THE ANTICLINAL THEORY OF OIL AND GAS.

by

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A thesis submitted to the Department of Geology
and the Faculty of the Graduate School in
partial fulfillment of the require-
ments for the Master's degree.

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May 22nd, 1915.

C O N T E N T S.

C O N T E N T S. Cont'd.

INTRODUCTION.

Ever since Col. Drake drilled the first well for oil in 1859, people have been trying to find oil. The first petroleum seekers assumed that oil and gas could be found at one point as well as another, provided the drill went down far enough. It has taken years of explorations and hundreds of thousands of dollars wasted in drilling dry holes to convince people of this fallacy. About 1883, investigations were begun with the special object of determining whether or not it was possible to predict the presence or absence of oil or gas from geological structure. Many theories as to the influence of such geological disturbances, as have occurred in the oil producing territories, were propounded and some of them have been maintained to the present day. First in importance among these is the "Anticlinal theory" which takes account of the low arches or folds which are found in many parts of the oil producing districts.

CONDITIONS NECESSARY
for an
ACCUMULATION OF OIL AND GAS.

Oil and gas are found associated with almost all kinds of rocks, from the oldest to the youngest. While they are widely distributed they are usually in small quantities, and accumulations sufficiently large to be of economic importance are restricted to a relatively small part of the earth's surface.

There are three elements essential to oil and gas production. Source, reservoir and cover.

The Source.

This is the fundamental element, but since in oil districts the sources of petroleum are so nearly universal, less importance is attached to it than to the other two. Whenever there are heavy deposits of sedimentary rocks, the beds generally contain organic material, either animal or vegetable, from which an abundant supply of hydrocarbons might be derived. At some time in the history of these beds conditions have generally been favorable for its conversion into petroleum.

The Reservoir Rock.

Rocks of various grain can be made to receive and retain these accumulations. All rocks which make up the earth's surface are to some extent porous. This porosity, the vacant space between the rock particles, varies from less than one half of 1 per cent, in rocks like granite, to 8 or 10 per cent in ordinary compact fine grained sandstones, and 25 per cent or even more in coarse gravel or cavernous limestone and dolomite. The porosity of a rock depends upon the shape of grains, their uniformity in size and the amount of cementing material. When the rock is a firm, fine grained sandstone, it yields its oil slowly, even when under great pressure and the yield continues for a long time. A cavernous dolomite offers little resistance to the passage of oil toward the well and the flow is consequently rapid and short lived.

The Impervious Cover.

There can be no large accumulation of oil or gas without an impervious roof. Where the rocks are saturated with water the oil or gas would be forced to the surface unless stopped by some impervious barrier.

Such impervious strata usually consist of clay, shale or dense limestone. In many districts the other two conditions (that is, source and reservoir) are so uniform that interest centers more in the roof shales and cover than in any other part of the system.

Thus it appears that the composition and order of arrangement of a series of strata have a vitally important relation to the accumulation of oil and gas. Some geologists count the composition of the series the main thing of importance. They regard the grain and thickness of the oil sand, accounting largely for the difference in production of different fields, or of different parts of the same field, by the character of the oil sand and the cover.

Structure.

Others have urged the importance of another element - a distrubance in the strata, especially in gas accumulation.

Statement of Anticlinal Theory.-

The sedimentary strata were deposited under water horizontally, and the distillation of oil probably took place when the beds were in that position. Subsequent disturbances took place causing the strata to be folded. When these undulations were formed the water, oil and gas within the porous stratum would tend to move and arrange themselves in the order of their specific gravities according to the laws of gravitation. Since the water was the heaviest of the three fluids, it sought the lowest places or synclines as far as possible, depending, of course, on the porosity of the reservoir. Its tendency was to displace the oil and gas, forcing the oil to float on the water and the gas to rise still higher. The oil was able to rise as far as the water extended up the slope of the syncline, while the gas was able to free itself and rise to the highest place in the porous bed.

Often there are minor irregularities on the anticlines and synclines themselves. Sometimes the surface of the oil sand is undulating; often there is a variation in the porosity of the sands. These two conditions greatly effect the distribution of oil and gas. Either one might explain, locally, the presence of dry holes within a productive territory. When the direction of an anticline coincides with the direction of an old ocean beach along which clean, porous sand has accumulated, we have the best possible condition for the formation of an oil and gas pool.

Another type of geological structure in which an accumulation often occurs is the "terrace". The terrace is an interruption in the uniform dip of strata where the rocks are approximately horizontal. The water of the reservoir causes the oil to rise to the terrace where it may be "trapped" by friction. The gas frees itself from the oil and accumulates in the terrace head or continues up the general dip to the anticline or to some impervious barrier.

CIRCULATION OF OIL AND GAS.

An important question to be considered is whether the oil and gas have originated in or near the rocks in which they are found or whether they have migrated into them from other rocks at a greater or less distance. Most geologists believe that the oil and gas have originated in shales either above or below the porous layers that act as the reservoirs.

