GEOLOGICAL SURVEY OF KENTUCKY

JOHN R. PROCTER, DIRECTOR.

REPORT

—ON THE—

OCCURRENCE OF PETROLEUM, NATURAL GAS AND ASPHALT ROCK

—IN—

WESTERN KENTUCKY,

BASED ON EXAMINATIONS MADE IN 1888 AND 1889, BY

EDWARD ORTON.

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NOTE.

Since the writing of this report, the "*Kentucky Rock Gas Company*" has changed its *firm* name. It is now known as "The Kentucky Heating and Lighting Gas Company."

LETTER OF TRANSMITTAL.

HON. JOHN R. PROCTER,

State Geologist of Kentucky:

DEAR SIR: I herewith transmit the manuscript of the report which I have prepared under your direction, on the various products of the bituminous series, viz: inflammable gas, petroleum tar springs and asphalt rock, as they occur in the western half of Kentucky. My report is based on a series of examinations made in the field during the summer months of 1888 and 1889. In the course of these examinations I visited every locality in which practical exploration by the drill was, at the time, going forward, and obtained first-hand information, as far as possible, as to the facts upon which I have made report. I also collected the most authentic statements available as to previous experience in the search for petroleum in the districts within which such explorations had gone forward.

As an introduction to the record of these facts of observation, I have given a brief review of the theories as to the origin and accumulation of petroleum and natural gas which command the largest measure of intelligent acceptance at the present time. The remarkable extension of the use of natural gas as fuel, which has been made in a few sections of the country during the last ten years, has awakened a widespread interest in this subject in particular, and questions pertaining to the origin, nature and duration of the supply are sure to be raised in every community that enters upon the search for the new fuel. The doctrines to which I have given prominence in this portion of my report will, if accepted, lead such communities as are fortunate enough to secure a good supply of this best of all forms of stored power which the world contains, to use it from the first with the strictest economy. Under the light of all the experience that is now available, a town that shall hereafter discover gas enough for public utilization ought to receive far more benefit from the discovery than it would have done at an earlier day.

You must permit me to make public acknowledgment of the constant and cordial assistance that I have received from you and from the entire force of your office in every way in which my work could be facilitated.

So uniform was the kindness and courtesy that I met in the prosecution of my inquiries, that it is almost invidious to select the names of any persons for special mention in this connection; but there are a few gentlemen from the districts in which I spent most of my time whose painstaking services I do not feel at liberty to pass by without express acknowledgments. In this list I include Major W. J. Davis, Louisville; Hon. Alonzo Moreman and Judge O. C. Richardson, Brandenburg; James Montgomery, Esq., Elizabethtown; Father J. J. Abell, Colesburg; Hon. David R. Murray and W. H. Bower, Esq., Cloverport; Gen. D. L. Adair, Hawesville; Hon. R. S. Triplett, Owensboro; Col. L. Green, Falls of Rough; Dr. Pinckney Thompson, Henderson; Hon. Geo. Huston, Morganfield; Hon. J. C. Hendrick, Smithland; Col. M. H. Crump, Bowling Green, and W. T. Knott, Esq., Lebanon.

Very respectfully,

EDWARD ORTON.

COLUMBUS, OHIO, April 2, 1891.

CHAPTER I.

THE EARLY HISTORY OF PETROLEUM AND ITS DERIVATIVES.

Petroleum is one of a definitely characterized class of substances which are widely distributed in the rocks of the earth's crust, and which have been known to man from the earliest times of which we have any records. Petroleum, strictly speaking, is to be distinguished on the one hand from the volatile naphtha, and on the other, from the semi-fluid, mineral tar, which is sometimes called maltha, but the boundary lines on both sides are indefinite. Mineral tar passes in turn into mineral pitch, or asphalt, a black or brownish-black solid, which breaks with a conchoidal fracture, and which melts and burns at comparatively low temperatures. The naphtha above referred to gives rise to natural gas in its volatilization; and thus the series, fully expanded, is seen to consist of these five distinct and separable substances, viz: natural gas, naphtha, petroleum, mineral tar, mineral pitch, or asphalt.

The entire group, with the exception of the gaseous form, is known as bitumens. In chemical composition they are all hydro-carbons, belonging principally to the methane, or marsh gas series. Petroleum is seen to arise from naphtha by the escape of its volatile matter and by the subsequent oxidation of the liquid residue. Still further oxidation converts petroleum into mineral tar, and a continuation of the same process gives rise at length to the most permanent form, asphalt. We have no knowledge of any other mode of origin of this last-named substance than that which is here indicated. Such a history would lead us to expect a varied composition in the entire series, and this expectation is fully realized in the results of chemical analysis. Each member of the series contains more or less of those that lie below it in order.

In the earlier history of these bodies, asphalt and mineral tar took the most prominent place. Their occurrence in large quantity in the neighborhood of several ancient centers of civilization, and especially in the valley of the Euphrates, led to their use there on a large scale. Prof. S. F. Peckham, in his article on petroleum and its products, in Vol. X of the Special Reports of the Tenth Census of the United States, gives a number of facts pertaining to their occurrence in these regions.

The accounts in the Book of Genesis of the Deluge of Noah, and of the building of the Tower of Babel, are undoubtedly of a high antiquity. The pitch with which the Ark was to be covered inside and out (Genesis VI, 14) is the mineral tar of the Euphrates Valley. It is used even to this day, as modern travelers inform us, for coating the bottoms of boats in this same region. The slime that is said to have been used for mortar in the construction of the Tower of Babel (Gen., XI:3) is the same substance. So, also, the slime pits of the vale of Siddim (Gen., XIV:10) indicate the locality from which this tar was derived in part. These references to this bituminous series are undoubtedly among the earlier ones that are now accessible to us.

The ancient cities of Ninevah and Babylon, as is well known, made extensive use of mineral pitch and asphalt as a cement for their various structures, after the fashion above referred to in the latter city. Bitumen was also used to some extent as fuel. The fountains of pitch from which the supplies of Babylon were largely derived are still shown in the valley of a small tributary of the Euphrates. These fountains were described by Herodotus, the Father of History, and his mention of this notable source of bitumen constitutes one of the earliest definite and authentic references to this line of substances.

Egypt made considerable use of asphalt in building its permanent structures, and also in the construction of cisterns for water and silos for grain, and in embalming the bodies of the dead. Its supplies are said to have been mainly derived from the deep trough of the Dead Sea, in which the vale of Siddim was also probably located. The ancient name of this body of water was

Lake Asphaltites, and from it the word "asphalt" is derived. The bitumen rises in immense, island-like masses in the sea, notably after earthquake shocks. This fact was noted by Strabo, and has been verified in modern times. The production of the Dead Sea valley is now insignificant, but there is no reason to doubt that in early times there was a considerable amount exported. At various points along the shores of the Mediterranean and on several islands of the sea, other sources of bitumen were found and utilized in early times. Several observant travelers and geographers of the early Roman period make mention of them in records which are still extant.

In China, oil and gas were discovered and utilized to some extent at a very early day, as is attested by records of high antiquity. They were found in connection with the salt production of the interior of the Empire.

The more stable forms of bitumen are not the only ones, however, that were turned to economic account in the ancient world. Petroleum itself was even more highly valued by some nations, because it was so available as a source of light and heat. The Persians, for example, employed it for this purpose on a considerable scale, and in some parts of the Mediterranean region, at the beginning of the Christian era, it was thus used, as Pliny states. Its use has been continued in this district even to our own time, from the first known sources.

From an unknown, but apparently ancient date, Burmah has also made use of petroleum as a source of light on a large scale. The supply of petroleum was derived from the valley of the Irawaddy, where the production is still maintained. The southern end of the Caspian Sea has also been, from a remote antiquity, an extraordinary source of oil and gas. A religious use was long ago found for these escaping products, temples being constructed over some of the natural gas vents, and perpetual fires being thus maintained here. These fire temples became the goals of innumerable pilgrimages from distant regions, and especially from India. The economic application of these extraordinary supplies has been effected first in our own time, and one of the great oil fields of the world, if not the greatest, has been developed here.

