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Oil and Its Geology

BY

MILTON A. ALLEN

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OIL AND ITS GEOLOGY

BY

MILTON A. ALLEN

INTRODUCTORY

In view of the lack of petroleum production in the State of Arizona and the probability of its occurrence, the State Bureau of Mines is to publish a series of bulletins, of which this is the first. It is hoped this series will give the fundamental principles of the origin, geological occurrence, physical and chemical properties of petroleum and natural gas.

The following is a list of subjects to be covered:

1. Oil and Its Geology.
2. Prospecting for Oil.
3. Drilling for Oil.
4. Laws Pertaining to Oil.

It is fully realized that the following will not completely cover the field of petroleum technology nor the exploitation and production of petroleum, but we do believe that the bulletins will contain sufficient information to be of material assistance to the searchers for natural gas or petroleum throughout the State.

THE WORLD'S PETROLEUM SUPPLY

Importance of Oil—The part petroleum or its derivatives play in our present day life would not be fully appreciated by many unless we were suddenly denied this valuable natural product.

It has become almost indispensable in our industries, and plays not an unimportant role in private life.

The world's marketed production of crude petroleum for 1915 is given in Table 1. The production of the United States was worth on an average eighty cents per barrel, the balance of the world's production was worth at least one dollar per barrel.

The value of the derivatives of this crude petroleum must have approached several billions of dollars.
Petroleum Supply Limited—We hear frequently of the famous oil gushers and the prodigious production of certain wells of famous fields; because of this, people generally have the notion that there is an unlimited supply of oil and that the world’s supply is inexhaustible.

Petroleum fields are fairly well distributed throughout the world but the areas of production in the producing oil fields are comparatively restricted. When it is considered that the oil fields of the United States have been intensely developed and that the proven oil-producing area in the United States contains only four thousand square miles, it will be readily appreciated that commercial deposits of oil are rare.

If the character, mode of origin and accumulation of petroleum are considered, the reason of its scarcity is readily explained.

Petroleum slowly evaporates and decomposes and forms gas and vapor, due to the fact that it is a mixture of unstable and complex oils, some of which are highly volatile. At the same time during earth movements it is forced to migrate by gravity, water, gas pressure and capillarity, thus causing losses. Our ordinary commercial pools of oil are the result of the accumulation in certain favorable spots of the migrating oil.

### TABLE NO. 1

**World’s Marketed Production of Crude Petroleum—1915:**

<table>
<thead>
<tr>
<th>Country</th>
<th>Production</th>
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<tbody>
<tr>
<td>Roumania</td>
<td>12,650,000</td>
</tr>
<tr>
<td>Italy</td>
<td>50,000</td>
</tr>
<tr>
<td>United States</td>
<td>281,104,104</td>
</tr>
<tr>
<td>Canada</td>
<td>250,000</td>
</tr>
<tr>
<td>Russia</td>
<td>69,000,000</td>
</tr>
<tr>
<td>Galicia</td>
<td>9,000,000</td>
</tr>
<tr>
<td>Japan</td>
<td>2,840,000</td>
</tr>
<tr>
<td>Germany</td>
<td>900,000</td>
</tr>
<tr>
<td>India</td>
<td>8,500,000</td>
</tr>
<tr>
<td>Dutch East Indies</td>
<td>12,800,000</td>
</tr>
<tr>
<td>Peru</td>
<td>3,500,000</td>
</tr>
<tr>
<td>Mexico</td>
<td>35,500,000</td>
</tr>
<tr>
<td>Trinidad</td>
<td>700,000</td>
</tr>
<tr>
<td>Egypt</td>
<td>800,000</td>
</tr>
<tr>
<td>All Other</td>
<td>1,500,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>439,084,104</strong></td>
</tr>
</tbody>
</table>
The above list is given in the order in which the countries commenced producing oil.

The origin of petroleum itself has not been completely explained, but the accepted theory is that petroleum is the result of complex changes in organic remains, either animal, vegetable, or both, which have been laid down under water in association with clays, slates and other sediments.

Petroleum can thus only be the smallest part of the organic source; and therefore, the smallest commercial deposits of today may represent vast, thick areas of petroleum-forming materials.

It is generally conceded that within the near future Russia and Mexico will outstrip the United States in production.

In the past sixty years the production of oil for the United States was 3,616,561,244 barrels, and the estimated future supply is 5,482,000,000 barrels. Judging from the production given in the table for 1915 we see that our supply will last about twenty years.

The life of any particular oil field or pool is limited, and of course is governed by many factors.

The following are the chief causes of their early depletion:

1. Decline of gas pressure in the districts due to the exhaustion of the lighter or gaseous hydrocarbons.
2. Formations of waxy sediments that obstruct the passage of the oil from the sand.
3. Decrease in the quantity of oil draining by gravity down the dip into the area affected by the well.
4. Decrease of the oil supply within the area of the well, on account of near-by development, or the original limits of the pool.
5. Flooding of the productive formation by salt water under high pressure.
6. Flooding by fresh water from the surface or from an overlying water-bearing formation.
7. Drilling of neighboring wells.
8. Poor management, such as improper casing, unwise rate and time of pumping, and failure to clean.


The foregoing facts illustrate that it is of the utmost importance to conserve in every way possible the oil resources of this country.

Of course in the near future substitutes in the form of oils from lignites and shales may be a necessity, but processes for the complete and economical extraction of these oils, as well as their treatment after extraction, have yet to be perfected.
The accompanying curve will serve to illustrate the rapid rise and decline of the Illinois oil fields.

This curve illustrates very strikingly the short life of these fields.

**PROPERTIES OF PETROLEUM**

Petroleum is a viscous fluid which emits a distinctive odor; when sulphur is present, as is often the case, the odor becomes disagreeable and often offensive. Temperature affects the fluidity of the crude petroleum.

The color of petroleum varies widely, often differing considerably in the same field. When viewed by transmitted light it varies from yellow, green and red to reddish-brown and various shades, to brown and black.