Most oil sands contain very little vegetable matter. On the other hand, shales show an abumdance of vegetable matter. Newberry states that as much as 20 gallons of petroleum to the ton have been distilled from certain shales in Ohio. These conditions would lead us to conclude that carbonaceous shales are the sources of oil and gas; that these hydrocarbons are not indigenous in the present producing strata but have migrated a greater or less distance from their source or origin. If the anticlinal theory is correct there must have been a movement resulting in concentration of the oil. The circulation is accomplished by (1) capillarity (2) gravity and (3) gas or rock pressure.

Capillarity.

Shales and sandstones are porous formations containing infinite numbers of minute spaces capable of holding liquid. The spaces are like capillary tubes and promote capillary action. There are 3 kinds of openings: openings larger than those of capillary size, or super-capillary openings ~~and~~ capillary openings and openings smaller than those of capillary size, or sub-capillary openings.

Super-capillary openings are found in bedding or joint planes, in coarse sandstones, gravels and in conglomerates. In these openings the flow of liquids is controlled by the ordinary laws of hydrokinetics, modified by the viscosity of the fluid and the regularity, size, and length of the openings. Capillary openings include the great majority of the openings between the grains of sand and sandstones and many of the openings caused by fracture. In these openings the velocity of flow depends upon the area and cross section of the opening, its length and the viscosity of the fluid. The movement is so slow that the friction of the moving fluid over the stationary film is very small. Sub-capillary openings include nearly all the openings between the grains of clays, shales, and slates. The movement of fluid in these openings is very slow. Under the hydrostatic pressure generally occurring in these strata, the movement will be reduced to such an extent that the fluid may be considered as (existing in) fixed films held by molecular attraction.

Capillary action is the physical phenomenon consequent upon the attraction or repulsion of liquid along sides of very fine passages. Thus capillarity has been effective in the expulsion of water and oil from the shales into the sands. The action may have been aided by compressions of the strata until the shales had given up most of their oil to the adjoining sandstones.

Gravity.

The relation of specific gravity of oil and water caused the oil to rise to the top of the water in the sandstones. The distribution of petroleum is greatly influenced by the presence of water. Oil is lighter than water. If both are present the oil rests upon the water, its position being controlled by the amount of water present. If no water is present the oil, due to the force of gravity, rests at the bottom of the porous layer upon the impervious one.

No doubt the presence or absence of water in the oil bearing sand is a very important factor in the concentration of oil in raised structures. Mr. W. T. Griswold, from observations in the Appalachian region, reaches the following conclusions: *(See next page)

"In dry rocks the principal points of accummulation of oil will be at or near the bottom of the syncline or at the lowest point where the slope of the rock is not sufficient to overcome the friction, such as structural terraces or benches. In porous rocks, completely saturated, the accumulation of both oil and gas will be in the anticlines or along level portions of the structure. Where the area of porous rock is limited, the accumulation will occur at the highest point in the porous stratum, and where areas of impervious rocks exist in a generally porous stratum the accumulation will take place below the impervious stop, which is really the top limit of the porous rock. In porous rocks that are only partly filled with water the oil accumulates at the upper limit of the saturated area. This limit of saturation traces a level line around the sides of each structural basin, but the height of this line may vary greatly in adjacent basins and in different sands of the same basin."

"Partial saturation is the condition most generally found, in which case accumulations of oil may occur anywhere with reference to the geological structure. It is most likely, however, to occur upon terraces or levels, as these places are favorable to accumulation in both dry and saturated rocks."

"Under all conditions the most probable locations for the accumulation of gas are on the crests of anticlines. Small folds along the side of a syncline may hold a supply of gas or the rocks may be so dense that

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* Bull. U. S. G. S. No.318,p.15.

the gas may not travel to the anticline but will remain in volume close to the oil."

These theories seem to be applicable to most oil fields.

Gas Pressure.

A third cause for the circulation of oil from its source to its present position is gas pressure or "rock pressure". This pressure is always noticeable when a new well is opened up. If gas is present it is under a certain pressure. Oil generally rises far up into the casing of the new well and sometimes spouts from its mouth. This pressure may accumulate instantly, indicating a very porous reservoir underneath, or it may take time to gather, thus showing a less porous one. It is thought that gas pressure helps to cause movement of oil through the containing rocks.

M. J. Munn offers the following suggestion to account for the transference of oil from shales to porous sandstones:*

"The writer suspects that movement of oil from the mud and shales to sandstones will be considered due principally to currents of moving water upward

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* Munn, M.J. Geol.Survey of Penn. No.1 of the Sewickley quadrangle (1910) page 131.

from the forming shales by differential compression of the shales and the overlying sands, as succeeding strata were laid down on the sea bottom."

Effect of Circulation.