The New World has been occupied by civilized man for a comparatively short period, and consequently no very ancient records as to the discovery or use of any of the members of the bituminous series within its limits are to be looked for. The petroleum of Western Pennsylvania appears to have attracted the attention of the first Europeans who traversed the district in which it occurs. Mention of the oil springs of the Allegheny valley goes back as far as 1629, and during the subsequent century there were many observations put on record in various connections as to the occurrence of petroleum in the eastern portion of the United States. When first discovered, it was highly prized as a medicinal agent by the Indians, and its use was soon communicated by them to their white neighbors. The oil springs of Western New York and Pennsylvania were in some cases apparently regarded with religious reverence by the native tribes, and from one or other of the causes above-named, when parting with their lands, they retained reservations in several instances, including the localities of these springs.

Mineral tar and asphalt were also noted and worked to some extent in the West India Islands at a similarly early period. One of the best known of these products is Barbadoes Tar. From the shores and islands of the Gulf of Mexico, our largest supplies of asphalt are still derived.

The South American mainland seems to be deficient in the surface indications of oil and gas. If any records of the occurrence of these substances have been made, they have at least failed to attract general attention.

From this brief review, it is seen that the several members of the bituminous series are not only very widely distributed in nature, but further, that they have long been known to man, and have been variously used and highly valued for several thousands of years.

CHAPTER II.

THE MODERN HISTORY OF PETROLEUM AND ITS DERIVATIVES.

The modern history of petroleum may be taken to begin with the present century. During this time, and especially during the latter half of it, all the great developments and applications of oil and gas have been brought about. In this development and utilization, the United States has taken the leading part. When the history of oil and gas in this country has been duly recorded, very little of importance will remain to be told concerning their modes of occurrence or the means employed in bringing them from their subterranean recesses to the light of day and in rendering them tributary to the service of men. The only great addition has been made within the last dozen years, in the development of the Baku field at the southern end of the Caspian Sea, to which reference has already been made. All this development, however, has followed directly from, and has been wholly based upon, American experience. No new lines of observation have been brought to light by this great production.

The modern history of petroleum begins with the present century. The scene of the history is laid in the upper portion of the Ohio Valley. As had happened in China two thousand years before, the discovery of petroleum in large quantity was here connected with the search for an adequate supply of common salt. The earlier settlers of the Ohio Valley and its tributaries were well assured in almost all respects as to the character of their new home. The soil was exceedingly fertile; the climate was in all respects favorable; against the Indian tribes that they were obliged to displace, they felt abundantly able to maintain themselves. They had established for themselves most of the simpler manufactories essential to an agricultural community, but there were two sources of anxiety that disturbed the minds of these hardy pioneers. The more thoughtful among them entertained grave fears that iron and salt could never be furnished in large enough amount and at low enough price to meet the wants of a large community. The fear in regard to iron was happily dispelled in the earliest years of the century by the establishment of blast furnaces among the Laurel Mountains of Pennsylvania, on the western side of the great divide. But all the salt used in the valley was either brought on the backs of pack horses by steep and narrow bridle paths, across the Allegheny Ridge, or else by flat-boats from the Gulf of Mexico, whose toilsome ascent of the river was never accomplished in less than four months, and which often required six months. The mouth of the river, it will be remembered, was at this time in the possession of a foreign power. From 1792 to 1800, the price of salt in the Ohio Valley ranged between eight and sixteen cents per pound.

As a consequence, all the natural sources of supply in the new territory were looked upon with extreme interest, and were watched with jealous care. Even the Congress of the United States did not deem the brine springs of the Ohio Valley unworthy of its notice, and when, in 1802, a part of the Northwest Territory was erected into the State of Ohio, tracts embracing the principal brine springs then known in this region were reserved to the State as being too valuable to become private property, and thus to lay the foundations of excessive fortunes, and what might become oppressive monopolies. The salt reserves of Ohio, and of the adjacent States as well, all proved worthless. The brine was weak and impure, and only the cheapness of fuel and labor and the high price of salt allowed the manufacture to go on from such sources, for even a few years.

Up to 1806 the rock had never been penetrated to secure a supply of brine in the United States. In other countries rock drilling for salt water had been practiced for long periods. In China, as already noted, deep wells were drilled for brine two thousand years ago; but here, as well as in many other cases, we have been unable to profit by the experience of the world, and have been obliged to work out our own methods and establish our own systems.

The American system of rock drilling, which is incomparably the best that has ever been invented, was originated in the Kanawha Valley, and in connection with the search for an adequate supply of salt. In the year above named, viz: 1806, two brothers, David and Joseph Ruffner, of Charleston, West Virginia, set to work to learn more of the source of the brine that was found in their neighborhood, and, if possible, to obtain a more abundant and stronger supply. In other words, they determined to drill into the rocks for salt water. They were obliged to invent their own tools, and to solve, without previous experience, all the problems involved. For two years they persevered in their search, overcoming, one by one, difficulties which, trifling as they now seem, would have discouraged faint-hearted men, until, on the fifteenth day of January, 1808, at a depth of forty feet in the sandstone rock, they were rewarded by an abundant flow of stronger brine. They had succeeded in their search, and doubtless made more account of the discovery of a better basis for salt manufacture than they did of the means that they had employed in finding it; but in reality the latter was the important feature of this history. The rock drill, where the Ruffner brothers left it, was in appearance an insignificant apparatus. It was simply an iron bar shod with steel, and swung by a rope from a spring pole; but it was now an actual fact, and ready to be acted upon by the process of evolution. The stages of its development followed rapidly. Hand power was soon replaced by horse power, which, in its turn, gave way to steam power. The efficiency of the outfit was greatly reinforced by various ingenious additions that were made by the drillers of the Kanawha Valley. It is here that the "conductor," the "casing," the "jars" and the "seed-bag" were all originated.

Dr. S. P. Hildreth, the pioneer geologist of the upper Ohio Valley, gave a description of the mode of drilling salt wells, in the American Journal of Science, in 1833, which is copied here, for the sake of bringing vividly before the reader the lines of progress in this remarkable art:

"PROCESS PURSUED IN SINKING A SALT WELL.

"The operator having fixed on a spot suitable for the purpose, always near some water-course, and where the adjacent hills are high, proceeds to excavate the earth down to the rock, and then the rock itself to the depth of twenty or thirty feet, and from four to six feet in diameter. In this cavity, called 'the head,' is usually placed a hollow sycamore trunk, called 'a gum,' which is imbedded firmly in the rock, in such a way as to exclude the springs of fresh water; others make use of planks to form the head. When this part of the work is accomplished, the process of boring, or drilling, commences. This was formerly done by hand, with the assistance of a spring pole, and was a tedious and laborious operation. It is now performed by a horse or horses, placed on an inclined tread wheel, and machinery very simply, but ingeniously, arranged, so as to act, by means of a lever, on the poles attached to the auger, raising it from two to three feet, at each rise of the lever, and letting it drop again very regularly. A grass rope, with which the poles are suspended to a high frame, by its spiral convolutions, at each rise and fall gives them a slight rotary motion, so necessary to the progress of the work. Two men are employed in this business, who stand regular tours, of six hours each, night and day. When so much of the rock is chiseled up and comminuted so finely as to make with the water, which always fills the hole, a soft, muddy mass, and impedes the motion of the auger, the poles are withdrawn and a tube made of copper, five or six feet in length and three inches in diameter, called 'the pump,' is screwed to the pole and let down. A valve, at the lower end, prevents the escape of the contents, which are discharged through a hole made for that purpose, near the top.

"A cord or rope is sometimes made use of in this process, in place of the poles. The poles are made of tough, white ash wood, twenty-five feet in length and two inches in diameter. They are attached to each other by strong iron sockets and screws, so as that a screw at the lower end enters into a socket at the upper end of each pole. By the addition of fresh poles, as the well descends, they are lengthened to any desirable depth.

"The auger is pointed with the best cast steel, and is from twelve to fourteen inches in length, and from three to four inches wide, as the operator may think best, it being very useful to have the well of a greater diameter at the top, as it necessarily and unavoidably grows narrower as it descends, and would not afford sufficient water, unless an allowance of this kind were made.

