion
C	10–25 million	60–150 billion
D	1–10 million	6–60 billion
E	Productive, but less than 1 million	Productive, but less than 6 billion

When considering oil reserves and gas reserves together, it is useful, as well as scientifically correct, to relate oil and gas to one another on the basis of British thermal units, or Btu.* Roughly speaking, we may assume that a barrel of crude oil contains 6000 Btu, and that a thousand cubic feet (usually written 1 MCF) of natural gas contain 1000 Btu. In other words, 6,000 cubic feet of natural hydrocarbon gas are roughly equivalent to one barrel of crude oil, on this basis. Actually, individual samples of different crudes and different gases may vary somewhat from this value, but for most practical purposes it may be accepted as a reasonable approximation.

If we allow a period of 4 years or more for development of the fields discovered by

* A British thermal unit is defined as the amount of heat required to raise the temperature of one pound of water at its maximum density one degree Fahrenheit.

wildcat drilling in each of the 10 years, 1943 to 1952, inclusive,* and if we estimate the total ultimate recoverable reserves in each of these fields, adding together both the actual oil reserves and the gas reserves translated into their oil equivalent on the Btu basis, and if we attribute to each discovery new-field wildcat all these reserves, not only those in the first reservoir opened by the discovery well, but also those in other reservoirs opened subsequently in the same field, we learn by this procedure that:

1. To find a field containing total ultimate recoverable reserves of 50 million barrels or more (class A), 422 new-field wildcats were drilled.
2. To find a field with 25 million barrels or more (class A plus class B), 219 new-field wildcats were drilled.
3. To find a field with 10 million barrels or more (classes A plus B plus C), 84 new-field wildcats were drilled.
4. To find a field having 1 million barrels or more of total ultimate recoverable reserves (classes A plus B plus C plus D), 27 new-field wildcats were drilled.

These are very significant figures. They demonstrate how great is the risk of failure incurred in drilling for new reserves of oil and gas. To find a field which will pay the costs of drilling and producing (D fields or better), on the average 27 new-field wildcats must be drilled. But no company can stay in business and grow and pay all its additional expenses of leasing, geological and geophysical exploration, etc., unless it discovers some fields of the A and B categories. Yet to find one such field, as we have shown, on the average 219 new-field wildcats must be drilled.

SUMMARY AND CONCLUSIONS

We may summarize this chapter by citing its obvious conclusions together with a few additional thoughts, as follows:

1. Petroleum and natural gas, which were formed during long periods of geologic time, occur underground in accumulations which are exhaustible.
2. The number of these accumulations is limited, so that, as each reservoir is found and drained, there is one less accumulation to be discovered; there is no replacement of the hydrocarbons removed.
3. In those regions where the search for oil and gas has been in progress for many years, extensive geological and geophysical exploration has resulted in the discovery of the more obvious geological reservoirs for these hydrocarbons.
4. The search for new oil and gas fields is ever more difficult.
5. In this search drilling is being carried to greater and greater depths.
6. In spite of many technical improvements in exploring, drilling, completing, and producing, the quantity of reserves found per foot drilled is declining.
7. The costs involved in exploring, drilling, and producing are increasing.

All these important facts should be clearly borne in mind by all persons concerned in any way with this industry.

Oil and gas are of such tremendous and far-reaching importance, both in the nation's economy in times of peace and as an essential commodity in times of emergency, that nothing should ever be done to delay or impede the search for them. From every angle—industrial, political, and utilitarian—aggressive exploration for these hydrocarbons should be vigorously encouraged.

* This decade was selected because data prior to 1943 are inadequate and data for years after 1952, allowing at least 4 additional years for development history, were not yet available when this study was made (see Statistics on Natural-gas Discoveries, *Bull. AAPG*, vol. 42, pp. 2037–2047, September, 1958).