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ARIZONA BUREAU OF MINES

G. M. BUTLER, *Director*

## PETROLEUM

By

G. M. BUTLER AND J. B. TENNEY

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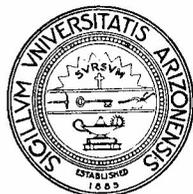
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# PETROLEUM

BY G. M. BUTLER

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## PREFACE

This publication has been prepared to replace Bulletins No. 65, "Oil and Its Geology," No. 69, "Prospecting for Petroleum," and No. 116, "Petroleum," issued by the Arizona Bureau of Mines a decade or more ago, all of which have been out of print for some time. It is essentially a reprint of Bulletin No. 116, but Part II has been entirely rewritten. Part I has been abstracted, with numerous modifications, from an address delivered many years ago at El Paso, Texas, which was published in the Arizona Mining Journal.

No attempt has been made to write a manual for petroleum geologists; in fact, the end sought was merely to impress the general public with the fact that the accumulation and distribution of petroleum are governed by certain fairly well understood, but generally unknown or unappreciated, laws which only a well-trained and experienced geologist can satisfactorily apply. It was, therefore, deemed unnecessary and even undesirable to go into details or to discuss exceptions to and deviations from the general statements made. The reader who wishes to know "the whole story" is directed to the books on petroleum listed in the Bibliography.

## PROPERTIES OF PETROLEUM

Petroleum or crude oil is a more or less viscous, oily, inflammable fluid that varies from transparent to only slightly translucent and has a distinctive odor. When the substance contains sulphur, as is often the case, the odor is rather disagreeable. The fluidity of the crude petroleum is dependent upon its temperature as well as its composition.

The color of petroleum varies widely, and such variation is sometimes seen at different points in a single field. When viewed by transmitted light, it may be nearly white, yellow, greenish, reddish, reddish-brown, brownish, or black, but it is usually greenish by reflected light. It has been proved experimentally

that crude oil can be deprived of its dark color by filtration through Fuller's earth or clay. No doubt natural filtration of originally colored oils explains the appearance of the very "white" oils that have been found in some fields such as at Baku, Russia, and in parts of California and Texas.

Petroleum is composed essentially of hydrogen and carbon combined as various hydrocarbon compounds, but it frequently contains combined and free oxygen, sulphur, and nitrogen. The term "asphaltic" or "asphalt-base" is applied to those oils that yield on slow distillation or evaporation a dark asphaltic residue which is readily attacked by acids and dissolves in the usual solvents; while those oils that yield after distillation or evaporation at a low temperature a relatively high proportion of light-colored, solid hydrocarbons, chiefly of the paraffin series, which are not readily attacked by acids and normal solvents, are called "paraffin" or "paraffin-base" oils. No sharp distinction can be drawn, however, between asphalt-base and paraffin-base oils, since transitional varieties are common, and nearly all asphalt-base oils contain paraffin, while many paraffin-base oils contain asphaltic material.

The oils of Pennsylvania and Ohio contain a paraffin base, those of California and Texas are generally asphaltic, whereas some of the Mexican oils are mixtures.

### THE REFINING OF PETROLEUM

The various hydrocarbon compounds found in petroleum have different boiling points and densities (specific gravities), and that hydrocarbon with the lowest boiling point evaporates or distills off first as a gas when the oil is heated. By raising the temperature of the oil from time to time, one after another of the compounds in petroleum are distilled, condensed, collected, and washed by acids and alkalies to remove the impurities. In such a fashion, gasoline, kerosene, heavy machine oils, and the many other different types of petroleum products are obtained. The process of distillation is, however, not as simple as might be supposed from the brief outline just presented, as many disturbing factors enter into it, but it is not deemed essential to discuss this matter here in greater detail.

### SPECIFIC GRAVITY OF PETROLEUM

In most cases, the specific gravity of petroleum is determined by comparison with water; a crude oil that is exactly as heavy as

water has a specific gravity of 1.0000, while oils with gravities of less than one are lighter than, and will float upon water. In the United States, however, the specific gravity of petroleum is almost universally given in degrees Baumé. The following table shows the corresponding specific gravities of various degrees Baumé. It will be noted that the higher the specific gravity of an oil may be, the lower is its gravity when expressed in degrees Baumé.

TABLE OF BAUMÉ AND SPECIFIC GRAVITY EQUIVALENTS

Baumé	Sp. Gravity	Baumé	Sp. Gravity
10.....	1.0000	55.....	0.7587
15.....	0.9658	60.....	0.7394
20.....	0.9339	65.....	0.7205
25.....	0.9047	70.....	0.7025
30.....	0.8755	75.....	0.6856
35.....	0.8492	80.....	0.6689
40.....	0.8254	85.....	0.6511
45.....	0.8017	90.....	0.6363
50.....	0.7794		

## ORIGIN OF PETROLEUM

*The Inorganic Theory:* The supporters of the inorganic theory claim that petroleum has been formed by a chemical reaction between superheated steam and metallic carbides deep below the surface of the earth. While no one questions the possibility of forming hydrocarbons in this way, the opponents of the inorganic theory point out that very few or no commercially important deposits of petroleum occur in such a way and have such rock associates as would be expected if the oil had originated in the manner suggested.

Chemists who are unfamiliar with the geological conditions existing in petroleum-bearing areas are apt to champion this theory, but probably no reputable petroleum geologist believes that any oil that exists in such quantities as to admit of its profitable extraction from the earth has been formed by such means. It seems useless, therefore, to devote more space to the discussion of the inorganic theory.

*The Organic Theory:* According to the organic theory, petroleum has originated by a process of natural distillation of the remains of sea organisms—both plant and animal, but principally the former, probably often very small, which settled on the bottom of the sea and were subsequently covered with layers of mud, sand, or calcareous sediments. Varying, but sometimes enormous, thicknesses

of such sediments containing organic remains thus accumulated, and by cementation and pressure, the sediments were changed into shale, sandstone, and limestone rock strata. By certain chemical processes which need not be here discussed, the organic material was converted into petroleum which at first existed as tiny globules disseminated more or less scantily throughout such sedimentary rocks.

It seems probable that the character of petroleum (whether it has an asphalt or paraffin base) is governed by the nature of the organic remains from which it was derived. Certain asphalt-base oils are believed by some to have been formed from animal matter.

There is a vast store of field and experimental evidence of the correctness of this theory of the origin of petroleum, and few question its almost universal applicability.

#### METHODS OF CONCENTRATION

Too strong emphasis cannot be placed upon the fact that petroleum disseminated through sediments in the positions where it was originally formed is never present in sufficient quantity to flow freely or to be pumped from wells. In many localities are found thousands of acres of petroliferous or bituminous rocks that yield pronounced tests for oil, yet in connection with which no economically valuable deposits of petroleum are found. It is unquestionably true that valuable oil deposits are formed only when disseminated petroleum in sedimentary rocks has been concentrated—when oil once scattered through a great mass of rock has been forced in some way to accumulate within a much smaller volume of such earth material.

*Influence of Rock Textures:* It should be evident that oil will find its way very slowly, if at all, through dense or compact rocks. Areas containing only such rocks, since they prevent migration or movement of the oil, are poor places in which to expect to find concentrations of petroleum. Almost equally unfavorable are areas underlain by frequent alternations of very *thin-bedded* porous and *decidedly* compact rocks.

Not only is rock porosity a prerequisite to the migration of petroleum, without which there can be no concentration, but concentrations or accumulations themselves can hardly exist except in porous rocks. So-called "oil pools" do not fill great caves in the earth. There are, in fact, only a few relatively unimportant exceptions to the statement that such pools are invariably merely saturated, restricted masses of porous rock, usually sandstone, but sometimes sandy shale or porous

limestone. In a few instances, the oil fills intercommunicating joints or other cracks.

*Influence of Water:* The capillarity of water is much greater than that of crude oil. In other words, water has a much stronger tendency than oil to enter and fill tiny openings. If such openings are filled with oil, water can exert sufficient capillary force to drive the oil therefrom, and the oil will not re-enter the openings while they are full of water. Evidence points to shales, which were laid down in the ocean or in large salt lakes as the original sources of the petroleum of most fields, and shales certainly contain pores of such small size as to make capillarity a powerful factor in forcing any oil present out of them and into more porous strata above or below.

Not only, then, does water, through capillary action, force the crude oil out of shales in which it is formed, but, once released and having found its way to a relatively porous rock, the petroleum, being lighter than water, will tend to percolate slowly upward through intercommunicating pores between the grains. It will move with relative rapidity if the rock is unusually porous and if the oil is comparatively light, and slowly, if at all, when contrary conditions prevail. It will continue to work upward until dry rock or compact, impervious beds, say of clay shale, are reached.

It is probably true, as stated by Rich,<sup>1</sup> that "the component of gravity tending to cause a globule of oil to move up the dip of the rocks, for the dips prevailing in a large number of oil fields, is much less than the static friction opposed to its movement." In fact, experiments seem to prove that oil will not rise at all through rocks saturated with *stagnant* water unless the rocks are uncommonly porous, the oil is very light, the liquids are agitated, or moving gas is present. Experiments made by Rich<sup>2</sup> show, however, that water will carry oil through rocks of average porosity *if the water is in motion*, even though the rate of flow be very slow. Oil thus set in motion by water moving horizontally through porous rocks will undoubtedly, because of its buoyancy, gradually move upward as well as laterally, and will eventually reach the dry and impervious rock already mentioned. In other words, upward movement of oil through water-saturated, porous rocks is inevitable if the water is moving horizontally or along beds that dip upward at any angle. If the water is moving along downward

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<sup>1</sup> Rich, John L., *Econ. Geol.*, vol. XVI, pp. 347-371, 1921.

<sup>2</sup> *Loc. cit.*

dipping beds with sufficient velocity to overcome the buoyancy of the oil, the latter will be carried downward, however.

It should, probably, be stated that the idea that water movement and pressure is more effective in transporting petroleum than is gravitation, is much disputed. It is claimed by some authorities that the movement of underground water is too slow to initiate and accelerate the movement of oil. So far as is known, however, Rich's experiments have never been discredited. As a matter of fact, it does not make a great deal of difference whether it is assumed that oil movement is or is not promoted by the movement of water. It is certainly true that oil will tend to work upward through water-saturated, porous earth materials because its gravity is less than that of water.

It is a well-established fact that underground waters within a few thousand feet of the earth's surface are usually in slow motion. If this were not so, wells would soon "go dry" through exhaustion of the water in the adjacent rocks. The theory just outlined of the method by which petroleum is concentrated is, therefore, not dependent for its validity upon any improbable assumption. The process of petroleum concentration is illustrated in Figure 1 which shows a thick series of horizontal beds (C) underlaid by the sandy shale (B) that originally contained disseminated oil, overlaid with a layer of impervious shale (D), and the whole saturated to the point indicated by the dotted line with water moving slowly from right to left. All the oil originally present in beds B and C will gradually work upward and accumulate below bed D, and there may be an oil seep or some escaping gas at point X.

The process outlined is so simple that a child can understand it, *but* it is a fact that no very valuable deposit of petroleum has been found where conditions are as shown in this sketch. The reason for this condition is found in the fact that, although some concentration has occurred, it has been insufficient to form a real pool. If a well is drilled at Y, the only oil encountered will be a relatively thin film that is moving slowly along beneath bed D. It is true that oil may slowly work into the well from the right, but the most favorable result that can be secured under such conditions will be a small "showing" of petroleum.

Stated briefly, then, it can be said that moderately or highly profitable wells have not been found, and should not be sought, in absolutely horizontal strata.