"The operation gradually cuts away the sides of the auger, and as it is repaired or a new one applied, unless this adaptation is carefully attended to, it becomes fast in the bottom of the well, and is with great difficulty removed. The progress made, each day, varies, with the density of the rock, from one inch to five or six feet, but is necessarily slower as the well deepens; for much time is necessarily consumed in taking up and letting down the poles, for the purpose of pumping or clearing out the detritus, which is composed of sand or mud, according to the nature of the rock. It is often necessary to line the upper portion of the well, for one hundred and fifty or two hundred feet, with a copper tube, to prevent the process of caving, occasioned by the disintegration of the soapstone or argillite, which principally composes the upper strata to this depth. It is also sometimes needed to keep out the springs of fresh water, which, mingling with the salt, would occasion additional labor in the evaporation."

For forty years the art was strictly confined to the search for which it was designed, viz: for brine to be used in salt manufacture. A class of men grew up whose sole business it was to drill salt wells, and a great body of practical experience in this art was gradually accumulated.

While sinking these salt wells the drillers were often annoyed by the presence in excessive quantity of two substances which were unfailingly found in the rocks that they penetrated, viz: petroleum and natural gas. The gas in particular would sometimes issue from the wells with uncontrollable violence, and, becoming ignited by accidental means, would destroy the machinery and otherwise interfere with the purpose of the wells. Some wells were found incorrigible in this respect, and were on this account abandoned. Where the gas was found in moderate amount, it came to be used at a comparatively early day for the evaporation of the brine, and probably also on a small scale for illumination. Use was also found for a small quantity of the petroleum that escaped from these wells. Rock oil had indeed been highly valued by the Indian inhabitants of the regions west of the Appalachians before they were occupied at all by the white race, as has been stated on a previous page. The first white hunters and pioneers that entered these regions learned probably from the Indians to place the same estimate on these natural fountains of oil. They came to consider the oil, in fact, a sovereign remedy for nearly all the diseases to which they were especially liable, and particularly for rheumatism, burns, sprains, and even for coughs and colds. It was known as Seneca Oil, from the fact that it was first found near Seneca Lake, New York. For a long while the demand was greater than the supply, so that a small bottle of oil would bring forty or fifty cents; but the drilling of the new salt wells made it much more abundant. In the neighborhoods where the wells were drilled it began to be used as a source of artificial light, being burned in the crude state in the oil lamps of the period. A little improvement was presently made by filtering the oil through charcoal. Its value as a lubricant was also early recognized; but the main use, after all, was as a medicinal agent. Through all these applications the oil became an article of commerce on a small scale.

When, however, as sometimes happened, a large quantity of oil was struck in drilling a well, no efforts were made to arrest the flow, but it was left to find its way into the streams upon which the wells were located, discoloring them often for miles with its iridescent hues. The great Kanawha river acquired, on this account, from the boatmen of the Ohio Valley, the soubriquet of "Old Greasy." One of the most remarkable instances of this sort occurred in Southern Kentucky. A well that was drilled in 1829 at Burkeville gave vent to an enormous flow of oil. The well was estimated by those whom we are obliged to accept as authority to have produced 50,000 barrels, all of which flowed out into the Cumberland river, in the valley of which it was drilled. The surface of the river was covered with oil for many miles, and while in this condition the oil was ignited, and furnished the strange spectacle of a river on fire. Only a few barrels of the oil were saved for commercial purposes. All that was used was put up in small bottles, and sold under the name of American Oil as a medicinal agent.

These descriptions show the general line of facts pertaining to petroleum up to the year 1850. For more than ten years thereafter there was no considerable progress in the demand for rock oil, but lines of investigation were being entered upon about this time in different parts of the world that resulted in an immense advance in the development of the several products of the bituminous series, and in contributions of inestimable value to the well-being of the whole civilized world. Some of the steps of this advance were as follows:

THE PARAFFINE INDUSTRY.

The growing wealth of the world was leading to the demand for new and better sources of artificial light than were generally available. Through the enterprise and energy of New England sailors, whale oil and sperm oil had been widely distributed through the eastern United States and through western Europe as an illuminating agent, for a considerable term of years, but the sharpness of the demand had led to the pushing of the whale fishery to the point of a practical exhaustion of the supply. The consequent diminution in quantity naturally led to a considerable increase in price, and the increase in price encouraged the search for some new source of light.

In 1830, a colorless, wax-like body, burning freely and without odor, and giving rise to an oil of peculiar character, was discovered by a distinguished German chemist in the course of a series of investigations on the products of wood-tar. He named this wax-like substance "paraffine," and as such, it soon became known to the scientific world, but no one suspected that it would ever be found to be widely distributed or to possess economic value. It remained for a score of years as little more than a chemical curiosity. About the year 1850, however, this growing need of a cheaper source of artificial light, to which I have already referred, led Mr. James Young, and others associated with him, after considerable experimenting and considerable increase in knowledge of the facts concerned, to begin the manufacture of paraffine, together with the illuminating oil that is associated with it from the outflow of a weak petroleum spring in Derbyshire, England.

The process was successful, but the amount of crude oil supplied by the spring proved altogether inadequate to the demand,

and in the search for other sources of supply, a rich variety of cannel coal, known in Scotland as the "Boghead mineral," or sometimes as "Torbane mineral," was presently found that gave excellent results. The process was soon found capable of extension to all cannel coals, and also to bituminous shales as well, and an extensive and exceedingly promising industry was speedily developed in Great Britain, and shortly afterwards in the United States. Paraffine oil-works were established at many points in this country, and among others at Cloverport, Kentucky, the manufacture being based in the last-named instance on the neighborhood of the famous Breckinridge cannel coal. On the Atlantic border, the Scotch minerals were imported in a large way for distillation. The American works were all operated under English patents. The latter applied only to the production of paraffine from cannel coal and bituminous shale, although, as already noted, the process was begun on crude oil.

During these same years investigation was going on in several American laboratories as to the possibility of obtaining desirable illuminating oil from the products of the famous oil springs of Western Pennsylvania, and the entire practicability of the operation was thoroughly demonstrated in both a practical and scientific way. The only trouble was found in the short supply of crude oil. Some examinations of the oil from the Pennsylvania field that were made at that time by Prof. Benjamin Silliman, Jr., of New Haven, Connecticut, were especially influential in leading to the next step, the importance of which can scarcely be overstated. That step was to drill a well, the sole object of which was to obtain as large a supply of petroleum as possible. Petroleum had, up to this time, always been a by-product of the oil wells of the Ohio Valley.

The well was located in the valley of Oil Creek, Venango county, Pennsylvania, near the natural oil springs that had been famous for more than a century. Mr. E. L. Drake, known as Col. Drake, was in charge of the work. He struck oil at a depth of 70 feet, and thus opened a new chapter in the history of the stored power of the world. One of the fiercest speculative excitements that has ever swept through the country followed this discovery. It can scarcely be said to have subsided yet.

In drilling this well and those that followed in swift succession, there was no one to compete with the salt well driller of the Ohio Valley. He had learned an art that was henceforth to become one of the most important that men have yet invented for gaining possession of the mineral wealth with which the crust of the earth is stored. The driller's art has been greatly modified, it is true, by the important experience which was entered on at this time; but the change has been in the way of improvement, and not in the way of origination. The drill has grown, in point of fact, from a bar that a child could lift, to a massive shaft fifty feet long and weighing two thousand pounds, which can hew its way down through solid rock at the rate of an inch a minute, or 150 feet in a day; but the elements of its present efficiency were all present and recognized in the earlier time.

In the thirty years that have passed since the drilling of the first oil well in Western Pennsylvania, petroleum has become a factor of great importance in the service and in the commerce of the civilized world.