Many investigations have been carried on in an effort to find the cause of the difference between such oils as those of Pennsylvania and those of the Trenton limestone. The Pennsylvanian oils are found to contain a larger portion of paraffin hydrocarbons and less benzine, unsaturated hydrocarbons, sulphur and nitrogen than the oils from Ohio or California. It is generally concluded that the Pennsylvania oils were migratory because the sands in which they are found bear little evidence of containing a source for the petroleum, while the oils of Ohio, etc, are thought to have originated in or near the limestone beds in which they are found. It seems that petroleum is everywhere the same substance except for the absence of certain hydrocarbons and the difference in the result of migration through filtrating materials. Dr. D. T. Day found that oil such as Pennsylvania oil could be produced from crude Trenton limestone oil. Glass tubes packed with dry Fullers earth were placed in vessels containing the crude oil. The oil began to move upward in the tubes by force of capillarity. Examination showed that light oils were found at the top and low grade heavy oils, sulphur and other heavy constituents at the bottom of the tube. Continued filtrations of the oil removed the sulphur compounds entirely.

GAS AS A LIQUID.

Some have made the assertion that gas exists under ground as a liquid, this accounting for the enormous amount of gas obtained, apparently, from a small area. The anticlinal theory would suffer if it were found that gas exists as a liquid. The difference in specific gravity between it and water is so small that it might not be sufficient to force the liquid hydrocarbon to the top and therefore into the anticlinal area.

Since the gas reservoirs are nearly horizontal rocks, the gas pressure must be less than the weight of these overlying layers; for whenever this pressure becomes greater, it would raise the rocks into a dome thus opening joints and fissures through which the gas would escape to the surface. An average of these rocks weigh, say 144 pounds per cubic foot, that is, one pound pressure per square inch for every foot in depth. At a depth of 1500 feet the weight, therefore the maximum gas pressure, would be 1500 pounds or 100 atmospheres.

Hydrogen and nitrogen require enormous pressures to be liquidfied. Ethane and Propane are in such small quantities that they need not be considered. The great bulk consists of Methane (Marsh Gas) which is the most easily liquidfied of these. According to Dewar* at 11° C, 180 atmospheres is required, the pressure increasing rapidly as the temperature is raised. The temperature of water and oil brought up from below demonstrate that temperature increases with depth and at 1500 feet is not less that 60° F. The pressure necessary to liquidfy marsh gas at this temperature is not known, but very great pressures (several hundred atmospheres) have been found insufficient.

Hence, it appears that a pressure very much more than the maximum possible pressure would be required to liquidfy this gas and therefore it must remain in the rocks as a gas.

Others have tried to explain the fact that an enormous amount of gas is obtained apparently from a

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* London, Edinburgh and Dublin Phil. Magazine 1884, p.214.

small area by claiming that the manufacture of gas is constantly going on underneath the gas sand. This idea is entertained by very few who are familiar with oil and gas wells. The limited life of many gas wells as producers is enough evidence to prove that the natural production underground can only be a fraction of the rate of consumption.

Professor Lesley maintains that water, gas and oil existing underground at enormous pressures will not separate but that the gas will exist in solution "mixed" like carbonic acid gas in a soda water fountain. If this theory is true it is fatal to the anticlinal theory.

Marsh gas is soluble in water to about 5 per cent at normal pressure, that is, it takes 20 volumes of water to dissolve one volume of marsh gas. The solubility of marsh gas in salt water is not known but may be still less. If 20 cubic feet of water absorb one cubic foot at normal pressure, then according to Henrys law, at 10 atmospheres pressure,10 cubic feet will be absorbed or 50 percent, at 30 atmospheres 30 cubic feet or 150 percent. It is easy to see that from an economic standpoint the amount of gas held by water is small and that a well would produce one, two or at most three feet of gas for every one of water, if the amount of gas mixed with water were its only supply. It appears that under all ordinary conditions the great bulk of gas will separate from the water and rise to the higher portions of the rock.

It is probable that a separation of oil and gas is not so easily accomplished and will not occur so readily in a country where the dip is very slight. Of course oil will rise to the upper and water sink to the lower layers of the rock, but it seems questionable whether the water will always flow down a very gentle dip - say 10 feet per mile and the oil rise along such a dip if the pores of the rock are very small.

THE BELT LINE THEORY.

Mr. C. D. Angel, one of the most successful oil operators in the early history of petroleum mining deduced a theory in 1867 accounting for the existence of oil in definite areas. This was known as the belt theory and maintained that oil would always be found along lines having a definite direction. It has been proven that within individual oil pools the most productive wells have been located along a certain line. Mr. H. M. Chance in writing on the anticlinal theory of natural gas, says: *

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* The anticlinal theory of Natural Gas. H.M.Chance. T.A.I.M.E. Vol. XV. p.3.