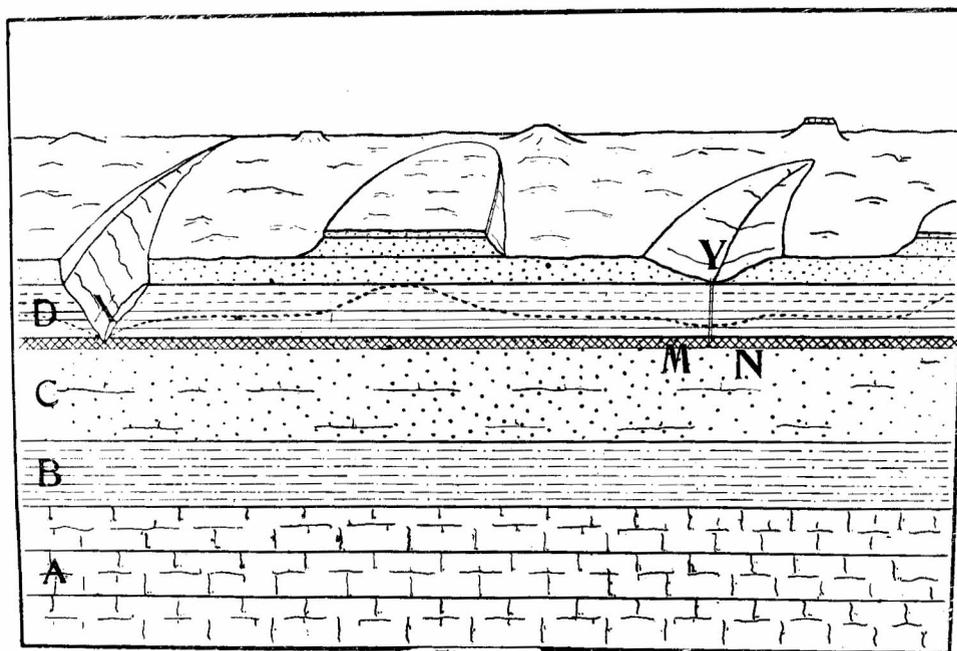


Fig. 1. Horizontal Strata.  
 "B" Sandy shale in which petroleum originated. "C" Porous reservoir rock.  
 "D" Impervious shale beneath which oil (cross-hatched) may accumulate.  
 "Y" Oil well. "X" Possible oil seeps. Ground water level indicated by dotted line.



## FAVORABLE STRUCTURES

*Anticline:* If beds of earth material, instead of lying horizontally have been bent upward and downward again so as to form a long, relatively narrow up-fold, the resulting structural feature is called an anticline. An anticline may be closely compressed with steeply sloping limbs and more or less broken crest, or it may be broad and low with an unbroken crest and limbs that slope or dip so gently (at such a slight angle from horizontal) that the structure cannot be recognized without the use of a level. A single anticline may stand alone, or a series of up and down-folds (synclines) may be formed. A transverse section through a single anticline is shown at the right side of Figure 2.

Under the conditions illustrated by Figure 2, oil carried forward along the top of the porous bed D below shale E by water flowing from left to right, will begin to rise rather rapidly a little to the right of point M, and will be trapped beneath the anticline where it will accumulate to form the pool M-O-N *unless* the velocity of the moving water is high enough to overcome the buoyancy of the oil and flush out the anticline by carrying the oil downward toward and past point N. Figure 2 is erroneous, however, in that the oil pool M-O-N would probably in most cases extend farther down the flank of the anticline on the side toward which the water flows than on the other side.

Even if the oil is flushed out of the anticline, gas may remain there, because of its great buoyancy; but both oil and gas may be entirely carried out from below an anticline if the rate of flow of the water is very high.

Some authorities deny that oil or gas which is once trapped below an anticline will ever be washed or flushed out by actively circulating water. In support of this view, they point out that it is now known that important deposits of oil and gas occur in structural traps in the Dakota sands of the northern Great Plains region, although water is flowing with relatively high velocity through these sands. This water, instead of penetrating through the oil-saturated sands and carrying the oil out of them, appears to flow around these accumulations. Possibly the oil accumulated when the water was flowing at a low velocity and sands completely saturated with oil cannot be flushed no matter how the velocity of flow may have increased. It is equally possible that no oil would have accumulated in the structural traps if the velocity of flow had always been high.

A pool formed by trapping of oil that reaches an anticline with circulating groundwater will not usually extend uninterruptedly for a very long distance parallel to the crest of the anticline, since the reservoir rock may be too dense at some points to yield much, or any, oil, or cross-folds may cause the axis of the anticline to curve up and down again at one or more points, in which case oil will tend to concentrate below those places where the beds in the anticline show upward transverse folding.

Experience has shown that a simple, very long anticline with a horizontal axis is rarely underlaid by a valuable oil pool. This is probably because there has been too little concentration in such places. In other words, a valuable pool is normally produced by the movement of petroleum *along* an anticline toward a high point, structurally speaking, as well as by the trapping of oil introduced from one side. It should be noted that, the flatter a fold, the greater the width of the resulting pool as compared to its length, and the shallower the depth. The common accumulation of oil in pools along the crests of anticlines explains the usual distribution of producing wells in most oil fields over areas that are long and relatively narrow like the pool or pools beneath.

Anticlines are not always of the symmetrical form shown in Figure 2. They may be asymmetrical as illustrated in Figure 3, or even overturned as shown in Figure 4.

*Monocline or Terrace:* A structure that is sometimes productive of oil is the monocline, or terrace, illustrated by Figure 5. In such a structure oil introduced in water flowing toward the right along X-Y may have too low a velocity to overcome the buoyancy of the oil when the water starts to flow down slope Y-Z. Oil therefore, tends to accumulate at Y and to form a pool there.

*Dome or Quaquaversal Fold:* A very favorable structure is a dome-like or quaquaversal fold. It is very difficult to illustrate such a fold by a diagram, but any vertical section through one would look exactly like an anticline. However, the beds, unlike the ones shown in Figure 2, slope down toward the back and front of the diagram as well as toward both sides, and any one bed has roughly the form of a dome or an inverted bowl. Under such conditions, petroleum introduced in water flowing from right to left and trapped below the fold will not only flow up from the right as in Figure 2, but will also gather from the front and back and the result is often a very high degree of concentration in a pool that is more or less circular in shape if viewed from above, instead of possessing the usual linear form.

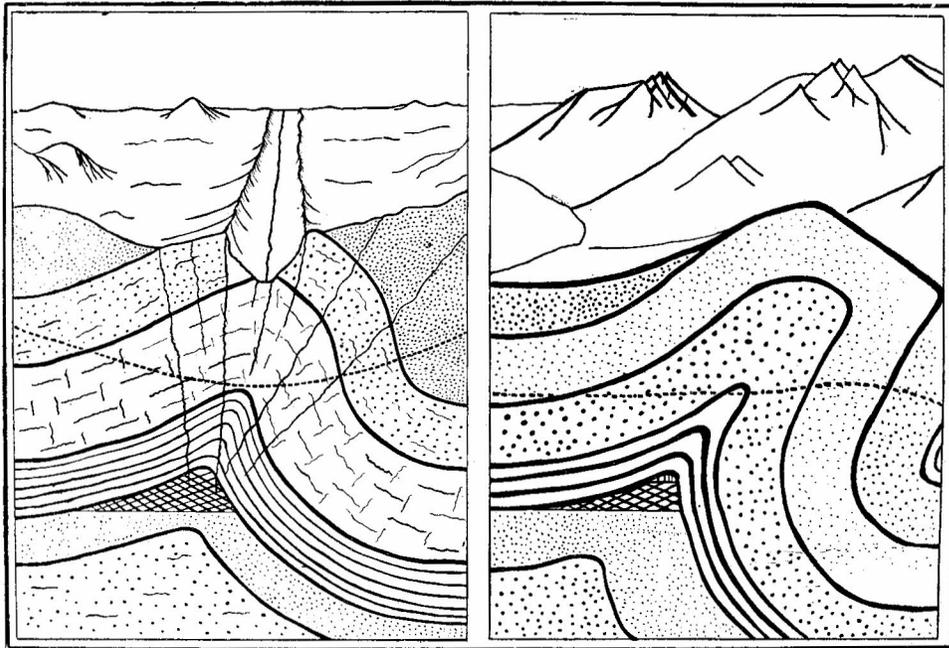


Fig. 3. Asymmetrical Anticline.  
(Conventions as in preceding figures).

Fig. 4. Overturned Anticline.  
(Conventions as in preceding figures).

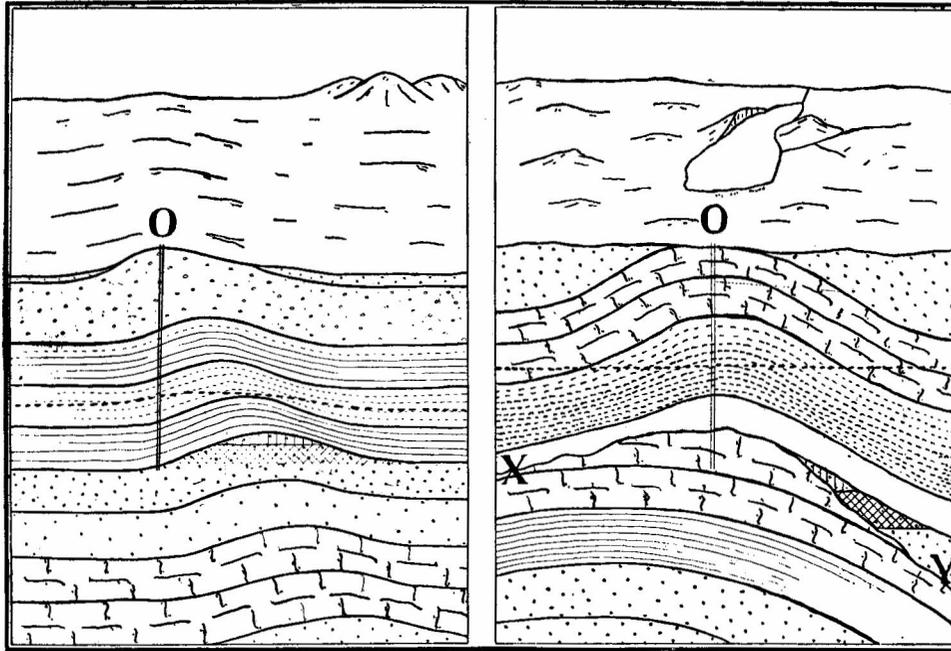


Fig. 5. Monocline.  
(Conventions as in preceding figures).

Fig. 6. Inclined Strata.  
(Conventions as in preceding figures  
excepting that the cross-hatchings  
may indicate solid petroleum residues  
instead of oil.)

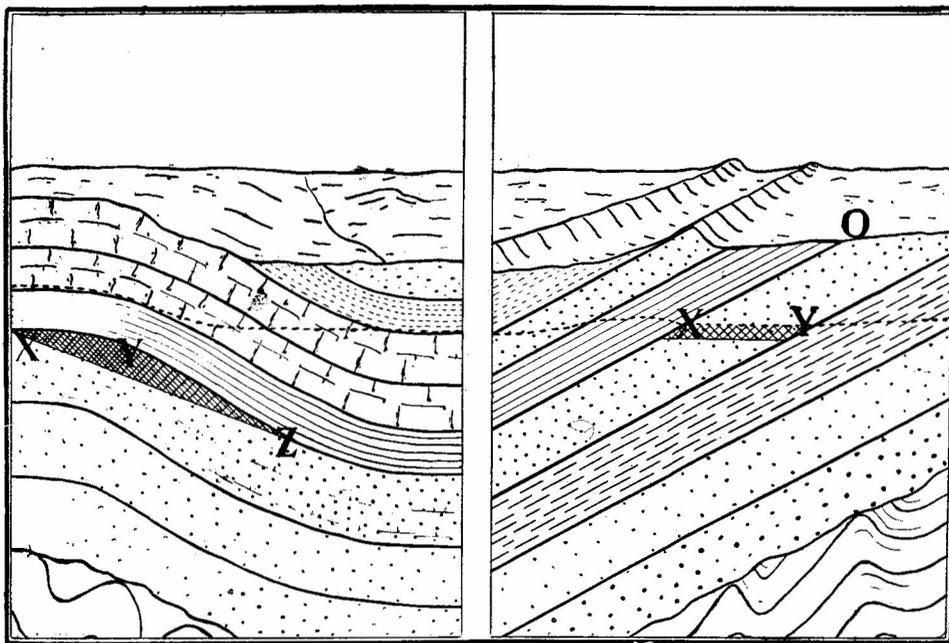


Fig. 7. Anticline with line of crests extending toward one side.  
 (Conventions as in preceding figures.)