When viewed by reflected light it exhibits a green fluoresence.

It has been proved experimentally that oil can be deprived of its dark color by filtration through Fullers earth or clay, and that also there is a certain fractionation which takes place. No doubt this is
the reason of the very “white” oils which have been found in some fields, such as the Baku fields of Russia, the California fields, and those of Texas.

Chemically, petroleum is practically hydrogen and carbon, combined as hydrocarbon compounds of different composition and complex form, and frequently contains combined and free oxygen, sulphur and nitrogen.

All petroleums are a mixture of different series of hydrocarbons, any one series being present in a greater or less degree.

To distinguish between the two main classes of petroleum the name “Asphaltic” is given to those oils which yield on slow distillation a dark asphaltic residue which is readily attacked by acids and dissolves in the usual solvents; and the name “Paraffin” to those which yield after distillation at a low temperature an appreciable proportion of light colored solid hydrocarbons, chiefly of the paraffin series, which are not readily attacked by acids and normal solvents.

No distinct line can be drawn between asphaltic-base oils and paraffin-base oils, as the name is given only for convenience of distinction between the two great classes.

Nearly all asphaltic oils contain paraffin and many paraffin oils contain asphaltic products.

Our Pennsylvania and Ohio oils are paraffin-base oils. Those of California and Texas are generally asphaltic; whereas some of the Mexican oils are a mixture. The presence of asphaltic products, as in the Mexican oils, considerably complicates the process of refining, a process through which all oils must pass before they reach the ultimate market, excepting some of the fuel oils which are used in the crude form.

All crude petroleums are a mixture of various hydrocarbons of different boiling points and densities (specific gravities) so that when heated, that hydrocarbon with the lowest boiling point is first evolved or distilled off; and so each hydrocarbon is distilled over as each successive and higher boiling point is reached. The vapors passing over are condensed, collected and washed by acids and alkalies to remove impurities.

The process of distillation, however, is not as simple as described above, since there are many disturbing factors entering into it. As for instance, the presence of two or more compounds of almost equal boiling points, the question of vapor tensions, etc.

The oils of paraffin base command a higher price than those of asphaltic-base. As an example, Pennsylvania crude is selling for $3.05 per barrel at the pipe line; California crude at $0.70 per barrel.
The reason of this higher price is primarily due to the large yield of gasoline and kerosene from the paraffin oils, amounting in some cases to 62 per cent of gasoline and kerosene; whereas the asphaltic base oils yield as low as 4 per cent gasoline and 38 per cent kerosene.

The density (specific gravity) of petroleum varies from 0.78-1.0, the more common oils having a specific gravity between 0.850-0.94.

The specific gravity of petroleum may vary widely in the same district or field.

In most countries the specific gravity of oils is compared with water as unity, but in the United States it is generally measured in degrees Baume'.

The refined product of petroleum are employed in many ways in our industries and enter into our private life in no small way.

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<tr>
<td>10</td>
<td>1.0000</td>
<td>55</td>
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<tr>
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<td>0.8254</td>
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<td>0.6363</td>
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<tr>
<td>50</td>
<td>0.7794</td>
<td></td>
<td></td>
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</tbody>
</table>

The following is a brief list of the many uses of crude petroleum and its products:

- Gasoline for motors.
- Kerosene for lighting.
- Fuel oil for burning in internal combustion engines.
- Paraffin wax for candles, insulating materials, chewing gum.
- Many medicinal uses, as vaseline, insecticides.
- Bituma for paving, electrical work, roofing, etc.
- Dust allayers on roads, binders for macadam.
- Lubricants for machinery, etc.
- Synthetic dyes and explosives.

**ORIGIN OF PETROLEUM**

Since the discovery of natural petroleum in sufficient quantities for commercial use, man's investigative mind has been engaged in the solution of the problem, "How did petroleum originate?"

Many theories have been advanced by eminent men, but the two
The Inorganic Theory—The initiators and followers of the inorganic theory have been chiefly chemists and many of their points have been ably demonstrated by laboratory experiments. Many geological facts have not been explained by the inorganic theory and, since the organic theory satisfies to the greatest extent our present knowledge, it is generally accepted.

The inorganic theory attributes the origin of petroleum to the condensed vapors of hydrocarbons, brought about by chemical action in the interior or molten parts of the earth. The existence in the earth of free carbon and metallic carbide has been demonstrated, and it is the action of water upon these carbides at high temperature which has resulted in the formation of hydrocarbons. Marsh gas, the lowest homologue of the paraffin series, has been produced in this way in the laboratory and these facts are used in support of the inorganic theory.

The supporters of the inorganic theory cite many physical facts, in support of their theory, as being necessary to the accumulation and migration of petroleum, such as faults and earth folding. Since the origin of these geological disturbances is usually deep-seated, the formation of petroleum is attributed to the same cause.

As opposed to this theory, however, it is a fact that petroleum of workable quantity never occurs in igneous rocks, although traces have been found in them.

Volcanic rocks are obviously unsuitable as reservoirs of petroleum and it is certainly more than a coincidence that 85 per cent of the world's petroleum is obtained from sedimentary beds of a recent (Tertiary) geological age. These rocks are generally underlain by enormous thicknesses of impervious sedimentary rocks which would have arrested any upward movement of petroleum.

The champions of the inorganic theory cite the many cases or apparent contradiction to the anticlinal theory as supporting their case. This theory will be discussed in detail later.

Organic Theory—The organic origin of petroleum is now almost universally accepted, although the supporters of this theory are divided among themselves on the question of whether petroleum is the result of vegetable or animal remains, or both; also it is not known whether the petroleum was produced in the beds in which it is found or has been introduced subsequently.

In any event there is no single explanation that will not fit all petroleum occurrences.
At one time the porosity of mineral masses was not thoroughly understood, but it is now demonstrated that all rocks are porous and can absorb fluids under pressure. Some of the common sands, sandstones, and limestones can absorb water to the extent of 10-50 per cent of their volume. This high porosity readily accounts for the large quantities of petroleum found in some deposits.