"By judiciously combining the anticlinal and belt line theories it seems probable that the chances of locating a good field in advance would be considerably increased. It is possible for a geologist to trace out an anticline with a fair degree of accuracy; but in determining the trend of porous streaks or belts he must rely upon the records of the wells already drilled. The most promising locality no doubt will be where one of the belt lines crosses an anticlinal axis."

Mr. Chance also states that he considers the "belt line" theory a more valuable one than the anticlinal theory. His reasoning is, that a necessary prerequisite to the existence of oil and gas is an area of porous rock and these porous belts, pools and streaks can be more easily discovered by tracing them from point to point than by boring for them haphazardly along an anticlinal axis.

EARLIER STATEMENTS OF THE ANTICLINAL THEORY.

Dr. T. Sterry Hunt, a canadian geolcgist, was probably the first to recognize the principals involved in the anticlinal theory, having published a paper on the subject in the Canadian Naturalist as early as 1859 and another in the American Journal of

Science and Arts for March 1863. He maintained that the petroleum supply of western Ontario was all derived from the line of a low and broad anticline which runs through the district in a nearly east and west direction. He distinctly states that the anticlinal structure is a necessary condition for a large production of petroleum and its accumulation in these anticlines was due to hydrostatic laws.

Professor E. B. Andrews of Marietta, Ohio, seems to have reached the same conclusions independently of Dr. Hunt. His article "The Oil Break", published in the American Journal of Science, May 1861, emphasizes the influence of anticlinal folds on the occurrence of oil and gas.

An uplift in the neighborhood of Burning Springs, West Virginia, (now called the White Oaks Anticline) is "Both considerable and conspicuous", and the productive oil wells, out of the great number of wells drilled in this region, were found to be confined to the region of this anticline. The discovery of the relation of the anticline to oil production seems to have been made by General A. J. Warner, associated with Professor Andrews in 1865. Besides this, Professor Andrews considered necessary a large number of crevices or fissures in the rocks from which the oil was derived. He also said that gravity separated the water, oil and gas and arranged them in the order of their densities.

This clew, given by Professor Andrews, to the location of successful wells was promptly followed up. The anticline was traced and mapped through its entire course and wells were drilled at many places. A large number of these proved to be failures. Mr. F. W. Minshall of Parkersburgh, West Virginia undertook sometime later to account for these failures. He found that instead of dipping regularly and uniformly the axis had domes in some places and sinks in others. All of the productive oil and gas wells had been located on the domes and the failures in the depressions.

Professor H. Hoefer, a geologist of Teoben, Austria, after studying the Pennsylvania oil fields in 1876, published in his book "The Petroleum Industry of North America" the elements of the anticlinal theory. He reached these conclusions without any knowledge of the previous publications of Hunt and Andrews.

Dr. Newberry's writings are in harmony with the anticlinal theory but his statements are less explicit than many writers on the anticlinal theory who followed him. In the geological survey of Ohio, speaking of Pennsylvania oil fields, he says:*

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*Geological Survey of Ohio, Vol.I.

"These strata have all felt the disturbing influence of the forces which raised the Allegheny Mountains. Here, then, we have a peculiar geological substructure, such as is especially favorable to the production and accumulation of petroleum, and such as must be more or less perfectly paralleled elsewhere to make productive, or at least flowing wells, possible. This structure consists of a great mass of carbonaceous matter below, more or less disturbed and loosened, from which the oil is supplied in a constant and relatively copious flow; above this, strata of porous, jointed sandstone, serving as reservoirs where the constant production of oil and gas may accumulate for ages; still higher, argillaceous strata, impervious in their texture and not capable of being opened by fissures, forming a tight cover which prevents their escape."

"The facts I have observed lead me to conclude that the distrubed condition of the strata in certain districts east of Ohio is the cause of the phenomena which they present. Where the oil and gas producing rocks and those overlying them are solid and compact . . . . the escape of the resulting hydrocarbons is almost impossible. Where they are more or less shaken up . . .

reservoirs are opened to receive the oil and gas, and fissures are produced which serve for their escape to the surface. Near the Alleghenies all the rocky strata are more or less disturbed, and here along certain lines the liquid and gaseous hydrocarbons are evolved in enormous quantities. As we come westward, however, we find the rocks more undisturbed and the escape of oil and gas, through natural or artificial orifices, gradually diminished."

Others also advocated this theory as early as the 70's. Even though this theory had long been known and its essential elements published it seems that up to this time the practical oil men were in ignorance of it or at least paid no attention to it. It was the work of I. C. White to apply the principles of this theory practically in the location and discovery of new oil and gas fields.

I. C. White was aided by a suggestion from Mr. William A. Earsenian, an oil operator of many years experience, who had noticed that the principal gas wells then (1883) known in western Pennsylvania were situated close to where anticlinal axes were drawn on the geological maps. From this he inferred that there must be some connection between gas wells and anticlines.