Fig. 8. Anticline Underlaid by Unconformity (X-Y).  
 (Conventions as in preceding figures.)

*Unconformity:* Sometimes a thick series of sediments is elevated above sea level, and then eroded or worn down by the action of water and wind to a more or less irregular surface. Later, this surface may be depressed below sea level, and other sediments deposited thereon. Such an old erosion surface as this is called an unconformity, and is illustrated by the surface X-Y in Figure 8. If impervious material (illustrated by the white bed in Figure 8) overlies such an unconformity, oil may collect beneath a variety of structural conditions. The figure shows an anticline superimposed by folding upon an unconformity after the deposition of the beds above the unconformity, but under the conditions mentioned oil might collect along an unconformity by seeping upward from lower beds even though the later-formed beds remain in a horizontal position. In other words, oil may accumulate below an unconformity even when no favorable structure exists on the surface.

*Miscellaneous Structures:* While there are a few other structures in which more or less important concentrations of petroleum have been found, or in which, theoretically, such concentrations might possibly occur, valuable pools are known to exist in them in only one or two fields in the world or have never been found therein. Since, therefore, the chance of finding good pools in such structures is usually too small to justify drilling operations, such structures will not be described.

### GEOSYNCLINES AS SOURCES OF PETROLEUM

A geosyncline is a broad, structural valley scores or hundreds of miles long and wide. In the center or at one or more sides the beds are approximately horizontal except where disturbed by minor folds, and the up-bending of the strata toward the sides is often so gradual as not to be evident to the eye. On one or more edges of the structure, however, the beds are usually up-turned with a relatively high dip, and their eroded outcrops frequently form the foothills of a range of mountains. Rain that falls upon, or surface water that runs over, the eroded edges of a porous bed overlaid by an impervious bed in such a structure will flow with relative rapidity down the dip; and eventually the porous bed, where horizontal, may be filled with water under considerable hydrostatic pressure, and an artesian basin may be thus formed. If oil works into the porous, waterfilled bed in such a structure where the dip is pronounced, it may be carried downward because of the comparatively high velocity of flow of the water, and may be trapped beneath an anticline or other favorable structure when it

reaches that part of the geosyncline where the beds are less steeply inclined. Near the upper edges of a great geosyncline, the water may have such a high velocity of flow that anticlines or other favorable structures will be completely flushed of gas or oil, while, farther from the edges, only gas will remain beneath such structures. Oil pools should, then, be sought some distance from the upper edges. Oil is doubtless more apt to be found there beneath anticlines with axes extending approximately perpendicular to the direction of flow of the water than it is below such structures with axes extending in the direction of flow. This is because less oil will reach the anticline in the latter case, and it will be more easily removed by flushing. If, however, an anticline with the axis approximately parallel to the direction of flow of the underground water plunges downward rather suddenly at the end toward which the water is flowing, oil may be trapped below the plunging end, and a pool may be found there. Rich<sup>1</sup> cites numerous examples of oil fields in geosynclines, and shows that they possess peculiarities in close accord with the theory of their formation that has just been outlined.

Those authorities who oppose the theory that oil may be carried for some distance laterally by flowing water explain the presence of oil and gas pools around the edges of geosynclines by assuming that the oil has worked upward and outward from the center of the geosyncline, beneath impervious inclined beds, until trapped beneath some suitable structure. In other words, they claim that oil moves up through the water because lighter than water, and then continues, for the same reason, to travel toward the edges of a geosyncline in a direction contrary to that in which the water flows.

#### INFLUENCE OF GRAVITY WHEN WATER IS ABSENT

Some people claim that in arid regions, where there is little or no water in rocks containing disseminated petroleum, the oil will gradually work downward until an impervious bed is encountered and will accumulate there. They state, further, that, if the beds are bent downward into a trough or syncline, a profitable pool may result. While it is probably unsafe unqualifiedly to deny the possibility that valuable concentrations have been formed in this way, it is a fact that none have yet been found in such structures, and that, if any are ever located, wells sunk to them probably will not flow or gush. It seems foolish to place any reliance upon the possibility of valuable oil pools re-

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1. Loc. cit.

sulting in this way from the action of gravity alone. It would seem to be the wildest kind of a gamble to drill on any structure containing only dry rocks; and for the reasons mentioned it may be necessary to drill at least to sea-level before there is any likelihood of finding oil accumulations in very arid regions. It should not be forgotten that, even in arid regions, so-called "perched" water-bearing rock may be found on top of compact, impervious beds, but that the thickness of such water horizons and the conditions under which they are found preclude the possibility of any oil pools resulting from their presence. As a corollary of what has just been said, it may be stated that striking water in wells in arid regions does not prove that the rocks below are saturated with water.

In connection with the question under discussion, it may be well to repeat the belief of most geologists that petroleum originates in shales, and is driven therefrom into porous beds only by the capillary action of water. Gravity alone will not cause the oil to separate from shale beds and to percolate downward through dry rocks until an impervious bed in a synclinal fold is reached. Of course rocks now dry may once have been wet, but it is decidedly risky to assume that such a change of condition has taken place.

#### UNFAVORABLE STRUCTURES AND CONDITIONS

*Inclined Beds:* It has already been shown that horizontal beds do not present conditions favoring the formation of oil. Inclined beds, as illustrated in Figure 6, are likewise poor places in which to seek concentrations, since, although petroleum may percolate upward to the point X-Y in the figure mentioned, at the top of the water-saturated rocks, it is likely that, instead of oil, a deposit of solid asphalt or paraffin will form there. This is because petroleum shows a strong tendency to disintegrate into solid material and gas under any conditions that will permit the escape of the latter; and, where the beds are highly inclined, there is nothing to prevent the free escape of the gas through the porous beds to the surface of the earth. Escaping gas may carry a little oil upward with it, giving rise to oil seeps at O.

It is true that petroleum imprisoned beneath impervious material through which neither gas nor oil can pass will also decompose to some extent in the manner just mentioned; but, unless there is free egress of the gas to the air, the process will be incomplete, and the products will not be a great deal of gas and solid asphalt or paraffin, but will consist of a lesser amount of gas, and a thicker, heavier grade of oil.

The facts just mentioned explain why wells drilled on the exact crests of anticlines often encounter gas instead of oil, while wells sunk at some distance to one or both sides of the crest may strike oil. Still farther from the crest only water, often salty, will be found. Such conditions are illustrated in Figure 2. Well No. 4 will first yield only gas (represented in all the figures by vertical hatchings). Wells Nos. 2, 3, and 5 will strike oil (represented in all the figures by cross hatchings), and wells Nos. 1 and 6 will encounter water. As the gas escapes through well No. 4, the oil will rise toward the crest of the anticline. The water below the oil will also rise, and first well No. 2, then No. 5, and finally No. 3 will cease yielding oil, and will produce only water. Also, when the gas has all escaped, well No. 4 will be converted from a gas into an oil well, but, when the oil has all been exhausted, it, too, will yield only water. Water associated with petroleum is nearly always salty.

In rare instances, little or no water is encountered directly beneath the oil. This is probably the result of a recent subsidence of the water which will run downward through some medium-dense rocks more rapidly than the oil can follow.

The reason why some wells flow or gush can also be understood by reference to Figure 2. The gas on top of the oil is highly compressed and exerts an enormous pressure upon the oil, forcing it out through wells Nos. 2, 3, and 5. Gushing or flowing wells will also occur when the water beneath is under strong hydrostatic pressure.

*Prevalence of Fissures:* In addition to a horizontal or inclined structure and a lack of groundwater, a badly cracked or fissured condition of rocks should be regarded as unfavorable to the occurrence of oil because the gas can then easily escape from any concentration of petroleum that may form and leave only a solid residue, as already explained. Since the rocks above a sharply folded anticline, like that illustrated in Figure 3, are not infrequently broken instead of being merely smoothly flexed, such anticlines are less favorable loci for valuable pools than are more open folds.

*Faults:* A fault is a crack through earth materials along which the rocks have slipped or been displaced. It is an undeniable fact that, in some important oil fields, faulting has had a decidedly beneficial effect on the accumulation of oil, either by serving as a conduit through which oil may rise from greater depths or by creating structural traps for the oil. In spite of such favorable influences of faulting, it is generally true that a badly broken-up and faulted con-

dition in any area is a decidedly unfavorable condition unless the faults and other cracks are sealed so tightly as to prevent the escape of gas.

*Proximity of Igneous Rocks:* While it cannot be stated that commercially important deposits of petroleum have *never* been found in rocks that were once molten (igneous), it is a fact that the chances of finding oil in such rocks are so small as to be unworthy of consideration. Certainly no oil can exist in or near them while they are hot, but, if they shrink and crack on cooling, and, if oil should, after they are entirely cold, reach them, it is possible that the oil will accumulate along the contacts or in the joints. In fact, it is known to have done so in several instances. In general, however, it may be assumed that the heat expelled from cooling igneous rocks, such as granite, porphyry, rhyolite, basalt, etc., greatly accelerates the decomposition of any petroleum near them, and the presence of such rocks, intruded into or through sediments in which it is hoped to find petroleum, should be considered a decidedly unfavorable feature.

*Evidences of Intense Pressures:* It is useless to seek for valuable deposits of petroleum in rocks that have been formed by extreme pressure, such as gneisses, schists of all kinds, and slates. Not only is heat always developed as a result of high pressure on earth materials (and such heat would tend to decompose the petroleum and leave nothing but solid residues), but rocks formed in this way are too compact to permit the accumulation of petroleum into valuable pools.

*Red Rocks:* Petroleum is not found in red rocks, since earth materials of this color nearly always owe their tint to an oxide of iron that cannot exist in rocks containing petroleum or any other organic material. For this reason the beds *at the depth where it is hoped to find oil* should not be red. The color of such beds can often be learned by examining outcrops of them at some distance from the location of the proposed well. For instance, the character of the beds below the anticline illustrated at the right of Figure 2 can be determined with a considerable degree of certainty by examining the outcrops to the left of the gulch shown on this figure.

It must be admitted that, in a few places, gray or black shale beds which contain bituminous material have, where exposed to the air, suffered a form of extreme oxidation which is similar to combustion, and appear to have been baked. The color is then changed to a distinctive brick-red. These effects disappear, of course, at no great distance below outcrops, and are rare.

Of course, the presence of red rocks *on the surface* has no bearing

on the problem that confronts the petroleum geologist, since such red beds may be overlaid with material of different colors. In fact, except as they may aid the seeker of petroleum to determine structural conditions, surface features mean little or nothing. The topography, the vegetation, and the age, kind, and color of the outcropping beds may perfectly duplicate similar conditions found in some productive region, yet there may be absolutely or practically no chance of striking oil in profitable quantities at some distance below the surface. It is, of course, equally true that certain unfavorable surface conditions may disappear at some depth. It is because of these facts that the services of a so-called "practical oil man" are worse than useless to a person seeking petroleum. The well-trained, experienced geologist cannot see any farther below the surface than the practical man, but he does know better than anyone else how to ascertain the probable structural and other conditions existing *below* the earth's surface, where it is hoped to find oil; and in many instances he feels such certainty in his deductions that he does not hesitate to make predictions that are so closely fulfilled as to appear almost miraculous to the uninitiated.

While the most competent geologists cannot guarantee that oil will be encountered in paying quantities by drilling at any point, they can tell whether the chances are good enough to justify the risks involved, and can often locate the well where the conditions are most favorable. A well sunk on an area which a competent geologist has examined and condemned fully deserves to be called a "super wild-cat." Such an enterprise is so risky that anyone would have a far better chance to win by playing roulette or engaging in any other common form of gambling.

The uninformed man may question the validity of the statements just made, but no one who knows the facts will do so. The operations of all the bigger and more successful petroleum companies are invariably guided by the advice of geologists. Long experience has shown conclusively to these people that, in the long run, they will both save and make money by following this plan. Sentiment or theory have little effect upon the capitalists who organize and finance such companies. They demand results, and it is because geologists have been able to give them these results that their advice is sought and followed. Small operators would do well to follow the examples of the successful leaders in oil exploration and production, and should hesitate to exhibit their ignorance by expressing a lack of confidence in the work of good geologists.