Artesian wells illustrate also the porosity of rocks and the ease with which fluids will flow throughout them.

Argillaceous shales, (rocks of sedimentary origin), contain hydrocarbons in some localities to a very great extent, and when subjected to heat will yield large quantities of oils high in paraffin. The Scotch shale industry is an instance of this. These shales will yield oils to the extent of 20-40 gallons per ton, besides gas. There are vast areas of these shales in New Brunswick, Nova Scotia, Colorado, Wyoming and Utah. There are shales in France which on distillation will yield 80 gallons of oil to the ton.

All coals when subjected to distillation will yield liquid and gaseous hydrocarbons. The nature and quantity of the oil and gas depends on the original nature of the coal and the temperature at which it is distilled. This is a fact that many of the supporters of the vegetable origin have overlooked.

It has been claimed that the products resulting from the destructive distillation of coal are not like the constituents of petroleum. This is true, but the processes of destructive distillation are usually carried on at comparatively high temperatures.

All coals when distilled at low temperature yield a greater percentage of the paraffin hydrocarbons.

Coals which are low in resin compounds do not yield, on distillation, such a large quantity of paraffin in the gas or tars as the coals containing a large percentage of resin matter.

Cannel coals which are high in resin constituents yield a large percentage of paraffin hydrocarbons, both in the tars and gas, when distilled at a high temperature. The paraffin compounds are materially increased when cannel coal is distilled at low temperature, the tars resembling crude petroleum very closely.

Many of the rock strata of the oil bearing fields contain great quantities of petrified wood.

Some oil fields are in strata which contain large quantities of the remains of fish and other sea life. This points to a probable origin of petroleum.

That an accumulation of animal life in sufficient quantity to form
Oil Series No. 1

the amount of oil met with in the largest oil fields is possible, one need only cite the chalk formations of England and France, which are some three thousand feet thick and are composed of the calcareous skeletons and remains of minute sea life.

THEORIES OF CONCENTRATION

From the above description of the origin of petroleum it will be understood that the present deposits of petroleum may be the accumulated result of large quantities of animal and vegetable life.

This accumulation has been brought about by various natural agents and is materially influenced by the physical properties of petroleum.

Whether the petroleum as it is found did or did not originate in the formation in which it occurs, is a matter which is widely discussed.

The influence of geology on accumulation and concentration of petroleum will be discussed under the heading, “Geology.”

From the research which has been done on the cause of the variation in color and composition of petroleum, it has been discovered that Fuller's earth and other clays have a peculiar effect on petroleum. When petroleum is allowed to filter through Fuller's earth, a mechanical fractionation takes place, the lighter hydrocarbons being separated from the heavier ones. Also such impurities as black color and sulphur are removed.

Coarse sand or highly porous material will not have this effect on petroleum. It is thus inferred that the oils of Pennsylvania and Ohio are migratory oils, the asphaltic and base ingredients having been separated out; whereas the oils of California and Texas have not undergone any appreciable migration.

The old theory that hydrostatic pressure accounted for the pressures met in gas and oil fields has been discarded as erroneous.

It has now been demonstrated, however, that capillarity of oil and water has the power of producing great pressures, similar to Osmatic pressures, which have reached forty atmospheres.

The fact that oil occurs in the porous sands, sandstones and limestones is partly due to their porosity and power of accumulating large quantities of petroleum. This does not satisfy the question as to how it got there. Perhaps the most satisfactory explanation is that of capillarity. The capillarity of water is about three times that of crude petroleum. Thus water has the power by capillarity of forcing the oil from the pores of shales. After water has once entered the shale,
the oil would not have the power to enter again by forcing out the water. Since the evidence points to the shales as the probable source of the petroleum of most fields and also that shales have a porosity of sufficient fineness to possess capillarity, the oils which were contained in the original shales were forced out by water into the more porous strata either above or below.

After the oil has entered the sands, no doubt gravity played a part in forcing it to its present localities.

When the oil, water and gas enter the more porous strata where capillarity has no great influence, gravity causes the water, which is the heaviest, to seek the lowest level, the oil remaining on top of the water and the gas above the oil. The three thus continue to rise in the strata until they reach the so called anticline and remain there, if there is an impervious capping to prevent their loss.

**GEOLOGY**

Nearly every oil field in the world occurs in close relationship to some earth fold or uplift and the position in which petroleum is now found is the result of this folding and disturbance.

A careful study of the rock structure in oil deposition is so important that a list is given herewith of many variations in oil occurrence:

1. **Anticlines:**
   - Single
   - Compound
   - Symmetrical
   - Asymmetrical
   - Overturned:
     - Figs. III. & IV. & VI.
     - Figs. VIII. & IX.
   - Fig. VII.

2. **Synclines:**
   - Single
   - Compound
   - Symmetrical
   - Asymmetrical
   - Overturned:
     - Fig. III.
     - Fig. XVII.

3. **Monoclines:**
   - Fig. XII.

4. **Combination of (1), (2), (3).**

5. **Domes:**
   - (a) Anticlinal
   - Saline
   - Volcanic
   - Fig. IV.

6. **Faulted form of any of the above:**
   - Figs. XI. & XIV.

7. **Unconformabilities.**

The rocks in which petroleum is now found are sedimentary and were originally laid down in a practically horizontal position.

The material from which petroleum was formed was evidently laid down in salt water of medium depth, similar to the places in which we would expect shales and clays to be deposited.

This is proved by the presence of fossil remains which are those of salt water fauna and flora. There was considerable variation of depth
Oil Series No. 1

during the deposition, as the deposits vary from fine grain sands to limestone, the latter being deposited at considerable depth.

Some of the changes were so abrupt that they were probably the result of alterations in water currents rather than the rise and fall of the sea floor. In other deposits there are indications that there were long periods of quiescence prior to any movements.

In order that the accumulation of large quantities of petroleum be possible, the strata in which the field is found must be porous; whether that formation be the origin of the oil or not.