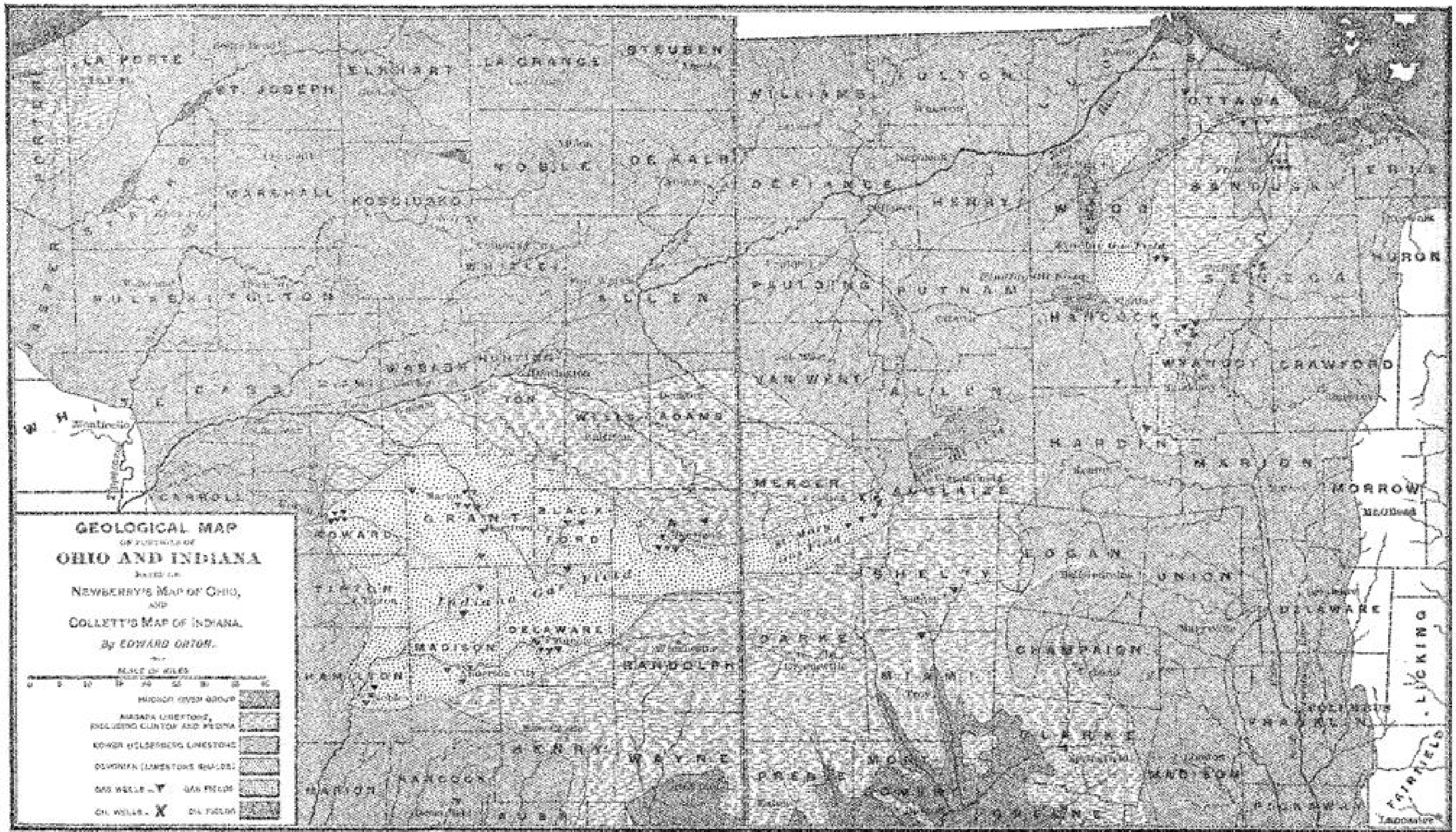
Within this period, according to current statistics, fifty-three thousand wells have been drilled in the two States of Pennsylvania and New York alone, at an estimated cost of two hundred million dollars. These wells have produced more than three hundred million barrels of petroleum, which has been sold at the wells for five hundred million dollars, giving a net profit to producers of three hundred million dollars.

To the other oil fields of the country at large, a production of about fifty million barrels must be credited, making the total yield to 1890, about three hundred and fifty-eight million barrels. In the Washington county (Pennsylvania) field, the last to be developed in this State, more than three million dollars have been already expended in drilling oil wells, and the business has still proved largely remunerative. The annual production of petroleum in the United States for the last ten years has ranged between twenty and thirty million barrels. The illuminating and lubricating oils, the naphtha and the paraffine derived from the crude oil, make an aggregate of many times its value. The amount of oil exported to date is placed at about six hundred and twenty-five billion gallons.

These figures, of course, pass beyond all clear comprehension, but they serve to indicate to a greater or less extent the magnitude of the interest which we are now considering. For a portion of the time in which oil has been a factor in the markets of the country, the price has been subjected to rapid and considerable fluctuations in value, in consequence of which large fortunes have been made and lost in dea' g in it in brief spaces of time. During the last thirty years the average annual price of petroleum has fluctuated between forty-nine cents and twenty dollars per barrel. The latter figure stands, however, for a small production at the very beginning of the recent history, namely, 1859. For portions of the year 1861 the price fell to ten cents per barrel. The next highest annual figure is nine dollars and eighty-seven and one-half cents in 1864. The facts pertaining to these annual values are shown in the appended table:

YEAR.	Average yearly price.	Total annual value of production in greenbacks.
1859	$20 00	$40,000 00
1860	9 60	4,800,000 00
1861	49	1,035,668 41
1862	1 05	3,209,524 50
1863	3 15	8,225,623 35
1864	9 87½	20,896,576 37
1865	6 59	16,459,843 00
1866	3 74	13,455,398 00
1867	2 41	8,066 993 00
1868	3 62½	13,217,174 12
1869	5 63	23,730,450 00
1870	3 89¾	20,503,758 64
1871	4 34	22,591,179 94
1872	3 64	21,440,502 72
1873	1 83	18,100,464 12
1874	1 17	12,647,526 84
1875	1 35	12,133,133 10
1876	2 56¼	22,982,821 62
1877	2 42	31,788,323 82
1878	1 19	18,044,519 78
1879	85⅞	16,953,151 38
1880	94½	24,600,637 84
Total	. . . .	$324,920,265 55

It is necessary to give these values in greenbacks rather than in gold, for the reason that an important part of the development was going forward at a time when the national currency was largely inflated.


GEOLOGICAL MAP
OHIO AND INDIANA
NEWBERRY'S MAP OF OHIO,
AND
COLLETT'S MAP OF INDIANA.
By EDWARD ORTON.
SCALE OF MILES
HUDSON RIVER GROUP
NIAGARA LIMESTONE, INCLUDING CLINTON AND MEDINA
LOWER HELDERBERG LIMESTONE
DEVONIAN (LIMESTONE SHALES)
GAS WELLS
GAS FIELDS
OIL WELLS
OIL FIELDS
LA PORTE
ST. JOSEPH
ELKHART
LA GRANGE
STEUBEN
NOBLE
DE KALB
MARSHALL
KOSCIUSKO
WHITLEY
ALLEN
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SENECA
PAULDING
PUTNAM
HANCOCK
VAN WERT
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MERCER
AUGLAIZE
LOGAN
UNION
DELAWARE
SHELBY
DARKE
MIAMI
CHAMPAIGN
CLARKE
MADISON
FRANKLIN
PREBLE
MONTGOMERY
LICKING
FAIRFIELD