Mr. White says:*

"After visiting all the great gas fields that had been struck in western Pennsylvania and west Virginia, and carefully examining the geological surroundings of each, I found that every one of them was situated either directly on or near the crown of an anticlinal axis., While wells that had been bored in the syhclines on either side furnished little or no gas, but in many cases large quantities of salt water. Further observation showed that the gas wells were confined to a narrow belt only one fourth of a mile wide, along the crests of the anticlinal folds. These facts seem to connect gas territory unmistakably with the disturbance in the rocks caused by their upheaval into arches, but the crucial test was yet to be made in the actual location of good gas territory on this theory. During the last two years I have submitted it to all manner of tests, both in locating and condemning gas territory, and the general result has been to confirm the anticlinal theory beyond a reasonable doubt."

"But while we can state with confidence that all great gas wells on the anticlinal axes, the converse of this is not true, viz., that great gas wells may be found on all anticlines. In a theory of this kind the limitations

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* Science. Vol. 5, p.521.

become quite as important as, or even more so than, the theory itself: and hence I have given considerable thought to this side of the question, having formulated them into three or four general rules (which include practically all the limitations known by me up to the present time that should be placed on the statement that large gas wells may be obtained on anticlinal folds) as follows:

(a) The arch in the rocks must be one of considerable magnitude; (b) a coarse or porous sandstone of considerable thickness, or, if a fine grained rock, one that would have extensive fissures, and thus in either case rendered capable of acting as a reservoir for the gas, must underlie the surface at a depth of several hundred feet (five hundred to two thousand five hundred); (c) probably very few or none of the grand arches along mountain ranges will be found holding gas in large quantity, since in such cases the disturbance of the stratification has been so profound that all the natural gas generated in the past would long ago have escaped into the air through fissures that transverse all the beds. Another limitation might possibly be added which would confine the area where great gas flows may be obtained to those underlaid by a considerable thickness of bituminous shale."

"Very fair gas wells may also be obtained for a considerable distance down the slope from the crest of the anticlinals, provided the dip be sufficiently rapid, and especially if it be irregular or interrupted with slight crumples, and even in the regions where there are no well marked anticlines, if the dip be somewhat rapid and irregular, rather large wells may occasionally be found, if all other conditions are favorable."

Mr. C. H. Ashburner takes exception to some of these statements. He says:*

"Professor White's theory that all great gas wells are found on anticlinal axes cannot be accepted until he shall limit, by definition, all great gas wells to exclude all gas wells, both large and small, comparatively, which produce gas from strata not found either on anticlinal axes or in close proximity to such structural lines. The Kane gas wells, the Ridgeway well, the "Old Mullin Snorter", and several Bolivar wells are notable instances among many which might be mentioned where large gas wells have been drilled in or near the center of synclines."

"Although it is a fact that many of our largest Penn-

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*Science. Vol. 6. 1885.

sylvania gas wells are located near anticlinal axes, yet the position in which gas may be found and the amount to be obtained depend upon (a) the porosity and homogeneousness of the sandstone which serves as a reservoir to hold the gas; (b) the extent to which the strata above or below the gas sand are cracked; (c) the dip of the gas sand and the position of the anticlines and synclines; (d) the relative positions of water, oil and gas contained in the sand; and (e) the pressure under which the gas exists before being tapped by wells."

Professor White answers these criticisms by saying that subordinate anticlines often run along the central line of synclines and that when gas is found in synclines it is at these points and that when found here it is seldom free from salt water, by which it is likely to be soon overpowered. He also states that all the successful gas companies in western Pennsylvania and West Virginia are getting their gas from anticlinal ridges and that those who have confined their operations to synclines have uniformly met with financial failure.

Mr. Ashburner, later on, states his views concerning the anticlinal theory.*

"Although the dip of the gas sand and the position of the anticlines and synclines have an important bearing upon the occurrence of gas, (in many cases this would seem the most important consideration), yet it is not believed that wells can be located on what has been formulated as "the anticlinal theory", since all great wells are not found allong anticlinal axes, although some of the largest and most important wells in Pennsylvania have been found in such positions. A great many wells have been drilled in synclines which have found gas. Many important wells have been located where the strata is nearly horizontal."

"A careful study of these facts makes it apparent that under special conditions the anticlinal theory alone may account for the existence of gas; but when, however, it is known that large gas wells have been found in synclines, under conditions differing from those prevailing in the vicinity of gas wells on anticlines, it is quite certain that the occurrence of natural gas in the Pennsylvania and New York regions cannot be explained but by a

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* T. A. I. M. E. Vol. XIV, p. 428.

careful consideration of all the geological and physical conditions under which it is procured."

Pronounced anticlines are of infrequent occurrence in Ohio. A few of the low arches of western Pennsylvania extend across the border but they soon flatten out and disappear. In Indiana there is no movement of the crust that deserves to be called an anticline.