Since sands, sandstones, and limestones are the most porous of rocks, it may be expected that the oil should occur in them.

The oil-bearing limestones of Pennsylvania and Ohio became porous by the secondary changes which converted the original limestone to dolomite; the resulting dolomite occupying less space than the original limestone.

Another of the necessary conditions which must exist to make petroleum deposits possible is the presence of an impervious cap or covering over the strata in which the oil occurs.

If this impervious cap were not present the petroleum and gas as it is produced or accumulated would escape and allow water with or without salts of lime and iron to replace the oil, or, dry strata would result.

Petroleum-bearing strata is invariably overlaid by impervious beds, usually clays or shales. These impervious beds have no doubt played an important part in the formation of oil, as already described, as well as assisting the retention of the oil after its formation.

A wet shale forms the most impervious of covers.

It is supposed that the salinity of the water found in oil deposits played an important part in the formation of oil; owing to the delay which such a solution would cause in the decomposition of the organic matter by its preservative action.

Great thicknesses of rock salt are found in the oil-bearing formations of Texas, Galicia and Roumania.

Although oil is sometimes completely foreign to the rock in which it is found it is generally conceded that it was formed in its present locality at a time when the beds were horizontal.

Petroleum and gas, being fluids, obey the laws of fluids. Any folding or earth movement would force the oil and gas to change its position. The present distribution of oil is the result of these earth movements.

The earth folding causes the strata to change from its horizontal position (Fig. II) to a slightly undulating position, possessing
known as anticlines and synclines. Fig. III. Anticlines and synclines may be likened to a series of water waves, the crest being the anticline and the trough the syncline.

Fig II. If these earth movements are not severe these anticlines and synclines are very gentle and their axes will extend for miles. The earth movements, when severe, will cause abrupt folding, forming sharp anticlines and synclines. When the folding is too severe, fissures may open in the rock and allow the petroleum to escape into other porous beds or come to the surface where it slowly evaporates and disappears. It is these surface indications that assist in the location of petroleum deposits.
During the folding, the gas, oil and water, which are almost always present, would be forced together in the more porous parts of the strata. The three, according to gravitation, would then separate in the order named; the gas being at the top, thus occupying the highest part of the petroleum-bearing strata or the crest of the anticline; the oil next occupying the flanks of the anticline, and the water occupying the syncline. Fig. IV.

There is no doubt that this separation would be influenced largely by the difference of porosity of the sands, and would require time; but there is ample time in geological ages.

Where the folding has been gentle, the axis of the anticline will undulate and stretch for miles across the country and the petroleum will segregate in places along the anticlinal axis.

Just such conditions as these give rise to our largest oil deposits. (See Fig. V. which represents the anticline extending through Oklahoma and Kansas, Pages 16-17.)

In many cases there have been secondary movements at right angles to the primary movements and in this way the anticline of the primary and secondary movements would create domes. Such formations exist in Texas, and in Baku, Russia, from which enormous quantities of oil have been obtained.

The anticlinal structure plays an important part in the accumulation of petroleum and it will be discussed in greater detail under the "Anticlinal Theory".

When the earth folding takes place, fissures and faults are gen-
erally produced. These fissures play an important part in the redistribution and migration of the petroleum, by allowing it to occupy strata other than that in which it was originally formed. These porous beds do not show any relation to their petroleum contents.

Petroleum in many fields is found at several horizons separated by many feet of strata, part of which is impervious, as in Illinois, Texas, Kansas, Wyoming and Russia.

Petroleum distribution is frequently influenced by the pressure existing in oil fields. These pressures vary in different fields but have reached as high as one thousand pounds to the square inch in Pennsylvania and West Virginia.

When a field possessing such tremendous pressure is tapped, this pressure is naturally relieved. In this way the oil redistributes itself according to the redistribution of pressure. Thus sections of fields would become productive that were non-productive before, and vice-versa. It has been claimed, by operators in Pennsylvania and the Baku field of Russia, that such redistribution has taken place in those fields.

A probable explanation is given by the Godiven Austin Theory for the occurrence of petroleum in strata of different ages, one above the other, which are separated by impervious beds.

That is, when one fold has been produced by an earth movement, any new movement will tend to fold the strata along the same lines.

Petroleum may be formed and collected in the anticline of an older formation; subsequently another deposit may be laid down over that formation, oil will form and accumulate owing to secondary folding along the same anticlinals.

An anticline may be completely eroded, resulting in the complete loss of any petroleum which it may have contained. However, petroleum-bearing strata which has not been eroded may occur underneath the eroded strata, having been laid down prior to the formation and folding of the strata of younger age.

**STRUCTURE FAVORABLE TO OIL CONCENTRATION**

Besides the many conditions just discussed as being necessary for the accumulation of petroleum and what may have already destroyed the already existing petroleum, the main structural conditions of oil fields listed in the first part of the chapter “Geology” will be discussed.
Symmetrical Anticline

Fig. VI. will serve to illustrate this ideal structure which has been found in some fields of the world. It represents a broad anticlinal fold covered by unbroken shales and clays having gently sloping strata on either side of the axis. This structure may undulate along the axis of the fold, producing minor anticlines at the angles to the axis of the main fold. This will give rise to pools as shown in Fig. V. Many of our eastern petroleum fields are of this structure. This, however, is almost an ideal form.

Asymmetrical Anticline

This type of structure has provided many excellent fields. This type is illustrated in Figs. VIII. and IX., and is an anticline with one flank dipping gently and the other steeply. The “terrace” structure is a form on which one side of the anticline is, to all practical purposes, horizontal. However, these anticlines may become so sharp as to make drilling in them almost useless, as no depth is gained.
MAP OF MID-CONTINENT GAS FIELDS, SHOWING POOLS.

Italic figures show original rock pressures and daily yields; heavy figures show pressures and yields in November, 1921.
by deep drilling, Fig. VII. An overfold often occurs when there is a sharp folding, Fig. VII., and it is only by careful and close study that the outcroppings would reveal the presence of an anticline.