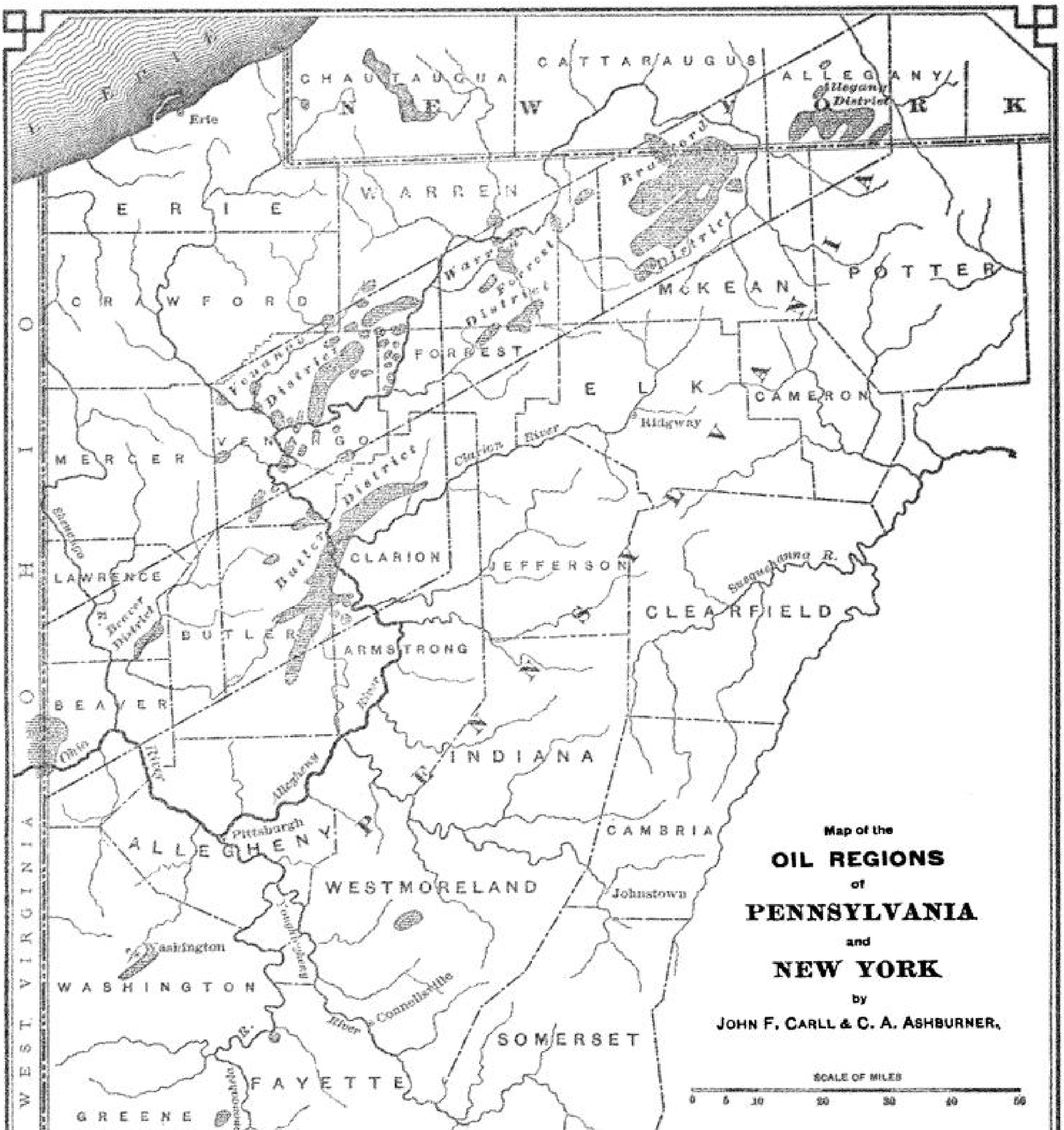
The drilling and care of these oil wells and the storage and transportation of their products have given rise to what may be called a new branch of mechanical engineering, in the development of which a large amount of inventive genius has been expended. Years of experience are requisite to gain a full knowledge of the drillers' art, and those who obtain such knowledge command the consideration and pay of other mechanical experts. The movement of petroleum from the oil fields to the sea-board, or to the centers where it is refined or otherwise used, in lines of pipe buried in the ground and hundreds of miles in length, constitutes an original addition to our systems of transportation. The cost of transportation is reduced by this system to the lowest terms.

Equal skill has been obtained among us in the manufacture of illuminants from petroleum. American oil is unquestionably the best source of artificial light for town and country alike that the markets of the world afford. Its superiority is fully recognized throughout Western Europe, where it comes into competition with illuminating oils from other fields.

Vast wealth has been already derived from the production, and especially from the storing, transportation and refining of petroleum. Much of this wealth has been distributed among a large number of persons associated in one way or another with this new interest, and much of it again has been massed in the hands of individuals. The oil well derrick, the pipe-line, and the refinery, in fact, stand by the side of the railway locomotive and the great lodes of the mining districts, as agents for the gathering of the colossal fortunes which constitute so striking a feature of our day. It is in connection with industries growing out of petroleum that the first successful attempt has been made to control the entire business of the country in a single line by a single company, organized for and directed to this end. The so-called Standard Oil Company, although not a corporation in a legal sense, practically controls, with enormous advantage to the individuals that compose it, the oil refining of the country, and incidentally the production and transportation of oil throughout the country at large. As has been already stated, the illuminating oil and associated products furnished by this company are the best of their kind in the world, and there is no general ground of complaint as to the prices at which they are sold; but there is a wide-spread feeling of distrust of and hostility to the company, growing out of the methods it has used in getting rid of competition in the business which it has organized. Its importance in the practical development of our oil fields can not well be over-estimated. It provides a vast and admirable system of storage and transportation of oil as it is produced, and it furnishes a cash market for the production of every well. Thus far, no important oil field has been developed independent of the agency and practical control of this great organization.

The search for and exploitation of petroleum have many of the characteristics of the mining of the precious metals. There is the same uncertainty of result, and the same possibility of enormous and disproportionate rewards that invest the search for gold and silver with such a charm for multitudes of men. As a consequence, speculative excitement is sure to rise high in all districts in which the successful development of oil territory is going forward. Large investments are made, money is freely spent, villages and towns grow apace, but in a very short time the high-water mark may be reached, and the ebb of the tide in many instances proves equally as rapid as was its advance. In all these respects, petroleum production follows the experience of the mining and development of the precious metals, as already noted. Some towns that have been begun under the excitement attending the discovery of a new oil field, become the centers of permanent interest and industries in this connection: those towns, namely, that are selected as the location of refineries and pipe-line centers.

The great oil production of the country has been confined to a few hundred square miles of territory located in Pennsylvania, New York, West Virginia and Ohio. The chief areas are shown in the accompanying sketch maps, Nos. 1 and 2. Additions to the territory on a small scale are made from other States. The productive districts, as is seen on the maps, are found in isolated areas, varying from one or two square miles to a few score of square miles in size. The separate pools are also found to be ranged in north-east lines, so far as the principal



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field is concerned, and these lines beyond question stand for the main structural features of the territory to which they belong. This point will be further discussed and explained on subsequent pages of this report.

From the fact that the petroleum of the country has been produced from so small a portion of its area, it must not be inferred that it has not been looked for elsewhere. The exploration has been widespread, and vast sums of money have been spent in the search through all the States which seem to agree in geological history and structure with the States to which the productive districts belong.

The new oil field of northern Ohio has made a very important, and, at the same time, an entirely unexpected addition to our resources in this respect; but the promise which it seemed at first to extend to a large part of the country, in the way of furnishing new oil fields of great extent, has been already broken. Widespread drilling has been carried forward, and money has been most freely expended in the search for oil through a few of the nearest States, without any addition of real significance having thus far been made to the new oil territory that was outlined in Ohio in 1885. It is now certain that the new field, like the older ones, is included within narrow boundaries. It does not exceed 200 square miles in area, so far as present knowledge goes.

Has the experience of the last thirty years warranted the expectation and belief that the stocks of petroleum in nature are adequate to maintain for long periods, as of centuries, the large and lavish use which our generation has been the first to enjoy? In other words, can we count upon petroleum as making a permanent addition to our sources of power? The answer derived from experience is explicit. There is no such warrant. The productive areas are of small size and far between, and the stocks are all seen to be sharply limited in amount. This subject will be discussed at greater length in a subsequent chapter.

NATURAL GAS, ITS DISCOVERY AND USES.

The discovery and utilization of petroleum have thus far been spoken of. It remains to describe briefly the steps by which natural gas, a constant accompaniment of petroleum, and a necessary derivative from it, has become invested during the last few years with even greater interest, or, to say the least, with a more widespread interest than oil has ever possessed. A paper, prepared upon this subject by Joseph D. Weeks, Esq., for a report on the Mineral Resources of the United States for the year 1885, has been freely used in the following statements.

It will be seen in this review that the recognition of the importance of natural gas as a source of light and heat has been attained by slow stages, and that the useful applications of it, which are here to be recorded, are separated from each other by unaccountably long intervals, especially when the readiness of our people to accept any new natural advantage or any new application of the mechanical powers, is taken into account. It is doubtless true that men were long deterred from attempting to use natural gas because of their lack of confidence in its persistence. It required many years of observation to satisfy them that the enormous power which it evidently contained was stored in quantities large enough to make the exploitation of it a successful investment for capital.

First Uses of Natural Gas.