Edward Orton is a thorough believer in the anticlinal theory - In his "The Trenton Limestone in Ohio and Indiana" he says:*

"Although distinct arches are for the most part wanting in Ohio geology, there is another sort of structural deformation found here which is connected in a direct way with the oil and gas of eastern Ohio. The structure referred to is associated with the arrest or suppression of the prevailing dip of the rocks for a given space and the establishment of a terrace or level bench in its place. If the series has lain level instead of being inclined at a slight angle, the movement to which the present terrace is due would have resulted in a low arch, but the uplifting forces were too feeble to do more than counteract for a short space the normal dip by which the entire series is affected."

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* Eighth Annual Report U.S.G.S. Part II.

"In the Macksburgh oil field of southern Ohio, the series dips gently to the southeast at the rate of twenty to thirty feet to the mile but it suddenly ceases its descent and for about three miles there is no appreciable fall. The amount of territory included in the terrace appears to be fifteen to twenty square miles. Beyond this the regular dip is resumed."

"In the 1500 feet of rock which composes the section that the wells here penetrate, there are not less than five distinct oil sands. Each one of these is productive of oil upon the terrace and of gas upon the upper margin of the terrace. The petroleum contained in the different sandstones varies in gravity, color and in chemical properties from sand to sand. That five sand rocks, distributed through 1,500 feet of stratified deposits, should each happen to secure the right grain and composition to make them repositories of oil within exactly the same geographical limits is, of course, incredible."

"There is but one explanation to the facts here given. The accumulation of oil and gas is due to the structure, or, in other words, to the arrangement of the rocks concerned. The facts in Ohio point to the conclusion that all other conditions for oil production are met with much more frequently than the structural conditions required. The source of gas is found in the universal sheet of shale that underlies the state. A reservoir is furnished by the Berea grit almost as wide in extent. The Cuyahoga shale has everywhere the essential conditions for a roof or cover of the oil sand. But all of these are powerless to produce an oil field until the right inclination is given to the series."

"So far as examination has gone, every one of the oil and gas fields of Ohio betrays structural irregularity, and most of them point to the terrace-like structure already desdribed. The drift deposits of north-western Ohio are so thick and so continuous that it is impossible to determine the dip of the underlying strata by natural outcrops. It has been a great surprise to find from the well records that the strata are dipping at some points at the rate of six hundred feet to the mile. It is in Findlay that the most marked disturbance occurs and the great supplies of gas that are found there appear to be closely connected with this disturbance. The largest gas wells are located near the edge of the steep descent, while others which are situated on the slopes yield both oil and gas. The wells at the bottom of the slope have yielded thus far oil alone or oil and salt water."

"The Indiana gas field has a remarkably regular and uniform structure, but it will be shown in the account of this field that its gas production is entirely controlled by its structure."

THE APPLICATION OF THE THEORY
in
PENNSYLVANIA.

Frederick G. Clapp says, in writing of the Pennsylvanian petroleum and natural gas:*

"The gas fields occur generally on anticlines; the oil fields part way down the slope if water is present, in the bottom of the syncline if water is absent. To take the Pennsylvania and northern West Virginia fields as a group, the evidence at present seems to warrant the following generalizations regarding structural distribution:

(1). When not effected by other conditions accumulations of oil and gas show a definite relation to the structure of the region.

(2). The greatest elongation of the pools is generally in a direction approximately parallel with the axes of the folds.

(3). When both oil and gas occur they are distributed according to their densities, the oil in the lower and the gas in the higher portion of a stratum.

(4). When salt water is present oil may occur in that portion of the stratum lying directly above the water level.

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*Bull. U. S. G. S. No. 300.

(5). Oil may occur on the crests of anticlinal folds below water level.

(6). When salt water is absent the occurrence of oil is more irregular and more effected by other conditions; may occur along the synclinal axes or at many points scattered along the slope.

(7). Oil may occur on a structural slope at points where the dip changes from gentle to steep.

(8). Gas occurs most commonly on the higher portions of the anticlinal above the upper level of the oil.

(9). Gas also occurs in widely scattered localities, owing to small local folds or changes in porosity."

"Structure is not the only condition determining the occurrence of gas and oil. The structure may be favorable yet neither oil or gas occur. The chief condition other than these given above is the existence of rock of such character as to act as a reservoir."

Ohio.

J. D. Bownocker in writing of the anticlinal theory in Ohio says:*

"This theory has been generally accepted by geologists and almost equally so by laymen. In many

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* Petroleum and Natural Gas of Ohio. 1903.

cases important reservoirs have been located by applying the principal, thus in eastern Ohio Orton predicted the presence of oil in the Moore's Junction field west of Marietta, and correctly located the Snyder and Bricker pools in Harrison county. White has been still more successful in West Virginia and Pennsylvania. Among other pools in eastern Ohio that have been demonstrated to lie on anticlines may be mentioned Macksburg, Cow Run, Newell's Run and Sisterville. In the northwestern part of the state the rocks form a broad arch, dipping to the northwest on one side and to the southeast on the other. This is readily sean by examining a geological map. The arch contains minor irregularities such as the wellknown Findlay break described by Orton. It was on or near this break that many of the largest gas wells were found, and in general it may be stated that the richest oil territory has been found where the Trenton rock lies highest."