It should be mentioned, however, that there are many men who claim to be geologists yet who have no real right to the title, and it is certainly very desirable to inquire into the training and standing of men who offer to make reports before employing them for such work or acting in accord with their recommendations.

*Oil and Gas Seeps and Vents:* The locators of oil seeps, gas vents, oil impregnated rocks, or oily scum on water, which may be designated as "oil signs" are apt to become excited and conclude that they are sure to strike oil if they drill near such signs. By recalling the facts previously set forth, and by observing on the diagrams the conditions under which such signs are apt to occur, it will be realized that it is a very poor policy to drill in the immediate vicinity of them, since these phenomena are usually found far from concentrations of oil, or are apt to lie over deposits of asphalt or paraffin rather than oil. So well established is the idea just set forth that geologists have a maxim to the effect that "many oil signs are a poor sign," although it is true that in one or two districts, important production has been secured close to great oil seeps. Of course this statement applies only to areas in close proximity to the point where such signs are found. They do prove that some rocks in such districts are petroliferous, and at once suggest that diligent search be instituted for a locality where favorable structures and other features exist.

The Arizona Bureau of Mines is frequently visited by people who report that they have found scums of oil in water wells, thin layers of asphalt while digging such wells, small oil seeps or gas vents, etc., and these people usually become decidedly provoked when the Bureau employees fail to share their enthusiasm and refuse to investigate their finds. They do not know that oil signs have been discovered in scores of localities in which no profitable accumulations of oil have ever been found; and they do not appreciate the fact that the Bureau has geological data obtained by laborious field work, which often makes it possible to decide that the conditions in certain localities are so unfavorable to the accumulation of any considerable quantity of petroleum that it is useless to investigate the signs reported, no matter how pronounced they may be.

In spite of the fact that numerous oil signs may be considered an unfavorable feature so far as the probability of finding oil in the territory immediately contiguous is concerned, it is always gratifying to find indications of the presence of petroleum in rocks which outcrop at some distance from an area where it is proposed to drill and

which underlie that area. For this reason, it seems desirable to describe briefly some of the features mentioned.

Wherever petroleum-bearing rocks outcrop or where more or less open fissures or faults that cut oil-bearing rocks come to the surface, oil seepages and the products of the volatilization of petroleum are apt to be found. It has already been stated that oil exposed to the atmosphere loses its more volatile constituents, and the residue has the form of a pasty or solid mass. The nature of this residue will depend upon the character of the oil and several other factors. If the escaping oil has a paraffin base, a substance resembling vaseline or reddish-brown flakes of solid paraffin may accumulate on the surface, but both products are apt to be scanty, and may easily be washed away or hidden by dust. The odor arising from such seeps may not be very noticeable.

Oils that have an asphaltic base usually cause masses of dark brown to black, stiffly viscous to solid asphalt to accumulate on the surface of the ground, and the odor is likely to be very noticeable.

Petroleum does not usually exude all along the outcrop of a petroleum-bearing formation; the greater part of the outcrop may have to be trenched to a depth of several inches or feet before showing any evidence of being petroliferous. If a seep is on a steep hillside in a region of considerable rainfall, the products of evaporation may be washed away as rapidly as formed, and may sometimes be found in the valley beneath; whereas, if the oil reaches the surface on relatively flat ground, extensive deposits of the residues may accumulate.

If a petroleum-bearing bed underlies a stream or lake, globules of oil may sometimes be seen to detach themselves from the bottom and rise to the surface of the water on which will appear at the same time films of oil that possess a beautiful iridescence. The odor will usually suffice to distinguish such films from those resulting from the presence of decomposing bicarbonate of iron.

Oil seepages are almost invariably accompanied by the emanation of more or less gas, but oil is not always found in regions where gas vents are found. This is partly because several natural gases (including marsh gas which is inflammable) may be formed through the decomposition of vegetable matter in swamps or ponds, or may come from coal beds. The gases escaping from decomposing petroleum can usually be recognized by their oily odor, and this odor will be most noticeable in sheltered gullies. It should be mentioned, however, that petroleum gas is apt to be accompanied by more or

less hydrogen sulphide, which has the odor of bad eggs, or sulphur dioxide which is the gas generated when sulphur is burned in air. Sometimes the gas escapes through water in the form of bubbles that break on reaching the surface, where they can be ignited.

The gas may reach the surface from the outcrop of an inclined oil-bearing bed, from the fractured crest of an anticline, or from a fault that cuts gas-bearing rocks at greater or lesser depth. The gas may escape in minute quantities over a large area, or may come from only one place. Its escape may be continuous or intermittent, and it may or may not accompany oil seeps. If considerable escaping gas comes to the surface through damp clay or shale, the emanations may form mud volcanoes. The clay and water combine to make a thin mud which the escaping gas blows into large bubbles that burst, sometimes with explosive violence. The continual rising and bursting of these bubbles cause the mud to accumulate in the form of cones that resemble small volcanoes. Such mud volcanoes cover large areas in some regions.

*Proximity to Deposits of Metallic Ores:* A commercially valuable deposit of petroleum has never been found in a region where deposits of metallic minerals abound. Such deposits are sufficiently rare so that the lack of petroleum deposits in their vicinity may seem to have little significance. It is true, however, that most deposits of metallic minerals are recognized as being genetically connected with intrusions of igneous rocks, and the very agencies that bring about the formation of metallic mineral deposits are those that would tend to decompose any petroleum in the neighborhood. It appears, therefore, unwise to seek for petroleum in areas where metallic minerals are plentiful.

#### MISCELLANEOUS CONSIDERATIONS

It is foreign to the purpose of this bulletin to discuss the methods followed in ascertaining the structure and the nature of the rocks existing below any given area. This is work for a well-trained, experienced geologist. Suffice it to say that their solution often requires the making of observations miles from the area under consideration, as well as a thorough investigation of the area itself. It is not work that can be completed in a few hours or, in most cases, in a day or two; and anyone who, after making a cursory examination of the surface features, pronounces the conditions existing beneath even a small plot of ground as favorable to the occurrence of an oil pool is either incompetent or else he has secured data from others who have worked

in the same or adjacent areas. No one can draw conclusions of the slightest value merely by examining or testing rock specimens unless they happen to be of such a nature as are very rarely or never associated with oil pools.

There is a generally prevalent, but utterly erroneous, belief that anticlines are marked on the surface by ridges, and domes by rounded hills. Such conditions are the great exception rather than the rule. As illustrated in several of the accompanying figures, the crests of anticlines are not infrequently eroded into valleys, but *in many cases there is absolutely no relationship between the surface topography and the underlying structure.*

In the Southwest, rainwater sinks into the ground and dissolves carbonate of lime. It may subsequently work upward by capillary action, and by evaporation or bacterial action precipitate the carbonate of lime in layers that are roughly parallel to the surface of the ground and a few feet therefrom. This material is called "caliche" or "desert limestone." The position or inclination of such caliche deposits has absolutely no relationship to the structure of the strata beneath, and failure to recognize this fact may lead to costly mistakes.

Within the past few years, processes and instruments have been perfected which have been used very successfully to work out sub-surface structural conditions. The science of using such processes and instruments is called geophysics, and few great oil companies will now drill a well until geophysical surveys have been made and competent geologists have pronounced the conditions revealed in this way and by geological studies as favorable.

#### HINTS TO PROSPECTORS

It is believed that a careful consideration of the facts already set forth will convince anyone that prospecting for petroleum is an enterprise requiring specialized knowledge and experience not possessed by most of those people who seek metallic and non-metallic minerals. However, it seems desirable to reiterate the salient features that should be sought by anyone desirous of locating new petroleum fields. Briefly, the scientific petroleum prospector is guided by the following rules:

1. Thick, relatively undisturbed (not greatly faulted, sharply folded, or compressed) expanses of sedimentary rocks which have been deposited in salt water should exist, preferably some distance from the edges of a great geosyncline.
2. A favorable structure as already described should occur at one or more points.

3. A suitable porous reservoir rock capable of containing an accumulation of petroleum must form a part of the sedimentary series.

4. The reservoir rock above mentioned should contain or be underlain by one or more beds of shales such as are presumably the original source of most petroleum.

5. Above the reservoir rock should be an unbroken bed of impervious shale or some other dense rock beneath which the oil can accumulate.

6. The ground-water level must be above the impervious bed last mentioned.

7. Oil or gas seeps should be sought where the reservoir rock or the included or underlying shales outcrop, or where faults or fissures that cut these beds reach the surface; but there should be few or no such seeps at or near the point where drilling is contemplated, and the absence of all seeps should not deter drilling operations where all other conditions appear favorable.

8. The presence of solid bituminous material, gypsum, or salt at the point where the reservoir rock or the included or underlying shales outcrop are favorable indications.

9. Little or no attention should be given to localities containing or in close proximity to masses of igneous rocks, areas that have been greatly disturbed, recent valley fills of non-marine origin, districts showing evidence of considerable metallic mineralization, places where only highly compressed rocks outcrop, or localities known to contain true oil shales as later defined.

If these directions were followed more generally (as they are universally by the great, successful oil corporations), far less money would be expended wastefully than at present.

#### TEST FOR PETROLEUM

The presence of carbonaceous matter, including petroleum, in rocks may be easily tested by crushing the material to a powder, placing a teaspoonful of this powder in a four-ounce bottle of sulphuric ether, and leaving it therein for at least half an hour. If the bottle is shaken vigorously several times, better results may be secured. After digestion for the period mentioned, the clear liquor should be poured into a white porcelain bowl, sauce dish, or evaporating dish, and set aside until the ether has evaporated. If carbonaceous matter is present, a greenish, yellowish, or brownish, oily ring will be deposited on the sides of the dish. When applying the above-described test, it should be remembered that animal or vegetable matter of any kind will give results simi-

lar to those yielded by petroleum. Even a small amount of oil in rock can usually be recognized by the odor, especially when the specimen is freshly broken; but this odor may not be strong in the case of paraffin-base oils. Because of the possibility of confusing various kinds of organic material with petroleum when specimens are tested with ether, it is usually more satisfactory to rely upon the odor as a proof of the presence of petroleum.

Iridescent films on water may be due to the presence of decaying organic matter or bicarbonate of iron, as well as petroleum, so are not necessarily oil signs.

Bicarbonate of iron films on water may be identified by the fact that, if broken, the segments do not tend to reunite. All other iridescent films do tend to reunite when broken.

#### UNAVOIDABLE RISKS INVOLVED IN WELL SINKING

Even when all the conditions appear to be favorable for striking petroleum, a dry well (a "duster") may be sunk; and such a hole may be located between two gushers and at no great distance from either of them. Such a condition of affairs may be explained by one or more of the following facts:

1. The density of the oil-bearing bed may, and not infrequently does, vary from point to point; and the well may strike a portion so dense as to contain little or no oil, although plenty of oil may exist in the bed at no great distance from the well. In several fields, the freely flowing oil occurs in lenses or irregular patches separated by denser rocks. If a well sunk in such a field is dry or yields relatively little oil, the production may sometimes be increased by igniting a charge of nitro-glycerine in the bottom of the hole. In this way the surrounding dense rocks may be fractured and channels opened through which oil may enter from nearby, more porous masses of rock. This process is known as "shooting" a well, and, unfortunately, does not always yield favorable results. If the rock at the bottom of the well is plastic, the explosion may merely make it denser than before, and a well that yields a little oil may thus be changed into a dry hole.

2. The thickness of the bed serving as the oil reservoir may vary considerably in short distances, and this bed may even pinch out and be totally missing at the point where a well is sunk.

3. Due to local gas outlets, the drill may encounter only asphalt or paraffin at one point, while at no great distance therefrom oil occurs.

4. Unknown intrusions of igneous rocks may exist below where it is proposed to drill.

5. Surface structures may not extend downward to the depth where it is hoped to find oil. Possible conditions of this kind are illustrated in Figures 7 and 8. In both cases, well O, sunk near the crest of the anticline, would fail to strike oil. While in most instances a geologist would be able to detect the existence of structures such as are shown in Figure 8, it is not always possible for him to do so.