Fig. X. will illustrate a common oil field structure where the crest of the anticline is broken and eroded.

**Compound Anticline**

This structure occurs only where the flexuring movement has been severe, and has produced a series of sharp folds, some of the flanks being steep. Persian oil deposits exhibit this structure. When folding is severe, as in this case, faulting occurs as in Fig. XI. This structure is discussed in another part of the bulletin.

When faulting does occur the wells are drilled in the fault. The oil is probably retained in the formation by the evaporation of the lighter hydrocarbons, leaving the heavy bitumen behind, which seals the crevice.
Domes

It will generally be admitted that the more favorable structure is the Dome or quaquaversal with gentle dips near the summit and steeper dips at the flanks which gradually pass into a horizontal position. A large area can be included in this structure. Domes are really special cases of the anticlinal structure, being produced by two folding movements at right angles. A broad round dome is very rare in nature, it usually being elongated in one direction. The Spindle Top Dome of Texas is a good illustration of this structure.

Monoclines

Oil may be obtained in great quantity from this type of structure. The more gentle the dip, the better; but even quite steeply inclined strata may yield good production. This structure is illustrated in Fig. XII. In Peru, Trinidad, some parts of California and Mexico good productions have been obtained from monoclines. The influence of change of dip in these and all structures is an important consideration.

Petroleum occurs throughout the world in sedimentary strata of practically all geological ages. Although as stated before, 85 per cent of the oil deposits of the world occur in strata of Tertiary age. The oil and gas of each field comes from rocks of an age peculiar to that field.

Table No. 3 gives a list of some of the larger fields and the geological age of the strata in which the oil occurs.

The relative ages of beds depend primarily upon the order of their deposition. Normally the older beds are beneath the younger. However, folding and faulting may change the position.
The proper correlation of sedimentary rocks is often materially assisted by a knowledge of fossils.

**TABLE NO. 3**

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<th>Locality</th>
<th>Name of Formation</th>
<th>Geological Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>N. W. Ohio Indiana</td>
<td>Trenton Lime</td>
<td>Silurian</td>
</tr>
<tr>
<td>W. New York Canada-Central Ohio</td>
<td>Medina &amp; Clinton Sands</td>
<td>Upper Silurian</td>
</tr>
<tr>
<td>W. Va., Penn., Kentucky</td>
<td>Sandstone</td>
<td>Devonian</td>
</tr>
<tr>
<td>Kansas Oklahoma</td>
<td>Sandstone</td>
<td>Carboniferous, Cretacious Tertiary</td>
</tr>
<tr>
<td>California New Mexico</td>
<td>Lime and Sandstone</td>
<td>Tertiary</td>
</tr>
<tr>
<td>Montana Wyoming</td>
<td>Sandstone</td>
<td>Cretaceous</td>
</tr>
<tr>
<td>Mexico</td>
<td>Limestone Sandstone</td>
<td>Cretaceous Tertiary</td>
</tr>
</tbody>
</table>

In Mexico the Feirbero oil field is very closely associated with igneous rocks, the first instance of this that is known. Fig. XIII.
The oil is closely associated with a basaltic intrusion which occupied a position between a series of shale and sands, forming a huge laccolith or sill.

The laccolith was intruded over the already existing anticline and so metamorphosed the shales as to cause the otherwise impervious shales to become porous and thus allow the accumulation of petroleum.

While the anticlinal structure is conducive to the accumulation of large quantities of petroleum, as in many of the world’s largest fields, it is not essential, as there are many highly productive fields in which this structure appears to be absent. This theory will be discussed fully under the chapter “Anticlinal Theory and apparent exceptions to the Anticlinal Theory.”

**MOVEMENTS OF PETROLEUM**

That petroleum is still undergoing movement in the earth, is indicated by the continual escaping of gas and oil from outcropping oil strata or at the fractured crests of anticlines both on land and under the sea.

The concentration of oil and gas must have been a long and slow process when it is considered that the oil is viscous and that although some rock strata is porous, it is very minutely so. That faults and crevices played an important part there can be no doubt.

Faults and crevices occur in oil fields of Russia, Roumania, Galicia and California, and no doubt play an important part in the distribution of the oil and productivity of the fields. At Baku a number of important fields have been located along fissures in which exceptionally large flowing wells have been drilled.

That oil is continually flowing is borne out by the fact that many wells, in oil fields which have been abandoned as dry, have been cleaned out and brought in again. Also new wells in the immediate proximity of the new fields have been drilled and yielded paying quantities of oil.

That fissures play an important part cannot be more forcibly illustrated than by the fact that many wells have to be blasted with large quantities of nitro-glycerin to open up the oil bearing strata before they can be made to yield oil.
CHARACTER OF PETROLEUM BEARING STRATA

The main supplies of oil and gas come from sands, sandstones, conglomerates, and limestone, although clays and shales are sometimes petroleum bearing.

Sands and Sandstones—Some of the most productive fields of the world are in sand and sandstone rocks, as for instance, those of Russia, California, Galicia and Roumania. These sands may vary from very fine grained loose sands like quicksands to coarse grained sands; similarly, sandstone varies in texture.

A study of the geological formation of sands and sandstones will readily explain the variation in texture and thickness of these beds in a relatively small area. In many places a sandstone could easily grade into a shale or clay. These variations could naturally affect the extent and production of any oil field. Concretionary nodules of secondary origin are often found in the oil bearing sands.

Limestones—The oil fields of the eastern states of America are mainly in the Trenton limestones, a rock, the extreme porosity of which has been brought about by the alteration of the limestone to a dolomite, (a calcium magnesium carbonate). These dolomites are estimated to be able to contain 10 per cent of their volume in oil. The Canadian oil fields are in a similar formation, as also are those of the Spindle Top fields of Texas. The cavities of some of the pieces of limestone ejected from the wells at Spindle Top were as large as an inch and there is reason to believe that cavities approaching feet in size, existed in the formation.

The thickness of the beds will influence the production of petroleum; the inclination of the beds accentuating this, as the well will pierce the formation diagonally.