The first conspicuous example of the use of natural gas for economical purposes in this country is found in the experience of the village of Fredonia, Chautauqua county, New York. The village is traversed by the valley of Canadaway creek, which has been worn out of the great system of shales that make almost the entire southern boundary of Lake Erie. These shales embrace beds that belong to the Hamilton, Portage and Chemung divisions of the geological scale, and possibly in part to a higher division also. They consist of interstratified beds of blue and black shales which occur in frequent alternations. The whole series is known in Ohio and Kentucky as the Ohio shale. Along the entire outcrop of this formation, for many hundreds of miles, weak flows of gas and oil abound. In the valley already referred to in Fredonia, inflammable gas was found escaping from the crevices in the rock from the first occupation of the country. Such escapes are common through all this region. In 1821, a well was bored one and one-half inches in diameter, and 27 feet deep, into these gas-bearing shales, and gas enough to supply twenty or thirty small burners was obtained. The gas was carried from the well in wooden pipes to the streets and buildings near by, and it was burned from small openings made in iron pipes for this purpose. In the course of a few years a small gasometer was added, and the supply was considerably improved thereby. Other wells were added from time to time of the same general character as the first. More recently deep wells have been drilled in the search for a supply that should be adequate to the demands of the village for heat and power as well as for street lighting. But all these attempts have failed. The shales furnish a small amount of gas with great persistency, but they can not be made to support wells of either large volume or high pressure by any device that has been applied to them up to this date. The original supply is still maintained, a dozen or more wells yielding about 16,500 feet per day, making an annual production of about six million feet. The supply is still confined to the original purpose for which it was introduced, namely, that of lighting the town.

A few years later, gas obtained from the same formation and under similar conditions was used for illumination in the Government light-house at Barcelona, the lake port of Westfield, New York. The harbor, and, consequently, the light-house were abandoned by the Government in 1857, but the flow of gas from the same wells has been maintained and used by the people of the neighborhood from that day to this.

Gas was turned to a small account for domestic fuel in Findlay, Ohio, at an early day. In fact, Findlay antedated all other experience in this practical use of gas. In 1838 Mr. Daniel Foster found gas so abundant in the wells and cisterns which he dug in his village lot in the unavailing search for a supply of potable water, that he determined at length to make account of the gas for fuel. He inverted an iron salt-kettle in one of his wells, to be used as a gasometer, and conveyed gas from it by a wooden pipe to his house a few feet away, burning the gas as it issued in a small and steady flame from a perforated gun-barrel, which he had built into a fire-place. This, as already remarked, marks the earliest use of gas as domestic fuel.

It is believed that gas was first brought into use in salt-making in this country in the Kanawha Valley of West Virginia, by William Tompkins, who drilled a well in 1841 for brine to be used in this interest. The well furnished a large amount of gas along with the brine, and Mr. Tompkins turned it to successful use as fuel for the salt block. It will be remembered that in the drilling of salt wells, which was first successfully begun in this country in 1808, gas was often found in large quantities, and often made itself obnoxious to the driller on account of the interruption and danger that it brought to his operations. But for more than thirty years he had carefully conducted away from the furnace this best of fuel, which nature had presented to him without money and without price.

After the new chapter in the history of petroleum was begun in 1859, the experience with gas became necessarily much more important than any that had been known before. More or less gas was found in all the important oil wells, and especially in the most valuable section of oil wells, namely, the flowing wells, or those that delivered the oil without the use of a pump. It was at once recognized that the escaping gas furnished a useful source of power in drilling and in pumping the oil wells, and it was accordingly introduced on a large scale into the boilers of the engines by which the power was supplied. At first the use of it was confined to the well where the drilling was going forward; but the gas was soon piped away for similar purposes to greater or less distances throughout the field where it was needed. All of its advantages as fuel were made fully apparent here, and yet, strange to say, the idea of utilizing it beyond the simple demands of the oil field proper seemed never to have found entrance into the mind of any one. Great gas wells were still abandoned as of old time, and were allowed to blow themselves out without restraint into the air. It was the main object of the driller to keep clear of the gas belts of the territory within which he was operating. Little by little, however, the use of gas for light and fuel was extended from the derrick and the boiler to the dwelling near by. With such a history as has here been briefly sketched, it is obvious that no sharply-defined dates for the general application of natural gas as a fuel can be given. The development was in full progress, but its separate steps can not be noted further than to say that between 1860 and 1870 a wide application of it was made in the villages and towns along the south shore of Lake Erie. Erie and Northeast, Pennsylvania, Conneaut and Painesville, Ohio, furnish examples.

Gas was introduced into an iron mill as its sole fuel at Leechburg, Pennsylvania, for the first time, in April, 1873, by Messrs. Rogers and Burchfield. This very important application of gas to manufacturing begins at this point.

Rochester, Pennsylvania, is credited with the first application of natural gas to glass-making, but the exact date of this use is not given. The Rochester Tumbler Works are believed to have used natural gas in their furnaces previous to 1883, but in this last-named year Mr. J. B. Ford, president of the Pittsburg Plate Glass Works, located at Creighton, Pennsylvania, introduced the new fuel into the extensive establishment of his company, and since that time it has become almost indispensable to the glass-makers' art.

The piping of gas on a large scale began with carrying the gas of the famous Harvey well, near Larden's Mills, Butler county, Pennsylvania, to the iron mill of Spang, Chalfant & Co., at Etna, near Pittsburg, Pennsylvania. The line was six inches in diameter and seventeen miles long, and the gas was first used from it in the iron mill in October, 1874.

In 1883 gas was first piped from the Murrysville field to Pittsburg; and this year may be taken as the date of its adoption as domestic and manufacturing fuel for large communities.

In November, 1884, the great reservoir of Findlay gas was first struck at a depth of 1,100 feet below the surface. The utilization of the gas was going forward in the town through the year 1885, but the great development and distribution of it for this entire section of the State were left to 1886 and 1887.

The new Indiana gas field, which derives its supply from the Trenton limestone or Findlay horizon was mainly developed in 1886 and 1887. It constitutes, on the whole, the largest and most productive connected gas territory that has ever been dis covered.

This review has brought us down to the present date. It will be well to recapitulate the leading facts in this remarkable history:

In 1821, natural gas first used for illumination, Fredonia, New York.

In 1838, natural gas first used for heating purposes, Findlay, Ohio.

In 1841, natural gas first used for salt-making, West Virginia.

In 1860, natural gas first used for steam production, Oil Creek, Pennsylvania.

In 1870, natural gas first used for domestic fuel, Shore of Lake Erie.

In 1873, natural gas first used for iron-working, Leechburg, Pennsylvania.

In 1874, natural gas first piped for long distances, Etna, Pennsylvania.

In 1883, natural gas first used in plate glass manufacture, Creighton, Pennsylvania.

In 1883, natural gas first piped for general supply, Pittsburg, Pennsylvania.

In 1884, natural gas discovered in large quantity at Findlay, Ohio.

In 1886, natural gas discovered in large quantity in Central Indiana.

The amount of gas now in use in the States already named is very large. The best idea of it can perhaps be obtained by putting it in tons of coal displaced by its introduction. The most recent calculations are those of Joseph D. Weeks, Esq., for the Mineral Resources of the United States. He concludes that in 1888, 14,163,830 tons of coal, valued at $22,662,128, were thus displaced.

The amount of capital invested in the distribution of gas from the various fields of the country it is impossible to determine with accuracy. It is certainly not less than fifty million dollars

CHAPTER III.

THE ORIGIN OF PETROLEUM AND GAS.

The enormous economic value that petroleum and its derivatives have recently attained, as shown in the history that has now been briefly reviewed, has invested all the questions pertaining to this subject with great interest and importance. The introduction of natural gas in particular, during the last few years, into a considerable number of towns in Pennsylvania, New York, Ohio and Indiana, to be used in these towns for a supply of light, fuel and power, the wonderful addition that it makes when thus introduced to the convenience and the commercial advantages of these towns, and the consequent widespread desire on the part of all other enterprising towns, near and far, to secure for themselves like advantages, have given to the questions as to the origin and distribution of natural gas a larger popular interest than has ever before been brought to bear on any geological subject whatever. For the first time, representatives of all the classes and interests of the community can be found trying to get for themselves clear and correct ideas of the geology of their neighborhoods, so that they may act intelligently with reference to questions that come before them in one way or another in connection with the new fuel.