"It cannot be said that all oil or gas fields in Ohio are associated with anticlines or terraces. Thus the great gas fields of Sugar Grove, the oil fields at Chester Hill, Corning, Scio and several smaller reservoirs have not as yet been demonstrated to lie on these structures. However, the reverse has not been conclusively demonstrated and the fields in question may yet fall in with the anticlinal or terrace theory."

Illinois.

In writing of the structural relations of the Illinois oil fields, Raymond S. Blackley says:*

"The work is based upon elevations and records of 5,200 wells. The method of study is to make structural contours of each producing sand. From the undulations on the surface of the sands and from the initial production of the wells, the oil, gas and water relations to the structure are observed. In addition cross sections are made which reveal the vertical amplitude of the arches. From all the data obtained it is clear that the LaSalle anticline is the controlling feature of the field."

"The greater part of Illinois lies within the eastern interior coal basin, which is, broadly speaking, an extensive spoon-shaped basin with its axis extending along a line, through Cerro Gordo, Fovington and Olney and into the deepest part in Wayne, Hamilton and Edwards counties. The east side of the basin rises into a strong longitudinal fold known as the LaSalle anticline. The ascent is at the average rate of 50 feet per mile but it is more rapid in Lawrence county as shown by contours of the very apex of the anticlinal dome. The basin and lower flanks of the fold are known to yield abundant water

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*Illinois State Geol. Survey. Bull. 22.

in all the sands which are productive in the main fields. The uppermost part of the flanks of the major fold contain abundant oil. The western limits of the field are abrupt and beyond this line the sands are wholly water bearing. Enough data are at hand to conclude that this is a line of water saturation and that above this line and over the fold most of the sands are oil bearing."

"The accumulation of oil and gas in their present position may be looked upon as ideal and is presumably due to the following factors:

1. There is an extensive anticline with a marked basin on at least one side.

2. The depressions on both sides of the fold, showing abundant water, comprise extensive "feeding" areas for the arch.

3. The sands are commonly porous and hence form suitable reservoirs.

4. There are abundant shales and some limestones overlying the sandstones, which serve as impervious covers to the reservoirs.

5. The sands in both limbs of the anticline are abundantly saturated with salt water, which is probably instrumental in holding the oil and gas captive in its present position.

6. Although the general structure of the oil fields is dominated by a major fold its crest is very irregular and is interrupted by numerous minor domes and transverse depressions, which together with irregularities in porosity have been instrumental in segregating the pools.

7. With one exception, the best collection of oil was found over the broad flat areas. The domes over the entire field are logical gas reservoirs but contrary to expectation the largest amounts of gas and oil do not lie at the apexes of the domes but a short distance below."

"There is considerable unevenness of distribution due to the following factors:

1. The sands vary in porosity and in many places are practically impervious to oil.

2. The sands thin and thicken rapidly and in some localities pinch out altogether.

3. The sands are so closely inter-bedded with the shales along the productive zone in some areas as to prohibit extensive collection of oil, gas and water.

4. The best productive areas have 20 to 40 feet of sand and are usually free from large amounts of salt water.

5. Local dry spots in the midst of very productive territory cannot be attributed to small depressions or knolls in the sand bodies, but rather to the non-porosity of the

beds. (Of the 5,150 wells of this district 362 were reported dry or 7 per cent.)"

Kansas.

E. Haworth says in regard to the relation of structure to oil and gas pools in the Mid-continental field:*

"Probably almost no phase of the detailed geology of the mid-continental field is of more practical importance than the one now under discussion. It must be said that in general our Kansas fields contain only very mild structural features. This, in connection with the work of surface erosion, renders it difficult to establish the presence or absence of anticlinal arches. The oil fields and gas fields are scattered here and there with apparent irregularity throughout the territory. We have been unable thus far to connect them with structural conditions to a sufficient extent to justify the general conclusion that structural conditions alone control the presence of oil and gas."

"The comparatively rich oil wells in the Neosho river valley certainly are in a synclinal trough. We must conclude, also, that structural conditions have but little, if anything, to dowwith the great Iola gas field and must look for the explanation of its existence to some other particular geological conditions. It would seem that the

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* The University Geol. Survey of Kansas. Vol.9.

explanation is found, in part at least, in the character of the sand rock 900 feet below the surface rather than in any structural conditions that may have existed. We must conclude, consequently, that no matter how important structural relations may be elsewhere, they are of only moderate importance in Kansas."

Oklahoma.

It seems that below the Kansas line anticlines become more prominent. Practically every important pool in Oklahoma, as far as surveys have been made, is situated on or near a marked anticline.