ANTICLINAL THEORY

Before discussing this theory in detail it may be well to define and explain an anticline.

An anticline is a long relatively narrow fold of rock the sides of which incline away from the line of folding, called the axis.

These anticlines are believed to be caused by shrinking, folding, or igneous intrusion.

The cross sectional appearance at right angles to the axis of the folding is like that of a wave and it's trough; the crest of the wave representing the anticline, the trough the syncline. (Fig. III.).

Many people confuse hills and valleys with anticlines and syn-
Hills are sometimes the result of uplift, but more often they are the result of erosion.

Anticlines can only be recognized by experience and more frequently by actual surveying.

The discovery of this theory is accredited to four men who announced and propounded it independently.

The credit for putting the theory into practical use is usually given to Dr. I. C. White, who re-announced it in 1882.

The theory is briefly stated thusly: That, provided the porous rock for the accumulation of the petroleum is present, and that there is an impervious cap to cover the petroleum-bearing strata, the oil and gas will invariably be found occupying the uppermost parts of the anticlinal fold; the gas being at the axis or top of the anticline, the oil next down the sides of the anticline, and the saline water below the oil.

Dr. White first met with a considerable amount of ridicule from geologists, as well as practical oil men. He had great difficulty in obtaining the financial support of these men.

It has only been after years of proof and hard work that this theory has been used by oil men.

The theory, of course, has been expanded to meet new conditions, though it does not, in its limited sense, meet the conditions that exist in some fields. Although the anticlinal theory characterizes many of the greatest oil fields, there are many highly productive oil fields in which the true anticlinal structure is absent.

The theory, however, in its broadest sense has been accepted by oil geologists.

Apparent Exceptions to the Theory—By recent studies the anticlinal theory has been developed and those accumulations which are discovered and which apparently are not covered by the theory, are usually found upon closer study to possess the conditions which duplicate the structure, though they are not true anticlines.

For instance, a monocline (Fig. XIV) which is petroleum-bearing,
may meet the conditions of the anticline because of the petroleum in the petroliferous strata being trapped by a fault movement, bringing about any of the following conditions:

The fault movement may bring an impervious rock over the petroliferous strata (Fig. XIV), or the fault plane may be filled with clay, a common filling of fault fissures, or the petroleum residue left by evaporation may seal the fault plane.

The petroleum bearing sands may pass into a shale near the outcrop, or may thinn out at that point, the impervious strata above and below meeting near the surface (Fig. XV). Petroliferous strata which has a low dip in one direction for miles may outcrop for miles and yet upon penetration, to the other side of the sands, may yield oil. These conditions are common in California, Roumania, and the Caucasus, and especially in Peru.

Oil has been found in synclines. This may be due to the fact that the anticline is broad and has a small syncline at its crest. It may also be due to the fact that the oil accumulation is large for the size of the anticline, the oil extending well down into the syncline.

If the water level be low, or no water exists, the gas pressure may force the oil into the syncline. Oil is generally found in anticlines, for it is this part of the oil-bearing strata which reveals oil deposition by bringing the oil nearer the surface, thus indicating its presence by emanations; thereby bringing the oil within economical distance of the drill. Drilling in many cases could not reach the depth of some of the synclines.

In many cases the general anticline is not extended over large areas without considerable variation in its level. Also the porosity and thickness of the petroleum sands may vary. Thus in one general anticline there may be domes and synclines of lesser extent.

*Fields Predicted by Theory*—Dr. I. C. White located a gas well
twenty miles east of Pittsburgh to demonstrate his theory, and this well was a success, giving large quantities of gas.

Dr. White, after failing to interest practical men in his theory, formed a company and located a well in West Virginia, thirty-five miles from any other producing well. Practical men predicted it would tap water, but it struck oil and is a celebrated producer.

Dr. Orton, who was one of the geologists to support Dr. White, rendered able assistance to the theory and demonstrated its application to the Ohio oil and gas pools.

Many of the more famous fields were opened by the accidental discovery of oil and gas when drilling for water or coal. Many of these fields have been extended by the application of geology where failures by practical men had denounced the extension as worthless.

These fields will be discussed under "Fields Reopened and Extended by the Theory."

The Illinois oil fields were mapped some forty years ago by the first Illinois State Geological Survey.

Others, chiefly geologists, had predicted the probable existence of oil in Illinois.

However, it remained for the oil to be discovered by chance in drilling for coal in the eighties. Another chance discovery was made by drilling for water. But even after these discoveries it was some time before actual development took place.

Two valid fields which are the result of geological prediction after careful work, may be cited; namely, the North Augusta and Eldorado fields of Kansas.

The geological structure of these fields was carefully summarized and mapped and the boundaries of the fields definitely stated before the first test well was sunk.

The so-called deadline was marked and all wells sunk outside of this line have proved to be failures. This will illustrate the importance of careful surveying.

Fig. XVI illustrates these survey results as well as showing the dead line prediction. This prediction is more clearly shown by the dark line or 1330-foot contour in Fig. XVII. Fig. XVII illustrates the fields after considerable development. The Eldorado field yielded 95 per cent pay wells.

FIELDS EXTENDED AND REOPENED BY THEORY

The mid-continent fields of Kansas and Oklahoma have been extended and opened up by careful survey and geological work, giving
them in two years a new productive area equal in extent to the area existing prior to that time.

Kansas is a state in which several million acres of land had been condemned as worthless from the standpoint of the oil operators. Record prices are now being paid for this acreage, which is the result of scientific application of the anticlinal theory to the oil industry.

By geological work three pools were opened in Butler County, Kansas; namely, the Augusta, North Augusta and Eldorado.

Practical men had made several unsuccessful attempts during several years to open the Augusta pool, but it was finally predicted by them to be worthless.

This field was afterwards very carefully surveyed and contoured, both topographically and stratigraphically. The limits of the field were marked and the development followed along the original lines determined by the survey. The result of this is that 97.4 per cent of the wells are paying wells.