It is equally true, however, that unfavorable or only slightly favorable structures on the surface may be replaced at greater depth by favorable or more favorable ones. For instance, at Ranger, Texas, the beds on the surface lie in an almost horizontal position, and an anticlinal structure is barely apparent. As depth is attained, however, the beds become more and more closely folded. Such a condition is decidedly unusual, and is difficult to explain.

### HINTS TO STOCK BUYERS

It is hoped that the facts already outlined will serve to impress a possible purchaser of petroleum stock with the extreme complexity of the problems involved and with the absolute necessity of satisfying himself that the promoters have secured and followed the advice of experts before starting to drill. Anyone tempted to speculate in oil stocks would do well to observe the following precautions:

1. Insist on a favorable report by a *good* geologist, not by a so-called "practical oil man," before becoming financially interested. Speculation in the stock of an enterprise that has not had the approval of a competent geologist is so risky that there is practically no chance of success.

2. Become financially interested only in a company that controls a tract sufficiently large to contain several wells, and which is not unduly narrow. If too small or narrow, offset wells may be drilled all around it and draw off much of any oil that may exist thereunder. To counteract such attempts, numerous offset wells must be drilled on the tract itself, often at great expense, so the property should be large enough to justify the drilling of a considerable number of wells.

Wells drilled in areas that have not produced oil are known as "wild-cats;" and, when wild-cat wells are to be sunk, the acreage should be especially large since the risks are then so multiplied that there should be a chance to secure enormous profits in case oil is struck.

3. Unless interested in wild-cats, see that there are producing wells on at least three sides of the area to be drilled, and as close as possible thereto, preferably within a few hundred yards.

Do not forget that promoters' maps often show strange distortions, and should be checked in some way if it is possible to do so.

4. Select a company with sufficiently high capitalization to pay for drilling several wells, providing there is no doubt of the company's intention to drill a number of wells and that the high capitalization is not largely water.

5. Avoid companies with excessive capitalization. Other things being equal, the lower the capitalization, the higher the shares will go if oil is struck.

5. Do not put all your eggs in one basket. Distribute your stock purchases among several companies in different proved fields.

7. Do not buy a share of stock in any company until assured that the officers are honest and capable men, and that not over one-third of the capitalization will be used for promotion purposes, or to pay for deeds or leases on the properties.

8. Avoid "super wild-cats."

9. Ascertain whether the stock is reasonably priced.

10. Do not speculate in oil at all unless you can well afford to lose the money expended. Recognize that you are engaging in a big gamble in which the capital prizes, while enormous, are comparatively few, and remember that the occasional successes are advertised far and wide, while one rarely hears of the failures which greatly predominate.

## OIL SHALES

*Shales Defined:* Shales are fine, dense, more or less consolidated sediments that were originally composed principally of fine silt. Their color is usually light gray to black, but yellow, brown, and reddish shales are found in some places. Shales have a noticeably clay-like odor when they are moistened by breathing upon them through the mouth. They can be readily scratched with a knife. The color of powdered shales is much lighter than that of the uncrushed material, and is often nearly white. Shales commonly have a noticeably laminated structure, that is, they appear to be made up of thin sheets or plates. Frequently surface exposures look like piles of cardboard or paper, and such masses can be readily separated into flakes or sheets. Shales are usually associated with sandstones and limestones.

*Oil Shales Defined:* Oil shales have the characteristics above mentioned, but are usually dark brownish-gray to black on freshly broken surfaces and various shades of brown where they have been exposed

to the weather. They usually lack all feeling of grittiness between the teeth. Oil shales contain little or no oil as mined, but they do contain variable portions of the solid gum called kerogen. Contrary to general belief, oil shales rarely emit the odor of petroleum except sometimes when freshly broken, and even then the odor is faint. Oil shales may be of the decidedly laminated "paper shale" variety, or the material may be a massive, more or less hardened, and very tough clay. Even the latter variety is usually composed of layers of different tints, or in some other way shows its relationship to laminated shales.

*Test for Oil Shales:* In order to ascertain whether a shale or clay-like rock is an oil shale, it is only necessary to hold a thin fragment of it in a flame for a few seconds. If it contains enough kerogen to be valuable, it will burn with an oily odor after removal from the flame.

It is necessary to apply this test to all rocks suspected of being oil shale since in no other way can shales that do and do not contain kerogen be readily distinguished. No rock that fails to burn when treated in the manner suggested should be called an oil shale, nor is it proper so to designate a rock that contains free petroleum, instead of kerogen, and has a decidedly bituminous odor before heating.

*Production of Petroleum Products from Oil Shales:* Heat changes the kerogen in oil shales to an oil that differs in practically no important particular from petroleum obtained from wells. All the substances recovered from petroleum by distillation may also be obtained from the oil secured from oil shales, and most of these products are of fine quality. It is slightly more difficult and expensive to distil shale oil than natural petroleum, however. The product obtained from heating oil shale is classed as a paraffin-base oil although it also contains a small proportion of asphaltic material.

One ton of shale will yield on distillation from 20 to 160 gallons of crude oil, the average being about one barrel; and, during the process of distillation, 2,000 to 3,000 cubic feet of gas and various amounts of ammonia will also be liberated. From four to six gallons of gasoline can be extracted from the gas, if desired. The gas may also be utilized to furnish all the heat necessary to distil the oil from the shale, and a considerable excess will also be available for use in other ways.

*Prospecting for Oil Shales:* Oil shales should be sought in gullies or canyons in areas covered by sedimentary rocks (sandstones, limestones, shales, and conglomerates). Search for them will probably prove unsuccessful where the country rock is largely igneous or schistose.

*Extent of the Deposits and Probable Future Importance of the Industry:* The supply of oil shales seems to be practically inexhaustible. If enough plants could be constructed to handle the necessary amount of shale, one deposit in Colorado could alone duplicate the present production of crude oil in the United States for about 150 years. This statement will give some idea of the wonderful possibilities that the industry offers.

While difficulties have been encountered by those who have attempted to distil the oil shales, there seems to be no doubt but that the problems involved will eventually be satisfactorily solved; in fact, many people conversant with the facts do not hesitate to state that the solutions will be found much more quickly than is generally anticipated.

The production of petroleum products in this country now exceeds consumption, and other countries can supply large quantities of these substances. There is, then, no immediate prospect of a shortage in the fuels so essential in our industrial civilization. The known supplies of crude oil are far from inexhaustible, however, and the time must eventually come when consumption exceeds production. Furthermore, consumption is now so heavy that a shortage of crude oil may confront us before the passage of many years unless a new source of petroleum products can be found.

It is confidently believed by many people who have investigated the subject thoroughly that such a source exists in the oil shales which are known to be plentiful in Colorado, Utah, California, Wyoming, and other states.

In view of the facts already set forth, the conclusion is inevitable that the oil shale industry is destined to become a very important one, and it is highly desirable that the unsolved or only partially solved problems already mentioned should be attacked with the utmost vigor and completely solved as soon as possible.

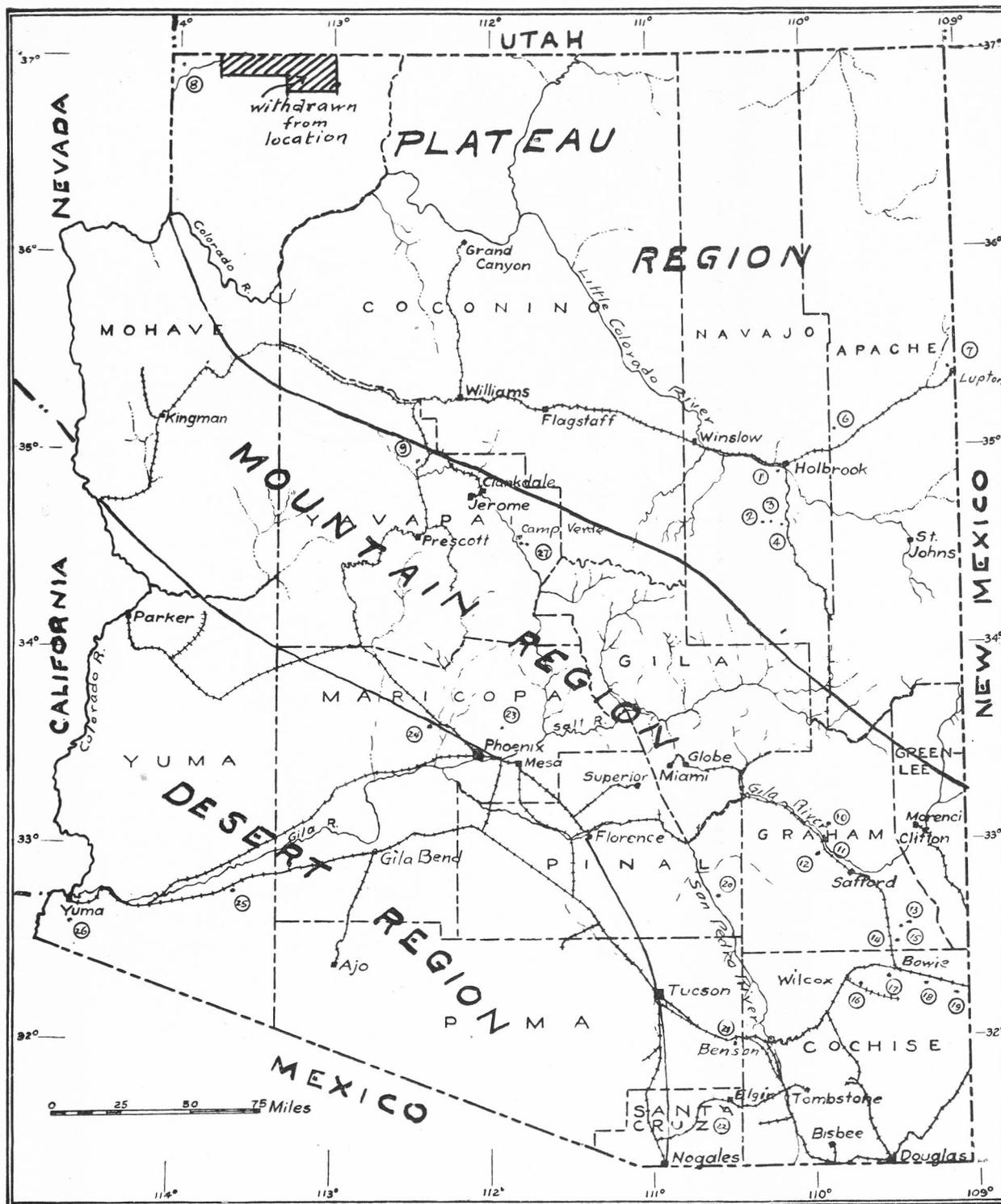
*Oil Shales in Arizona:* Two years ago the writer offered to send specimens of rich Colorado oil shales to all applicants, and took other measures to stimulate search for this mineral in Arizona. Many samples were distributed in this way, but no discoveries of oil shales have been reported to the Bureau

#### PETROLEUM NOT ASSOCIATED WITH OIL SHALES

True oil shales as herein described have not been found in areas that yield petroleum. If all petroleum did not originally exist as

kerogen, it seems necessary to assume that the conditions that lead to the formation of kerogen and petroleum are distinctly different, and that both substances can hardly be formed in any one locality. In other words, the presence of kerogen shows either that the natural chemical reactions involved in the formation of petroleum have not been completed or else that conditions favored the formation of kerogen, rather than petroleum, in which case no petroleum would be formed.

Of course, shales more or less saturated with petroleum, known as bituminous shales, do exist in oil fields, but they are distinctly different from "oil shales," and the two substances should not be confused.



- EXPLANATION
1. Great Basin Oil Co.
  2. Holbrook Oil Co., Jerome-Navajo Oil Co.
  3. Hopi Oil Co.
  4. Adamana Oil Co.
  5. Zuni Oil Co.
  6. Hogback Oil Co.
  7. Virgin Oil Co.
  8. Chino Valley Oil Co.
  9. Yavapai County Oil Dev. Co.
  10. Ashurst Oil Co.
  11. Gila Oil Co.
  12. Underwriters Syndicate
  13. Pinal Oil Co.
  14. Whitlock Oil Co. No. 1
  15. Whitlock Oil Co. No. 2
  16. Willcox Oil and Gas Co.
  17. Bowie Oil Co.
  18. San Simon Oil Co.
  19. San Simon State Well
  20. Mammoth Oil Co.
  21. Century Petroleum Co.
  22. Nogales Oil Co.
  23. Camelback Well
  24. Beardsley Well
  25. Baird Well
  26. Yuma Basin Oil Co.
  27. Verde Valley Oil Co. No. 1 and No. 2.