Frank Buttram says of the remarkable Cushing oil and gas field:*

"A study of the structural map together with the production map and the sections, shows that the fundamental idea of the anticlinal theory holds good in the Cushing field. In the discussion of the different producing horizons it was proven that the gas in general occurs on the axis of the anticline while the oil is usually found along the slopes immediately overlying the salt water. Practically every well that has been drilled in the Cushing field on or near the axis of an anticline has produced large quantities of gas."

Louisiana and Texas.

The saline dome type of structure is typical of most of the fields in Louisiana and Texas - the Caddo

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* Oklahoma Geol. Survey. Bull. No. 18.

field and the fields of north Texas being excepted. The term "dome" refers to the shape of the geological structure. The formations are domed whether the surface is or not; several thousand feet of uplift is not uncommon in an area a mile across. Beneath these domed Cretaceous beds are extensive deposits of rock salt, sulphur and gypsum.

For instance at Spindle Top the rock structure has been figured out very carefully from many well logs and found to have a symetrical dome shape. Sands and gravels are penetrated for several hundred feet, then dolomite is encountered, below which sulphur, gypsum and rock salt are found. These minerals are supposed to have nothing to do with the presence of oil; but the oil has been accumulated from the surrounding strata into the dolomite on account of the upward doming of the sediments. In other words a dome may be considered as an anticline having minimum length.

Oil has been found in greater or less quantities in a great many domes and nowhere else (than in a saline dome) in southern Louisiana and southern Texas. A satisfactory theory as to their origin has not yet been advanced, Although these domes are not strictly comparable with the anticlines of the Appalachian field, they are equally efficient in furnishing the structural conditions favorable for the accumulation of oil.

Application in California.

Mr. G. H. Eldridge says in his resume of the petroleum fields of California:*

"The Coast Range, considered as a topographic province, includes all the mountains lying between the great central valley of California and the Pacific ocean. Structurally the coast range consists of numerous parallel anticlines with their corresponding synclines. There is no dominant axial fold, the crust having been crumpled into a close succession of ridges of varying amplitude and height of arch."

"The productive areas have been in every instance developed in connection with anticlines, either in proximity to their axes, along their flanks or about their terminals. In several instances faults, or intense disturbances of the strata, have accompanied the folding, causing along their lines interstial spaces in which petroleum could accumulate and thus resulting in an increased supply and yield."

Russia.

"On the continent of Europe" according to I. C. White[1], "and in Russia, no other theory has any followers whatever, due largely to the work of Hoefer, Sogren and other geologists. No one can visit Baku, Grosny, Gallicia

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* U. S. G. S. Bull. 213.

[1] West Virginia Geol. Sur. Vol. I.

and other oil fields of the old world and see the great anticlines which accompany every great deposit of petroleum without concluding that rock disturbance is the important factor in such accumulations."

But A. Beebe Thompson (see below)* says that in Russia it is unlikely that an anticline is necessary for the accumulation of petroleum although indirectly it plays the important part of bringing the oil beds to within a workable depth from the surface. Mr. Thompson maintains that Russian oil was produced where it is now found and that it has not migrated from one place to another; that no relation exists between the water level and the level of oil in wells and that the pressures in the oil fields are due to the presence of gas held in solution in a compressed state by the petroleum. The rapidly evolved gas, which follows a relief of pressure, carried with it sand and oil and ejects them in the same manner that the contents of a champagne bottle are expelled on releasing the cork.

However, the productive fields in Russia are all on anticlines. There is no evidence that the synclines are productive.

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* A. Beebe Thompson "The Oil Fields of Russia."

RESUMÉ.

There is an extensive literature on this subject, but when it has all been summarized the resulting information is far from satisfactory. However, writers are generally agreed that:

(1). The source of oil and gas is the organic matter which was deposited in the sedimentary formations.

(2). The manner in which they are formed is commonly stated to be a process of decomposition and distillation.

(3). Their concentration as economic deposits is a result of circulation.

(4). For their existence in economic quantities two conditions are necessary.

a. A porous stratum in which they can accumulate.

b. The presence of an impervious layer over the porous stratum to prevent the escape of the oil and gas.

(5). In their movements they have been influenced chiefly by gravity, temperature and pressure.

(6). Their movements have been principally through capillary openings.

(7). During their movement through the rocks they have been in intimate relation with underground water.

(8). The structure of the rocks has something to do with the accumulation of oil and gas.

The reservoirs are rocks such as sandstones or limestones which have fracture spaces or open texture. The cover is commonly a shale. The favorable structure is an anticline or upward arching of the formation, arrested anticlines and terraces are the less symetrical forms of this structure.

Accumulation within the reservoir proceeds in accordance with hydrostatic laws and the oil and gas arrange themselves in the openings in the rocks in accordance with their specific gravities. Since oil and gas are lighter than water they will be displaced upward thus occupying the highest parts of the pervious stratum.