The famous Cushing and Blackwell fields of Oklahoma are remarkable concurrences to geological structure. The extent and limits of the Cushing field were clearly forecasted by geological surveys made after its discovery, but prior to its development.

In Washington County, Oklahoma, there is a territory which had been condemned by the old methods, there being an unusual percentage of dry wells or failures. Two good oil wells have been opened recently by geological forecast.

It must be pointed out that in this work care must be taken that the surveys are accurate and that the outcropping rocks are properly correlated. On this depends the whole final result of the location of the anticline or dome structure.

NATURAL PETROLEUM GAS

This gas is usually found accompanying petroleum accumulations and is the only natural gas of economic value.

There are two kinds of natural gas, "wet gas", and "dry gas". Wet gas, or casing-head gas, is the gas coming from oil wells and it contains quantities of the lighter hydrocarbon as vapor. These vapors can be recovered either by compression and liquifaction or scrubbing. Both systems are used commercially.

Dry gas is gas which comes from gas wells in which no petroleum is found, and does not contain enough such vapor to be of commercial value. A certain amount of gas is always found with petroleum, but petroleum does not always accompany gas accumulation.
In general, the same laws which govern the accumulation of petroleum are applicable to natural gas. Although oil and gas occur in formations of Cambrian to recent age, the greatest and most extensive gas deposits so far as is known, are found in the older, drier and more consolidated sedimentary rocks from the Cretaceous to Cambrian.

![Fig. XVIII](image)

The economic importance of natural gas is not appreciated to its full extent and hence large quantities of this valuable natural resource is wasted each year. Occasionally wells have been known to produce 30,000,000 cubic feet of gas per day, and in Louisiana some wells are reported to have given as much as 75,000,000 cubic feet of gas per day.

SEDIMENTARY OR POSSIBLE PETROLEUM AND GAS BEARING ROCKS IN ARIZONA

It is rarely appreciated that approximately one half the State of Arizona is made up of sedimentary rocks, not including the recent deposits making up the desert basins of the southwestern part of the state.

The oldest of the sedimentary rocks are exposed in the Grand Canyon of the Colorado, west of its junction with the Little Colorado. Here the Cambrian and Ordovician rocks are exposed.

Generally speaking, Mohave County, north of the Grand Canyon, Coconino County, and part of Gila County are covered on the surface by Jurassic, Triassic and Cretaceous rocks.

These sedimentaries are broken through in places by igneous intrusions of Tertiary or later ages. On the whole the sedimentary rocks are not greatly disturbed by volcanic action.

The Dakota Sandstones (Cretaceous Age), oil and gas-bearing rocks of Southwestern Canada, Wyoming and Colorado, extend into the
State of Arizona, but they are practically eroded away in the north and are so near the surface in the central part of the State that their petroleum-bearing possibilities are doubtful. The lower carboniferous (Pennsylvania Series) which yielded oil in Kansas, Oklahoma, South Utah, extend over large areas in Northern Arizona. The San Juan oil fields of Utah are situated along the San Juan River, and there is every reason to believe they extend south into Navajo and Apache Counties in the State of Arizona. Some oil has been found in this field, but owing to economic conditions and natural obstacles this field as yet has not been greatly developed.

The oil encountered so far has been only a few hundred feet below the surface (200-500) and is found in the synclinal folds of the district. This is explained by the presence of the San Juan Canyon and the comparative great depth, therefore, of the water level of the country. Oil could easily be in the syncline if there was no water present in the petroleum-bearing strata.

No wells of any great depth have been sunk, so the oil possibilities are not known. However, when oil wells of depth are sunk and the water level is reached, the oil will be found in arrested monoclines or on the flanks of the anticlines.

The question of water level, in tracing the probable accumulation of petroleum in the State of Arizona, would be an important consideration, as noted by the San Juan fields. This water level would be influenced by the depth to which the river action had cut into the sedimentary rocks, as is shown in the instance of the Colorado Canyon. Again, the area which would be drained by this action would considerably influence the condition of petroleum accumulation.

In view of the close proximity of the San Juan fields of Utah it will not be out of place to describe these fields in some detail.

Notice was drawn to this part of the country as being possibly oil-bearing by the occurrence of oil seepages on the San Juan River. All these “springs” are near the level of the river but are not in the same strata because the beds rise to the west, and the river cuts through them into lower formations.

The highest seepages stratigraphically occur in the “Goodridge” oil sand where it is exposed along the San Juan River. The largest is at the foot of the Honaker trail. The stratigraphic distance between these two seepages is 1,450 feet. At some places the oil seems to follow crevices, at others it saturates unbroken rock. It is noted that the oil does not come from any one horizon in this field.
A more complete knowledge of the geology of the district may reveal some important information.

The fact that the first attempts to produce oil have met with failure should not discourage continual prospecting, as many fields of large production met with just such failure at the start. Many of the older fields, as Pennsylvania, Galicia and Russia, received only surface development (0-500) in their early stages. Though oil in very large quantities has not been found as yet in the San Juan field, every indication is encouraging.

There is the possibility that the San Juan field may represent only one of many pools that exist along the North South anticlines which extend from Southern Utah into the State of Arizona. The fact that it is probably being drained by the San Juan River erosion would naturally cause this pool to be pocketed, as the evidence indicates; the remains of what once existed being now tapped.

The erosion of the Colorado River shows that rocks of Silurian and Ordovician age exist in Arizona below the carboniferous. The great oil fields of the Appalachian region are in the Clinton Sands (Silurian), and the Trenton Limestone (Ordovician).

Where the erosion has been sufficient to bring the Silurian and Ordovician rocks within economical drilling distance of the surface, tapping the anticlines in these formations may yield petroleum.

A section across the northern part of the State of Arizona about twenty-five miles south of the San Juan River shows that there is a bread anticline (25 miles) over the Monument Valley. This upward movement, known as the Monument uplift, has produced a sharp anticlinal fold on the west of the uplift, known as the Hoskinnini Monocline, and another on the east known as the Combmonocline.