Fig. 9.—Index map of Arizona, showing physiographic divisions, after F. L. Ransome, and the locations of the principal wells.

## PART II

# ARIZONA PETROLEUM PROSPECTS

By J. B. TENNEY

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### INTRODUCTION

The search for petroleum in Arizona has been proceeding spasmodically for many years with generally discouraging results, and the search still continues. The high freight rates on all fuels into Arizona have stimulated the search to a considerable degree. A productive oil or gas field in Arizona would be a great boon to the State in furnishing cheap power for agriculture and mining, the two leading industries. The object of this part of the bulletin is to review the attempts made and to indicate the most favorable localities in which to concentrate work.

### GENERAL GEOLOGY

The State of Arizona has been divided physiographically by Ransome<sup>1</sup> into three parts: The Plateau Region covering the northeastern third of the State, the Mountain Region extending diagonally across the State from the northwest to the southeast, and the Desert Region covering the southwestern part of the State with the lower Gila River as its center.

The Plateau Region, through which the Colorado River flows and out of whose rocks it has carved the Grand Canyon, is generally made up of nearly flat-lying sedimentary rocks locally flexed into gently dipping and broad folds. These sediments lie on a basement of crystalline rocks predominantly granitic in composition. In this region, especially on its southern edge, old volcanoes have poured out great thicknesses of lava, and throughout the region are found isolated buttes, the eroded remains of old volcanic vents, together with smaller fields of lava.

The Mountain Region, in the central part of the State, on the edges and within which are the major agricultural and mining centers, is made up of mountain ranges of a generally northwest trend, separated from each other by alluvial plains. The mountains comprise a much disturbed complex of old crystalline and later sedimentary rocks and large intrusions and extrusions of igneous rocks. The plains

<sup>1</sup> Ransome, F. L., Globe Copper District, Arizona, U. S. Geol. Surv. Prof. Paper 12, 1903.

are filled to a great depth by alluvial deposits of conglomerate, sand, and clay, locally partly cemented by lime carbonate and iron oxide.

The Desert Region is like the Mountain Region, geologically, except that erosion has acted for a longer period and has generally stripped what sediments were deposited and has laid bare the older crystalline rocks. In this region, the mountain chains have been eroded to low lying ridges separated from each other by wide alluvial plains. Like the Mountain Region, vulcanism has been very active and the majority of the ranges are made up of effusive eruptive rocks, which rest on the old crystalline complex.

The plains, like those in the Mountain Region, are filled to a great depth with outwash material from the erosion of the mountains.

In neither the Mountain nor the Desert regions is there any evidence that the sea ever encroached during the formation of the "valley fill" deposits, except possibly in the lower reaches of the Colorado River near Yuma. These desert and mountain plains are filled with material washed from the mountains into deep structural troughs. At various times during the accumulation of this material, it is probable that brackish water lakes existed and that during these periods vegetable and some animal matter accumulated to form black muds. Penetration of these black muds in wells drilled for water has been the stimulus for the drilling of a number of wells in the search for oil. The best that can be said for these sediments is that they are oil shales in the making, an early stage in the formation of shales, similar to the oil shales of eastern Utah and western Colorado, in the valleys of Green River and its tributaries. Oil shales have never been known to have produced oil or gas wells. They have been defined and discussed in the first part of this bulletin, pages 31 to 33.

Wild-cat oil wells have been drilled in all three of the physiographic provinces of the State and will be reviewed by provinces in the following paragraphs.

## PLATEAU PROVINCE

### STRATIGRAPHY

The sedimentary rocks of the Colorado Plateau range in age from pre-Cambrian to upper Cretaceous. The pre-Cambrian sediments have been exposed in only two places: Chuar Valley and other parts of the Grand Canyon and at the crest of the Defiance Uplift on the New Mexico-Arizona line. They are highly indurated and predominantly quartzitic. A few beds of limestone and shale are

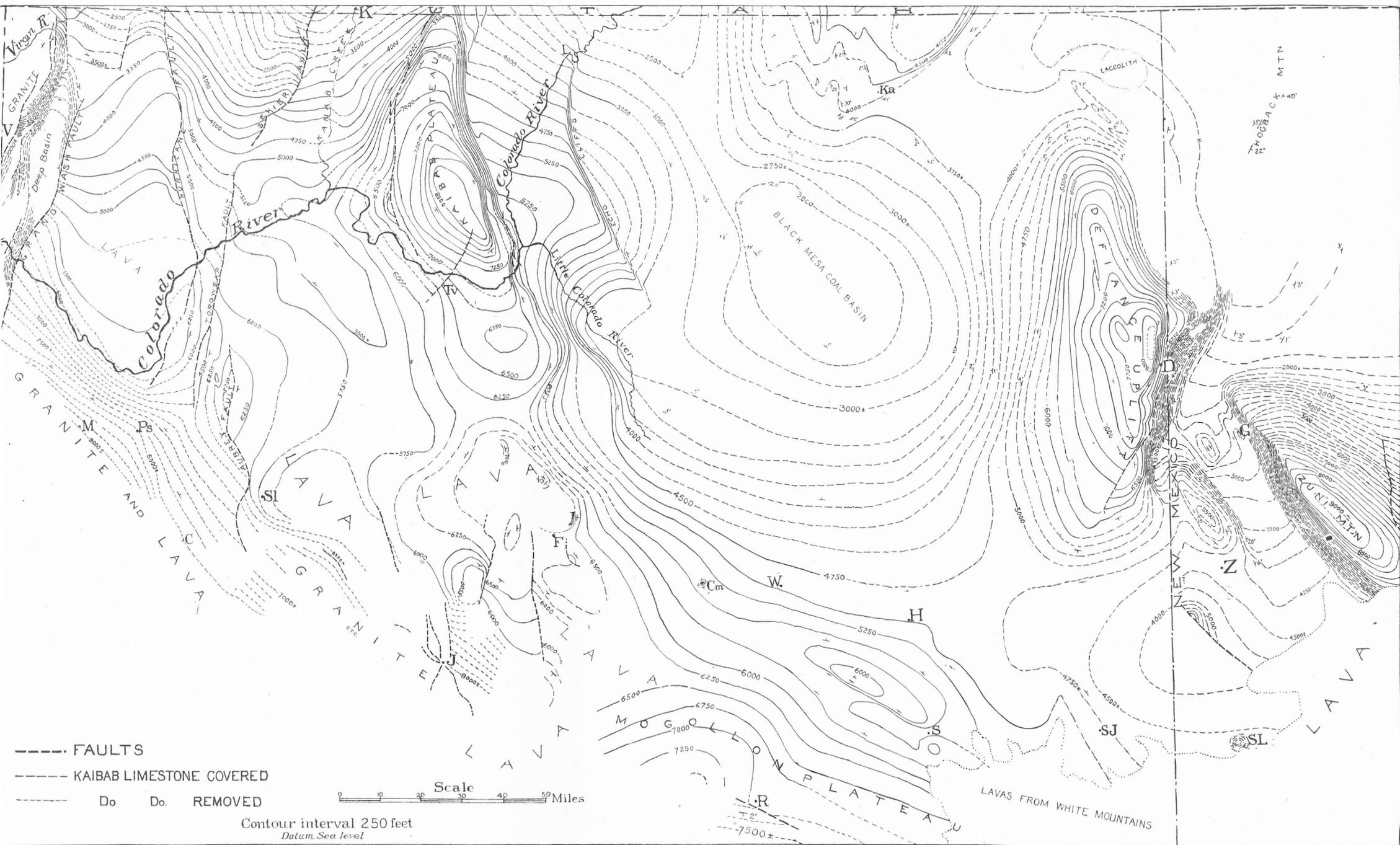


Fig. 10.—Map showing deformation of strata in Plateau Region of Arizona, by contour lines at the base of the Kaibab limestone. By N. H. Darton, *V*, Virgin Mountains; *M*, Music Mountain; *Ps*, Peach Springs; *Sl*, Seligman; *C*, Cross Mountain; *K*, Kanab, Utah; *F*, Flagstaff; *L*, Lees Ferry; *Tv*, El Tovar; *Cm*, Crater Mound; *R*, Ramer (Wallace) Ranch; *J*, Jerome; *W*, Winslow; *H*, Holbrook; *Ka*, Kayenta; *S*, Snowflake; *D*, Fort Defiance; *Sj*, St. John; *SL*, Salt Lake, N. M.; *G*, Gallup, N. M.; *Z*, Zuni, N. M.

found in the Grand Canyon section, but they have been so highly altered by long and deep burial and by repeated mountain-building forces that any oil that may have accumulated has long since been dissipated.

The Paleozoic beds are not altered and consist of alternating sandstones, shales, and thick limestone beds with intercalated sandstones. These sediments, under favorable structural deformation, have distinct possibilities for the accumulation of oil and gas. They tend to be thickest in the western part of the region and gradually wedge out in the eastern part. At the Defiance Uplift, they are represented by the top members only, composed of red shales and cross-bedded sandstones.

The Triassic and Jurassic beds, which generally lie conformably above the Paleozoic, are composed of brown shales, conglomerates, and cross-bedded sandstones with only a few thin, lenticular, marly limestone members. In general, they are not favorable sources of oil, but might be beds in which oil from greater depth could accumulate.

The Cretaceous beds which overlie the Jurassic sandstones are composed of sandstones and shales with a number of impure coal beds. Under favorable structural conditions, they have good possibilities for oil accumulation. It is in these beds in northwestern New Mexico that oil and gas have been found in the Farmington oil field.

#### STRUCTURE

Over most of this Plateau Region, the sediments lie almost flat. There are, however, several large folds which have produced structural domes and basins. Three of the largest of them are the Kaibab dome through which the Colorado River has cut the Grand Canyon, the Black Mesa basin in northern Navajo County, and the Defiance Uplift in northern Apache County, just west of the New Mexico-Arizona line. South of Holbrook is a smaller and sharper monoclinical fold with many minor irregularities. In northern Navajo County is the southern end of a large dome developed to its greatest extent in southern Utah. On the northern flanks of this dome, oil has been found in the San Juan River valley in Paleozoic beds.<sup>2</sup> On the western edge of the Plateau Region are a series of north-trending faults with minor domes and basins developed between them. In one of these minor folds in the southwestern corner of Utah, near Virgin City, shallow oil has been found in small quantities in lower Triassic

<sup>2</sup> Woodruff, E. G., Geology of the San Juan oil field, Utah, U. S. Geol. Surv. Bull. 471a, 1912.

beds. The structure is reported to extend into Arizona between the Hurricane and Grand Wash faults south of the village of Hurricane, Utah.<sup>3</sup> Other folds doubtless exist in this region and will be recorded when more detailed mapping is done.

Two of these major structures have been partly tested, the Holbrook Monocline and the Defiance Uplift. In the latter, shallow holes soon demonstrated the fact that the lower Paleozoic beds are missing. The upper Paleozoic red beds are not favorable sources for oil. On this large structural dome, erosion has stripped the Triassic and Cretaceous beds. The oil possibilities are therefore slight due to the absence of sources of oil.

#### HOLBROOK STRUCTURE

In the large monoclinal fold south of Holbrook, structural conditions are quite favorable. A possible source of oil exists in the thick Paleozoic limestones and shales, and there are numerous beds of sandstone and sandy limestone both intercalated with the limestone and above it. The crest of the fold is capped by Triassic shales and sandstones, the Cretaceous having been removed by erosion. The district has been carefully studied by Dorsey Hager<sup>4</sup> and Chas. Edward Major,<sup>5</sup> and numerous wells have been drilled with somewhat encouraging results in that a little gas or oil was encountered in some of the. The district has the attraction of being accessible to railroad transportation. It lies 10 to 30 miles southeast, south, and southwest of Holbrook on the Santa Fe main line.