As a consequence, there has been a very great extension of geological knowledge among the people at large throughout considerable sections of the country during the last five years. It would be hard to overstate the advance that geology has thus made, especially throughout the new oil and gas fields and the regions that are obtaining their supplies of fuel from these fields. Of course, knowledge obtained in this way will be crude and superficial. All popular knowledge of science necessarily has these characteristics ; but, after all, it is a great deal better than no knowledge. There is underlying it a wakeful interest and a desire to learn, which is the indispensable condition of all progress in these subjects. As a consequence, there are scattered throughout the new fields more or less persons, manufacturers, capitalists and others, who have made themselves, within the period named, good geologists, so far as the power of drawing sound conclusions from geological data is concerned. They have studied the facts and theories pertaining to the subject of natural gas with a real desire to learn the truth, whatever it may be, and to this study they have been impelled, in many cases, by a motive that is never lacking in efficiency, namely, the desire to win the prizes in the new mining ventures, or, in other words, to make profitable investments in the line of gas and oil.

As much can not be said, however, of the speculators and boomers, so-called, who always swarm around the regions in which oil and gas are undergoing developments. These classes find no more promising fields for exercise of their peculiar powers than these. It is still true, with respect to them, that "a little knowledge is a dangerous thing." The trouble with them is, that they do not care to know the actual facts of the case. They find exaggerations and distortions of the facts better fitted for their purposes than the facts themselves. The truth often stands in their way. These real estate geologists, as they may be termed, settle all the hard questions of the science in a very positive and peremptory way, and thus sometimes give temporary currency to the crudest and most improbable and contradictory geological doctrines.

The question of the largest popular interest in connection with oil and gas relates to the duration of the supply; but it is readily seen that the question of duration is intimately connected with the origin of these substances, and, therefore, this last topic commands a large share of interest. Of what are oil and gas originally made? How were they formed? When were they formed? Are they in process of formation now? These are the questions that are heard on every side.

What are the geological answers? It can be said in reply, that within the last fifty years, and particularly within the last twenty-five years, there has been a great deal written upon the general subjects that these questions cover, namely, the modes of origin of oil and gas, and it can further be said that a great deal has been learned in regard to these subjects, but still it is true that no one answer as to their origin commands universal acceptance. A distinguished German geologist, Prof. C. F. Zincken, of Leipzig, writing recently, goes so far as to say that in regard to the origin of petroleum, one might well adopt the inscription that was placed over a meteorites that fell in Europe many centuries ago: "*Multi multa, omnes aliquid, nemo satis.*" The words can be translated thus: "Many men say many things. Everybody says something. Nobody gives a satisfactory account." When we come to analyze the various answers, however, as to the origin of petroleum, the case is not as discouraging as this statement would lead us to conclude. There is one point of vital consequence in the discussion, and in regard to this, it may be said that there is now substantial agreement among all geologists who have gained a right to speak upon the question. Even the author last quoted remarks in the same connection: "Not a doubt any longer prevails as to the derivation of petroleum from organic matter."

In this chapter, a brief account will be given of the various theories or classes of theories that have been put forward to account for the origin of the bitumens with which the earth is so abundantly stored. One or two points need to be made clear before the discussion proper is begun.

1. In the first place, all forms of bitumen must be considered together. They constitute a definite and well-graded series throughout. There is no question, for example, as to mineral tar being derived from petroleum. Mineral tar *is* partially oxidized petroleum, and it is obvious, therefore, that this element needs no separate theory as to its origin.

In like manner, no line can be drawn between mineral tar and asphalt. Asphalt is simply petroleum still further oxidized, and we are, therefore, absolved from the necessity of providing a theory for the origin of asphalt in addition to the origin of petroleum.

When petroleum, so called, is considered, a great many varieties of crude oil are found to be included under the term, depending partly upon the chances for oxidation that the products have had. Natural oils range in gravity from below 20 degrees to above 50 degrees, Beaumé, the former so thick that they can scarcely be poured, the latter light enough to be burned in common lamps in the crude state.

If a line were to be drawn anywhere in the series it would be between gas and oil. The former, as we know, originates under many conditions in which petroleum does not appear; but, on the other side, petroleum is never found free from inflammable gas, and in a large way all the facts and the occurrences of both so exactly correspond that it is impossible to separate them in respect to their origin.

Which of these is the original substance? The question has been already answered. Petroleum is the parent product. From it all the varieties of the series are directly derived. Our task, then, is a simple one, to this extent. We are to inquire how rock oil originates in nature. When we can answer this question, we know that we understand as well how mineral tar and asphalt, and natural gas also, originated.

2. In the second place, we need to bear in mind that the various members of the bituminous series are abundantly and almost universally distributed among the unaltered sedimentary rocks of the earth's crust. The valuable accumulations of these substances are rare, it is true, but one can scarcely go amiss of petroleum, asphalt or gas, at least in small quantities, among the stratified rocks that retain their original structure. In particular, the rocks of the entire Ohio Valley can be said to be charged with petroleum. A well can not be drilled at any point in the valley, for even a few hundred feet, in which careful examination will not reveal the presence of some representative of this bituminous series. The aggregate of this disseminated petroleum is often found to be very large. A fifth of one per cent. of petroleum, if distributed through a thousand feet of rock, would make a total to the acre or square mile far beyond any production that has ever been realized from the richest oil field, and percentages of this amount are not only not rare to find, but are even hard to miss.

It is a popular impression that oil and gas are unusual substances in nature. The object of this paragraph is to show that this impression is entirely unfounded, and that we must free our minds from it if we would consider in proper light the questions as to the origin of rock oil.

ORIGIN OF PETROLEUM.

While all geologists now agree, as before stated, that petroleum is in some way a product of the organic world, there are certain other theories current as to its origin that must be considered in this connection. The most important class of these separate theories can be called chemical, as contrasted with and distinguished from geological theories bearing upon this subject. These chemical theories refer the bituminous series for its origin to an inorganic source, or, in other words, they make them the result of chemical affinity acting upon mineral matter. The geological theories, on the other hand, regard the entire bituminous series as the result of a partial and peculiar decomposition of vegetable or animal substances that have been stored in the rocks. The differences between these theories are wide and well marked. The chemical theories will be stated first.

I. THEORIES OF CHEMICAL ORIGIN.

It has been claimed by a number of chemists, some of whom have high standing in the scientific world, that the several members of the series now under consideration can be referred to a purely mineral origin.

1. In 1866, the distinguished French chemist, Berthelot, propounded a theory that would, in his view, account for all the natural hydrocarbons in this way. He supposed the alkali metals, viz: potassium and sodium, to exist in the interior of the earth in a free or uncombined state, and, necessarily, at a high temperature. If, now, water carrying in solution carbonic acid—and the crust of the earth abounds in both—should find access to these metals, he pointed out the steps of the chemical action that must take place, and that would result in the formation of a series of hydrocarbon compounds. In this case the process of oil and gas formation would be deep-seated and continuous, the reactions that give birth to them being constantly renewed in the recesses of the earth.

2. Another theory that invokes chemical force only for the origin of these bodies was advanced by the eminent Russian chemist, Mendeljieff, in 1877. It attracted a large measure of attention and interest throughout the scientific world. He

supposed the interior of the earth to contain large masses of metallic iron, and also metallic carbides (compounds of carbon and metals), all at a high temperature. The contact of water under these conditions with these bodies would, in his view, generate metallic oxides and hydrocarbons. Mendeljieff, accordingly, holds that petroleum is never of organic origin, but is as purely a product of chemical affinity as a veinstone or an ore. It would follow from this theory also that the process of oil and gas formation is continuous. This, in fact, constitutes its chief recommendation, as will presently be shown.

There are several other theories of the same general character, but none that have been supported by as great authority, or that have attracted as wide attention, as the two already named.

In regard to this class of theories, it is to be observed that they are the work of chemists and not of geologists, and, as might be expected, they match better with the chemical than with geological facts involved. They especially fail to account for the different sorts of oil and gas that characterize different rocks, as limestone and sandstone, for example. More important still, they not only fail to account for the distribution of petroleum and gas, but they are entirely discordant and irreconcilable with the facts of distribution.