This upwarp has exposed the upper Carboniferous and Permian strata at Monument Canyon. Here the Canyon has almost cut into the lower carboniferous limestone.

No doubt this folding movement is the same as that which produce the San Juan oil field conditions.

The oil in the San Juan oil fields is found in the Goodridge or Pennsylvania series of the carboniferous age.

It must be realized that the Monument upwarp may have produced a series of minor anticlines and synclines between its eastern and western extremities. The north and south axis of the anticlinal fold which produced the Monument upwarp is parallel to the Rocky Mountain range. The De Chelly upwarp in Apache County may be the southern extension of the anticlinal axis. Along this anticline
there may be pools of petroleum, as in the Kansas, Oklahoma fields. Fig. V.

Taking another cross section from east to west about fifty miles south of the Utah and Arizona boundary, two large uplifts are seen to exist, which are the DeChelly upwarp in Apache County on the eastern end of the section and another uplift occurring near the Colorado Canyon.

The eastern uplift does not expose the lower carboniferous or Pennsylvania series but the western one does, the Colorado River cutting through the carboniferous strata here.

There have been reports made that there is a possibility of oil occurring in the Chino Valley in Yavapai County and in the San Pedro Valley of Cochise County, in the southeastern part of the State.

Since there seems to be no material surface indications of oil, such as seepage, etc., the possibility of oil in various parts of the State can only be determined by careful geological work, as discussed in the first part of this paper, together with careful exploratory work after geological results have been obtained. Further prospecting, however, may reveal extensive surface indications of oil.

It is a fact that the possibility of oil in Utah and New Mexico is being more realized every day. That oil exists in great quantities in Southern California still more enhances the possibilities of there being oil in Arizona.

Since there are no seepages and other oil indications so far as is known in the State of Arizona, geological records of all water wells, artesian wells or any other boring which passes through sedimentary rocks should be kept in order to assist in the development of this resource of the State. These records may be of untold value in the near future.
GLOSSARY TO BULLETIN 1

1. Anticline—A bend with the convex side up.

2. Argillaceous Shale—Shale containing clay.

3. Artesian Well—A well bored down to a depth where the pressure is so great as to force the water out at the surface.

4. Asymmetrical—See Fig. VIII. and IX.

5. Cannel Coal—A variety of coal high in volatile matter.

6. Capillarity—Phenomena exhibited by liquids in small or hairlike cavities.

7. Carbide—Compound of carbon and some other metallic element.

8. Casing—Iron pipe used to line oil wells.

9. Concretionary Nodule—Small, round grain resulting from the action of small organism.

10. Distillation—Extraction by vaporization and condensation.


12. Dome—A rock strata arched in the shape of an inverted saucer.

13. Dry Gas—Natural gas which does not contain gasolene.

14. Fault—Fracture in the earth along which there has been movement.

15. Filtration—To separate solid matter from liquid by a filter.

16. Fluorescence—The power by which some substances, when illuminated, give off light differing from their own.

17. Fractionation—Dividing by mechanical or physical means.


20. Inorganic—Devoid of organized physical structure.


22. Limestones—Rocks of marine origin, composed of the calcareous remains of deep sea life.

23. Migratory—Roving.

24. Natural Gas—Inflamable gas found in the earth in commercial quantities.

25. Organic—Pertaining to organisms.

26. Reflected Light—Light which is reflected from a substance.

27. Saline—Salty.

28. Sandstones—Rocks consisting chiefly of particles of quartz, sand, cemented with silica.

29. Sediments—Settled matter.
31. Shale—A sedimentary rock resulting from clay.
32. Stratigraphy—A description of the earth’s rock formation.
33. Symmetrical—See Fig. III., IV. and VII.
34. Syncline—A bend with the concave side up.
35. Vapor—Gaseous state of a liquid.
36. Viscous— Thick, sticky nature.
37. Volatile—Evaporating rapidly when exposed to the air.
38. Wet Gas—Natural gas containing gasoline.
STATE OF ARIZONA,
COUNTRY OF PINA—ss:

Before me, a Notary Public in and for the State and County aforesaid, personally appeared Charles F. Willis, who, having been duly sworn according to law, deposes and says that he is the Director of the University of Arizona Bulletin and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily paper, the circulation), etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, embodied in Section 433, Postal Laws and Regulations, printed on the reverse side of this form, to wit:

1. That the names and addresses of the publisher, editor, managing editor, and business managers are:

   Name Of- Postoffice Address
   Publisher—University of Arizona Tucson, Arizona
   Editor—Charles F. Willis Tucson, Arizona
   Managing Editor—None
   Business Manager—None

2. That the owners are: (Give names and addresses of individual owners, or, if a corporation, give its name and the names and addresses of stockholders owning or holding 1 per cent or more of the total amount of stock.)

   University of Arizona

3. That the known bondholders, mortgagees, and other security holders owning or holding 1 per cent or more of the total amount of bonds, mortgages, or other securities are: (If there are none, so state.)

   None.

4. That the two paragraphs next above, giving the names of the owners stockholders, and security holders, if any, contain not only the list of stockholders and security holders as they appear upon the books of the company but also, in cases where the stockholder or security holder appears upon the books of the company as trustee or in any other fiduciary relation, the name of the person or corporation for whom such trustee is acting, is given; and also that the said two paragraphs contain statements embracing affiant's full knowledge and belief as to the circumstances and conditions under which stockholders and security holders who do not appear upon the books of the company as trustees, hold stock and securities in a capacity other than that of a bona fide owner; and this affiant has no reason to believe that any other person, association, or corporation has any interest direct or indirect in the said stock, bonds, or other securities than as so stated by him.

5. That the average number of copies of each issue of this publication sold or distributed, through the mails or otherwise to paid subscribers during the six months preceding the date shown above is: ———. (This information is required from daily publications only.)

   CHARLES F. WILLIS,
   Sworn to and subscribed before me this 5th day of October, 1917.
   THOS. R. BLAIR,
   (My commission expires 1-28-19.)