*Oil Prospecting:* The following wells have been drilled: *Adamana Oil and Land Company*. One well was drilled from 1920 to 1924 to a depth of 3,380 feet. Petroliferous shale was struck at 1,700 feet in upper Paleozoic (Supai formation), and an oil sand with considerable gas was penetrated from 2,260 feet to 2,300 in the Supai formation, while a third thin oil sand was encountered from 2,480 to 2,492 feet, also in the Supai formation. The more massive Paleozoic limestone was penetrated at 2,850 feet, and the hole continued in alternating limestone, thin sandstone, and black shale to a depth of 3,380 feet. Salt water was encountered, and, at 3,380 feet, the hole was reported as having a water column of 2,800 feet. This hole was located in Sec. 4, T. 14 N., R. 20, E., nineteen miles south of Holbrook.

<sup>3</sup> Bassler, Harvey, and Reeside, John B. Jr., Oil Prospects in Washington County, Utah, U. S. Geol. Surv. Bull. 726c, 1921.

<sup>4</sup>Hager, Dorsey, Oil possibilities of the Holbrook Area in northeast Arizona. 1921 (Private Publication.)

<sup>5</sup> Major, Chas. Edward, The Holbrook Oil Field, 1921. (Private publication.)

*Holbrook Oil Company.* The well sunk by this company on the southern flank of the Holbrook monocline, about ten miles northwest of the Adamana hole, in Sec. 23, Township 15 N., Range 18 E, 21 miles southwest of Holbrook, was drilled to a depth of 2,400 feet in 1922.

*The Jerome-Navajo Drilling Company.* (Organized in 1924 to continue the Holbrook well). This company drilled to a depth of 3,775 feet in 1925. Traces of gas and oil were reported at that depth.

*Hopi Oil Company.* The well of this company, about half way between the Holbrook and Adamana holes, was carried down 2,500 feet. A few showings of gas were reported. This hole is in Sec. 21, Township 15 N., Range 19 E., about twenty miles southwest of Holbrook. The lower Paleozoic beds were not tested.

*Great Basin Oil Company.* This company, promoted by E. S. Taylor, sank its well in 1925 and 1926, considerably north of the Holbrook monocline, five miles southwest of Holbrook on a doubtful structure. The hole was carried down to a depth of 4,675 feet, and was drilled to within a few hundred feet of the base of the Paleozoic section. Traces of oil were reported at about 1,700 feet and again from 4,245 to the bottom of the hole.

*Conclusion.* The Holbrook monoclinial fold is a major structural feature of the region which extends in a southeasterly direction from between Clear and Chevelon creeks, south of the railroad to about eleven miles east of Snowflake, a distance of fifty miles. This structure has been tested only in one limited part, covering a distance on the strike of about 12 miles, and there by only two holes. At the points tested, definite traces of gas and oil were found at various horizons. The results achieved, although disappointing, are, notwithstanding, inconclusive.

#### ZUNI AREA

In this area, about twenty miles northeast of Holbrook, there exists a very gentle synclinal trough with minor crinklins, a structure not favorable for oil accumulation.

*Oil Prospecting:* One hole was put down by the *Zuni Oil Company* in Sec. 6, Township 19 N., Range 24 E., 22 miles northeast of Holbrook. The well was drilled over 1,000 feet deep and it was reported that a trace of oil was found at 950 feet. The hole started in Triassic and penetrated only the top Paleozoic sandstones.

#### LUPTON STRUCTURE

This structure, on the southern end of the Defiance Uplift, is a

monoclinical fold which strikes northwest, with the southern end open. The structure is not very good and the evidence presented at the crest of the Defiance Uplift is that the lower members of the Paleozoic sediments are probably very thin or entirely absent.

*Oil Prospecting:* One hole was put down on this structure by the *Hogback Oil Company* in the NW  $\frac{1}{4}$  of Sec. 24, Township 23 N., Range 30 E., about five miles northwest of Lupton. It was started in top Triassic beds and was carried down only 500 feet with no favorable results.

#### CHINO VALLEY

This alluvium-filled valley extends from a point about 24 miles north of Prescott, 24 miles in a northwesterly direction and is flanked on its northeast side by lower Paleozoic sediments. At its southeast end, where Chino Creek joins the Verde River, turns eastward, and has cut a deep trench in the Paleozoic beds, slightly petroliferous shales of probable Mississippian age have been exposed. No definite structure is exposed in the valley or on its sides. The beds lie uniformly, nearly flat, with a dip of from 0 degrees to 10 degrees south.

*Oil Prospecting:* Several holes have been drilled in Chino Valley north of Del Rio with negative results. One well, drilled by the *Chino Valley Oil and Mining Company*, located in Sec. 27, Township 18 N., Range 2 W., drilled in 1913, was carried to a depth of 1,800 feet and a trace of oil was reported at the bottom of the hole. This valley is on the southwest edge of the Plateau Region.

In 1931, the *Yavapai County Oil Development Company* was organized to drill a well near Del Rio. No data are available as to the exact location.

#### LITTLEFIELD-VIRGIN CITY AREA

In this area, on the western border of the Plateau Region, in northwest Arizona and southwest Utah, minor folds exist in the sediments which range, in age, from Cambrian to Triassic. Near Virgin City, Utah, several shallow wells were drilled and oil was found. About 15 wells were drilled in 1907, and one produced as high as 36 barrels a day. In 1908, a small, local refinery was built, and three of the wells were cleaned out and shot and a new well drilled. A production of four or five barrels a day was reported from one well and a total daily production of about 20 barrels from the field (1920). The wells are from 550 to 600 feet deep and the oil is found in a lower Triassic limestone bed.

A continuation of the structure is reported to extend across the Arizona line, south of the town of Hurricane, Utah.<sup>6</sup>

*Oil Prospecting:* The *Virgin Oil and Mines Company* has drilled one hole a few miles north of Littlefield to a depth of 1,405 feet. This well is located on alluvium which fills the valley of Virgin River and its tributary, Beaver Dam Creek. To the east of the valley, the structure of the Virgin Mountains is quite complicated. Sharp folds and many faults exist. The depth of alluvium in the valley is unknown and there is no means of forecasting what rocks exist below.

## MOUNTAIN REGION

### GENERAL FEATURES

The mountain ranges of Central Arizona are, in general, of the Basin and Range fault block type, found characteristically developed in western Utah and Nevada. The sediments are greatly disturbed and much metamorphosed by igneous intrusions. The valleys or plains between the ranges are filled to great depths by alluvium washed from the elevated fault blocks which form the mountains. The age of the alluvium ranges from late Tertiary to recent.

The disturbed and altered rocks found in the mountains consist of pre-Cambrian schists, granites, and indurated sediments, Paleozoic and Cretaceous sediments, and intrusive and extrusive igneous rocks.

The Paleozoic and Cretaceous sedimentary series is composed of sandstones, shales, and limestones. Except in a few localities, they have been so extensively faulted and altered by the intrusion of igneous rocks that any oil or gas which might have been present must have escaped or been changed to solid hydrocarbons.

In the southeastern end of the Mountain Region, close to the Mexican border, there exist large areas of Cretaceous sediments which are made up predominantly of sandstones and shales. Some of these sediments, where unaltered, are distinctly petroliferous, and have long been recognized as possible sources of oil or gas under favorable structural conditions.

The location of the principal industries of Arizona, agriculture in the intermountain plains and mining in the mountains, adds to the attractiveness of the search for oil or gas in this region, for local power needs.

### GILA RIVER, SAN SIMON, AND SULPHUR SPRING VALLEYS

The most intensely prospected area in the Mountain Region has been

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<sup>6</sup> Bassler, Harvey and Reeside, John B. Jr., Oil prospects in Washington County, Utah. U. S. Geol. Survey Bull. 726c, 1921.

the intermount plains in the southeastern corner of the State, covered by what are known as the Gila, San Simon, and Sulphur Spring valleys. As previously stated, the sediments in these plains are partly lacustrine. The lakes at times have been filled with brackish water. Sediments formed in these ephemeral lakes in the past, composed of black muds, have been penetrated in numerous shallow wells drilled for water. In some of the deeply buried mud strata, tests for oil have been reported, and traces of gas have accumulated in a few places in the loose, partly indurated sand and silt, under clay caps. These "oil showings" have been the stimuli for the drilling of many deep wells in this large area. None have to date penetrated the "valley fill" into the rock basement. Numbers of wells have reported oil and gas showings.

Very little deformation has taken place in these conglomerates, sands, silts, and marls since the mountain building period during which the depressions were formed. Some faulting has occurred and regional uplift without folding. No "structures" exist.

*Oil Prospecting:* The deepest wells drilled have been the following: *Bowie Oil Lease Syndicate*, three miles southwest of Bowie, 4110 feet deep; *Underwriters Syndicate Well No. 1* in the Gila River Valley, fifteen miles northwest of Safford, 3,765 feet deep; *Gila Oil Syndicate Well* in the Gila River Valley, two miles north of the Underwriters Syndicate well, 2,680 feet deep; *San Simon Oil Company Well*, six miles west of San Simon, 3,586 feet deep; *Willcox Oil and Gas Syndicate Well*, two and half miles southeast of Willcox, 2,360 feet deep; and the *Whitlock No. 1 Well* in the San Simon Valley, fifteen miles north of Bowie, 1,900 feet deep. Numerous other wells have been drilled to shallower depths.

*Conclusions.* The possibilities of finding commercial accumulations of oil or gas in the "valley fill" formations in this large area are extremely remote. The presence of Cretaceous and older sediments underlying the plains is possible, but there is no means of forecasting where they exist, or ascertaining whether, if present, their attitude is such as to make the structural conditions favorable. There is, then, a double risk in prospecting for oil in such areas which risk must be considered most unattractive. If favorable structures can be found in the Cretaceous and underlying beds in the mountains, or on their edges, drilling these structures should be the first step in prospecting for oil in this area, with the possibility that a continuation might underlie the plain. The risks run in drilling in the plains at a distance from rock exposures, in this intensely faulted and altered region, far outweigh the possible profits.

## SALT RIVER PLAIN

This plain as field for oil or gas prospecting has all the unattractive features of the Gila River, San Simon, Sulphur Spring plains, and the additional bad feature that the rocks of the flanking mountains consist mainly of pre-Cambrian metamorphics, igneous intrusions and lava. A few deep wells have been drilled in this area, chiefly for artesian water. None have drilled through "valley fill."

*Oil Prospecting.* The deepest wells on record are the following: *Beardsley No. 1*, thirty miles northwest of Phoenix, 3,352 feet deep, and *Camelback*, fourteen miles northeast of Phoenix, 2,789 feet deep. The Beardsley well reported a trace of oil and gas at the bottom of the hole.

## ELGIN-BENSON AREA

The southwest and north flanks of the Whetstone Mountains, the southwest flanks of the Huachuca Mountains, and all sides of the Empire Mountains are made up of thick sections of marine Cretaceous shales, sandstones, and conglomerates with a few lenticular limestone beds. In the Whetstone Mountains, the base of the section is composed of about 10,000 feet of black shales, some of which give a distinct test for petroleum. These petroliferous shales are overlaid by several thousand feet of white, coarse-grained sandstone with red shale partings. This series in the Whetstone Mountains is very little altered by mountain-building forces and only slightly intruded by rhyolite prophyry sills in the lower part of the section. Very little faulting occurs. The whole series in the Whetstones dips generally to the southwest, but, toward the top of the section, on the western edge of the foot-hills, the beds flatten and have been arched into a nosing anticline plunging westward, the axis of which strikes east and west. The length of this structure is about two miles and the maximum breadth one mile. Ideal conditions for the accumulation of gas or oil prevail here. A company has been organized to exploit the possibilities. A legitimate "wild-cat" field exists at this place.

*Oil Prospecting.* The presence of petroliferous shale, mis-named coal by the prospectors of the region, has been known for many years, but the first attempts to prospect for oil were poorly advised. Two wells have been drilled, both many miles from known outcrops, in the valleys surrounding the Whetstone Mountains. The first well, drilled by the *Nogales Oil Company*, was sunk near Elgin and the divide between Babocomari and Sonoita Creeks, about ten miles from ex-

posures of Cretaceous rocks. There is no evidence that these rocks underlie the "valley fill" in which the hole was started, and there is still less evidence of the existence of any structure. This well was drilled to a depth of 1,115 feet and did not penetrate the valley fill.

A second well was started eight miles west of Benson, by the *Century Petroleum Company*, within a few miles of exposures of the Cretaceous beds flanking the Whetstone on the north. The hole was started in alluvium and penetrated probable Cretaceous shale at 250 feet. The total depth reached is 1,550 feet to date. There is no evidence of the existence of a favorable structure, and considerable evidence at the nearest exposures that the beds have been badly faulted.

#### SAN PEDRO VALLEY

This valley, a narrow, alluvium-filled valley between the lava-covered Galiuro Mountains on the east and the Rincon Catalina range on the west, made up of a highly metamorphosed complex of pre-Cambrian and Paleozoic rocks, is not an attractive area. A part of the sediments in the valley were formed in a shallow lake, and thick deposits of gypsite and of diatomaceous earth occur. Early geologists interpreted the diatomaceous deposits as having been formed under marine conditions.<sup>7</sup> Work done since has shown conclusively that the diatoms found in the San Pedro Valley are freshwater forms.

*Oil Prospecting.* One hole has been drilled in this valley, about twelve miles southeast of Mammoth. The total depth reached was 1,350 feet, all in "valley fill." No "structure" exists.

#### VERDE RIVER VALLEY

In the upper Verde River Valley, from a point about five miles north of Clarkdale, down the river for forty miles, with a width of about twelve miles, there is exposed a thick section of lake deposits of late Tertiary age. This lake was formed by the damming of the river by volcanic flows. Since the breaking of this dam by erosion, these sediments have undergone degradation. They consist of limestone, sands, and silts with intercalated deposits of thenardite, (sodium sulphate), gypsum, and salt.<sup>8</sup> The thickness is several thousand feet. Very little deformation has taken place in these sediments since their deposition except minor faulting due to regional uplift. There are no possibilities of oil or gas having been

<sup>7</sup> Blake, William P., Diatom-earth in Arizona, A. I. M. E. Trans. vol. 33, pp. 38-45, 1903.

<sup>8</sup> Jenkins, Olaf P. Verde River Lake Beds, American Jour. of Sci., vol. V, Jan. 1923.

formed under the depositional condition under which these beds were laid down.

*Oil Prospecting.* One company, the *Verde Valley Oil Company*, drilled two wells a few miles south and southeast of Camp Verde. The first well penetrated the formation into underlying lava at a depth of 1,225 feet, and the second well was carried to a depth of 1,625 feet, the last 225 feet drilled in lava.

#### DESERT REGION

In this large area in the southwestern part of Arizona, the geological conditions are more adverse than in the mountain area due to the almost complete absence of sediments other than late alluvium. In the lower part of the valley of the Colorado River<sup>9</sup> extending up the river at least as far as Cibola, forty miles north of Yuma, is an older series of partly consolidated sandstones, conglomerates, and marly limestones probably of marine origin. The age of these sediments has not been determined. They are probably late Tertiary. They have not been subjected to deformation by folding as far as observed. Although the chances of finding oil in these beds is far better than in the valley fills of the Mountain and greater part of the Desert Region, the probable absence of folding and the probable recent age of the sediments militates against them.

*Oil Prospecting.* A well was drilled seven miles south of Yuma by the *Yuma Basin Oil Company*. This hole reached a depth of 1,815 feet. Traces of oil and gas were reported.

Another deep well was drilled in the Cristobal Valley, eight miles northeast of Mohawk. This well was drilled to a depth of over 2,400 feet. A gas-bearing sand was reported at 1,650 feet. Typical alluvial material was encountered—red clay, sand, gravel, and boulders.

#### CONCLUSIONS

A large part of the drilling in the search for oil or gas in Arizona has been done in areas where the chances for the existence of commercial pools are extremely slight. Most of this work has been done without competent advice.

In the Plateau Region, and in certain limited areas in the Mountain and, perhaps, the Desert regions, the possibilities of the existence of oil or gas in commercial amounts warrant the careful geologic study of these areas, and the drilling of the most attractive structures. It is of extreme importance that this pioneer work should be done with the advice of competent well-trained oil geologists.

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<sup>9</sup> Wilson, Eldred D. Marine Tertiary in Arizona, Science. In press, 1931.

To facilitate this work, logs of all wells, whether drilled for oil or for water, should be filed at some central agency in the State, for inspection by any interested party. If a serious search for oil is to be made in Arizona, legislation should be enacted, similar to that in oil-producing states, enforcing the filing of well logs and protecting and promoting the industry in other ways.

#### PETROLEUM LAW

By an Act of Congress, approved February 25, 1920, which was passed to promote the mining of coal, phosphate, oil, oil shale, gas, and sodium on the public domain, such deposits, with a few reservations, were thrown open to exploitation by citizens of the United States, associations of such persons, or corporations organized under the laws of the United States or of any State or Territory thereof, under the following conditions and regulations:

##### LANDS EXCLUDED:

Those lands acquired under the Act known as the Appalachian Forest Act, approved March 1st, 1911 (Thirty-sixth Statutes, page 96.)

Those lands in National Parks.

Those lands withdrawn or reserved for military or naval uses or purposes.

##### CONDITIONS:

The United States reserves the right to extract *helium* from all gas produced under the provisions of the Act under such rules and regulations as shall be prescribed by the Secretary of the Interior, provided, further, that, in the extraction of helium from gas produced from such lands, it shall be so extracted as to cause no substantial delay in the delivery of gas produced from the well to the purchaser thereof.

It is provided, further, that citizens of another country, the laws, customs, or regulations of which deny similar or like privileges to citizens or corporations of the United States, shall not, by stock ownership, stock holding, or stock control, own any interest in any lease acquired under the provisions of this Act.

##### REGULATIONS:

A Prospecting Permit may be granted by the Secretary of the Interior to any eligible applicant, giving him exclusive rights for a period not to exceed two years on a tract not to exceed two thousand

five hundred and sixty acres, providing it is not within any known geological structure of a producing oil or gas field. He shall have to begin drilling within a year after the date of permit, and shall have to drill during the period of the permit one or more wells at least five hundred feet deep unless oil or gas is found at a shallower depth, and must drill an aggregate of two thousand feet unless oil or gas is found before.

A maximum extension of two years may be granted on a prospecting permit if diligence has been shown.

Prior to filing application, the applicant must cause to be erected a monument at least four feet high at some conspicuous place together with a notice describing the tract, the date of the notice, etc. This will protect him for thirty days.

Within ninety days after receiving his permit, an applicant must mark his corners with substantial monuments, and must post a notice at some conspicuous place that permit has been granted, with a description of the tract.

Having found oil or gas to the satisfaction of the Secretary of the Interior, the permittee shall be granted a twenty year lease on a selected one quarter of the prospecting permit tract, or to at least one hundred and sixty acres of the tract. He shall have the leased area surveyed and shall pay a royalty of five percent and a yearly rental of \$1.00 per acre. He shall also be entitled to a preference right to a lease on the remainder of the prospecting permit tract at a royalty of not less than 12½ percent.

Until a lease is obtained, any oil or gas extracted shall be subject to a royalty of twenty percent.

In any lease granted, no wells are to be located within two hundred feet from the boundaries of the lease.

Any unappropriated land within a known geologic structure of a producing oil or gas field may be leased by the Secretary of the Interior to the highest bidder by competitive bidding at a royalty of not less than 12½ percent and a yearly rental of not less than \$1.00 per acre. These leases shall be for twenty years with the right to renew for ten years.

The rights of any owner of land who has title through the staking out of placer claims is protected, and he may transfer his holdings to a lease under the Act.

In the case of lands entered as agricultural and not withdrawn or classified as mineral at the time of entry (excluding railroad grants).

if the entry has been patented with the mineral right reserved, the entryman has a preference right to a permit and to a lease if discovery is made. In case of discovery, and within an area not greater than a township, such entrymen and patentees may apply for a joint lease on a tract not greater than two thousand five hundred and sixty acres. The royalty shall be not less than 12½ percent.

GENERAL PROVISIONS:

The usual provisions for right of cancellation are reserved.

Not more than three oil or gas leases in any one state, and not more than one lease on a geologic structure of a producing field shall be held by one person. This shall apply to individual stock ownership in companies.

Any number of leases may combine their holdings, however, when it is necessary to construct a refinery, common pipe line, railroads, etc., subject to the approval of the Secretary of the Interior.

Rights of way for pipe line are granted through public lands including forest reserves.

No lease may be assigned or sublet without the approval of the Secretary of the Interior.

The full text of the Act may be obtained on application to the Secretary of the Interior, referring to:

[Public - No. 146 - 66th Congress]

[S 2775]

An Act to promote the mining of coal, phosphate, oil, oil shale, gas and sodium on the public domain.

ARIZONA LAND WITHDRAWN FROM LOCATION

The following public lands in Arizona have been withdrawn from location by the Federal Government and are not subject to location or prospecting for oil and gas.

GILA AND SALT RIVER MERIDIAN

*North and West*

T. 40 N., R. 7 W.

T. 41 N., R. 7 W.

T. 40 N., R. 8 W.

T. 41 N., R. 8 W.

T. 40 N., R. 9 W.

T. 41 N., R. 9 W.

T. 41 N., R. 10 W.

T. 41 N., R. 11 W.

T. 41 N., R. 12 W.

T. 41 N., R. 13 W.

*State Lands.*

By virtue of the Revised Code of Arizona, 1928, Chapter 71, "Lease of Mineral Lands; Forfeiture," the State Land Department is authorized to execute oil and gas prospecting leases on any unsold lands of the State, to any citizen of the United States, for a term of two years, at a rental for the two-year term of \$100.00 for each six hundred and forty acres or for \$25.00 for each one hundred and sixty acres or fraction thereof if less than six hundred and forty acres are leased.

Not over two thousand four hundred and sixty acres is to be leased to any one person.

Renewal of such leases may be granted if drilling is under way at time of application for renewal.

If gas or oil is found in commercial quantities prior to the expiration of the lease, a development and operating lease shall be issued on the land for a five-year period on a ten-cents-per-acre rental basis and a royalty of 12½ percent on any oil or gas sold.

A renewal for five years shall be granted if two wells have been drilled. Successive renewals shall be granted until three wells shall be drilled for each section of land included in the lease.

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## MAPS OF ARIZONA

The Arizona Bureau of Mines now has available for distribution four different maps of the State, as follows:

1. Base map of Arizona in two sheets on a scale of about eight miles to the inch. This map is strictly geographic, with the positions of all towns, railroads, rivers, surveyed lands, national forests, national parks and monuments, etc., indicated in black, and the location of mountains and other topographic features shown in brown. It also indicates where the various mining districts are situated, and is accompanied by a complete index. It was issued in 1919 and is sold, unmounted, for 35c., or mounted on cloth with rollers at top and bottom for \$2.50.

2. A topographic map of Arizona in one sheet, on the same scale as the base map. It shows 100-meter contours, and there is a meter-foot conversion table on the map. It was issued in 1923, and is sold, unmounted, for 50c, or mounted on cloth with rollers at top and bottom for \$2.50.

3. A geologic map of Arizona on the same scale as the base map, printed in many colors. It was issued in 1925, and is sold both mounted and unmounted for the same prices as the topographic map.

4. A relief map of Arizona on the same scale as the base map, printed in various shades of brown, black, and blue. It was issued in 1925, and looks exactly like a photograph of a relief model of the State. This map was prepared by the U. S. Geological Survey, and is sold by the Survey for \$1.00. Unmounted copies may be obtained from the Arizona Bureau of Mines at the same price. The same map mounted on cloth with rollers at the top and bottom is sold by the Bureau for \$3.00.

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The Arizona Bureau of Mines will classify free of charge all rocks and minerals submitted to it, provided it can do so without making elaborate chemical tests. Assaying and analytical work is done at rates fixed by law, which may be secured on application.

The Bureau is always glad to answer to the best of its ability inquires on mining, metallurgical, and geological subjects; and takes pride in the fact that its replies are always as complete and authoritative as it is possible to make them.

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