It is further to be observed that the hypotheses which they depend on, and which are indispensable to the theories, are of the sort that are doomed forever to remain hypotheses. They are, in their nature, incapable of verification. They can not advance beyond their present stage, that of chemical and geological possibilities. There are fields of scientific speculation in which we have, and, from the nature of the case, can only have such materials ; but this is not true of the subjects now under consideration. In the fact that all of these theories "require the assumption of operations nowhere witnessed in nature or known in technology," we find enough to condemn them, or, at least, enough to forbid any large measure of confidence in them.

It must be confessed that these chemical theories are popular with the general public far beyond their merits. What is the ground of this popularity? The cause is not far to seek. They furnish to us an unwasting supply of power. They encourage us to expect that, in the matter of gas and oil, "to morrow shall be as this day or even more abundant."

Such doctrines are always welcome to men. Especially in newly-developed gas and oil fields they are sure to take strong root. It is natural that people, who are rejoicing in the new and unexpected supply of the best fuel of the world, which brings with it no end of incidental benefits and advantages, should desire to have their supply continued forever, should even resent the suggestion that the gas is a stored product, the days of which, as soon as its reservoir is tapped, are numbered.

It is in the new gas fields, as before stated, that this chemical doctrine of the origin of gas and oil is likely to prevail. To find such doctrines current in any field is clear proof that the field is still in its infancy, so far as development is concerned. It must be added that these views are often fostered in new fields by those who know better, but who have an object to gain in pushing forward wholesale explorations. A very different frame of mind characterizes the operators and producers of the older districts. They have learned by experience, often of the most discouraging sort, that, without exception, the supplies of gas and oil when worked are gradually or even rapidly reduced, and that all are sure to be exhausted in no long periods of years. They know that these substances are stored in definite reservoirs, because they have exhausted these reservoirs one after another. Some of the reservoirs last much longer than others, but the duration is seen in all cases to be connected with, and dependent upon, their thickness and volume.

Views as to the origin of petroleum like those already quoted, though they must be rejected as failing to conform to the facts, are still entitled to respect as embodying important chemical possibilities, and as characterized by learning and ingenuity. But the same can not be said of the many crude notions that are floating through the minds of some who are engaged in the production or utilization of gas and oil. These notions are often dignified with the name of theories, but they fall far short of the mark. Of such are the claims that natural gas is a product of the decomposition of salt water contained in the rocks, through the agency of subterranean heat. Sometimes the salt water is supposed to be connected with the sea, and a still larger source of gas is thus provided. The action of the tides is also invoked in the same connection.

It is needless to discuss these vague and crude ideas. They are not the product of knowledge, and they are not, therefore, amenable to scientific criticism.

II. Theories of Organic Origin.

The theories of the next class stand on a very different footing from those already named. According to them, petroleum and natural gas are derived from vegetable and animal matter contained in the rocks in which they are found or in associated strata. The argument for the view is simple and direct. Compounds similar to or identical with petroleum and natural gas are easily derived by the process of destructive distillation from both vegetable and animal substances, as from wood, peat, bones, oil, &c.

The manufacture of artificial gas from bituminous coal is also a familiar illustration of the possibilities in this direction. Bituminous shale may be substituted for coal in the manufacture, and may be made to yield a series of these bituminous products, including both petroleum and gas.

Further than this, the decay of vegetation, at ordinary temperatures, gives rise to light carburetted hydrogen or marsh gas, if the air is excluded from the decaying substance. These conditions are met when vegetable matter, as wood and leaves, is buried at the bottom of ponds and lakes, or on a larger scale, in the beds of glacial drift. As is well known, large accumulations of ancient vegetation are buried in or beneath the bowlder clay in many parts of the country, and these masses sometimes yield gas in large enough amount to be of economic value. Peat bogs not only yield inflammable gas, but it is held by respectable authority that they sometimes produce other members of the bituminous series, nearly allied to petroleum and asphaltum. In a word, it is scarcely too much to say that in the natural or artificial decomposition of organic substances in the absence of air, both petroleum and gas are normal products. If this is so, and if in the rocks both material and force are found that would produce these substances in the ordinary course of nature, why invent far-fetched and unverifiable theories to account for their presence?

While, therefore, the derivation of petroleum and gas, from vegetable or animal substances, is at present accepted by all whose opinions on the subject are entitled to consideration, there is still a good deal of diversity of view as to the manner in which the work has gone forward. In fact, the inquirer soon learns that beyond the general conclusion already noted, there is little agreement among our most responsible authorities as to the particular mode of origin of the substances under discussion. There is not only a want of positive knowledge upon the subject, but there is also a lack of self-consistent and thorough-going theory. Two views have become especially prominent in this country in the discussions of the last twenty years, and to the one or other of these, most of those persons who seek for well-balanced and presentable opinions on this line of questions, are found to subscribe.

The first view is, that petroleum is in large part derived from the *primary decomposition* of organic matter that was stored in or associated with the strata that now contains it. According to this view, the decomposition was mainly effected *in situ*, and the product resulting is therefore mainly indigenous to the rock in which it is found. The last feature is seized upon in most popular statements, and a theory of indigenous origin is made to include most beliefs in this class. It must be borne in mind, however, that no author is to be found who holds strictly and consistently to such indigenous origin; but the name can still be used as a general designation without harm.

The second view is, that petroleum is derived from the *secondary decomposition* of organic matter stored in the rocks. It supposes the original vegetable and animal matter to have suffered a partial transformation, and to be now held in the rocks as hydrocarbon compounds, from which, by a process of distillation, oil and gas are derived. The so-called bituminous shales are counted the chief sources of these products. After distillation, it is held that the gas and oil are mainly carried upward by hydrostatic pressure to some overlying porous stratum that serves as a reservoir. This class of views can be conveniently grouped under the name of the distillation theory. A few words will be devoted to each of these theories.

1. Theory of Origin from Primary Decomposition of Organic Matter.

a. Statement of Hunt's Theory.

The most elaborate and effective exposition of the theory that petroleum is derived from the primary decomposition of organic tissue is that of Dr. T. Sterry Hunt. He urges, with great force and vigor, the view that petroleum mainly originates in, and is derived from, limestones. When found in limestones he counts the oil indigenous, but when found elsewhere, as in sandstones and conglomerates, he counts it adventitious, and he then refers it to underlying limestones. In regard to this latter point, however, he makes concessions, as will be seen on a later page.

The following extracts from various articles that he has published contain a clear statement of his views upon this subject.

In speaking of the oil fields of Canada, he says:

"The facts observed in this locality appear to show that the petroleum, or the substance which has given rise to it, was deposited in the bed in which it is now found at the formation of the rock. We may suppose in these oil-bearing beds an accumulation of organic matters, whose decomposition in the midst of a marine calcareous deposit has resulted in their complete transformation into petroleum, which has found a lodgment in the cavities of the shells and corals immediately near. Its absence from the unfilled cells of corals in the adjacent and interstratified beds forbids the idea of the introduction of the oil into these strata either by distillation or by infiltration. The same observations apply to the Trenton limestone, and if it shall be hereafter shown that the source of petroleum (as distinguished from asphalt) in other regions is to be found in marine fossiliferous limestones, a step will have been made toward a knowledge of the chemical conditions necessary to its formation." A. J. S. (2), 35, 168.

Again he says:

"In opposition to the generally received view, which supposes the oil to originate from a slow destructive distillation of the black pyroschists, belonging to the middle and upper Devonian, I have maintained that it exists, ready formed, in the limestones below." A. J. S. (2), 46, 361.

This statement seems to recognize the possibility of the transfer of petroleum from its sources to reservoirs in associated strata.

Again, after describing the occurrence of petroleum in certain fossils and certain layers of the Corniferous limestone, he says:

"The facts observed in this locality appear to show that the petroleum, or the substance that has given rise to it, was deposited in the bed in which it is now found at the formation of the rock." A. J. S. (2), 35–157.

Finally, in referring to the bitumen-bearing dolomite in the Niagara series near Chicago, he says:

"With such sources ready formed in the earth's crust, it seems to me, to say the least, unphilosophical to search elsewhere for the origin of petroleum, and to suppose it to be derived by some unexplained process from rocks which are destitute of the substance." (Essays, p. 174.)

In this passage, also, a possible transfer of petroleum seems to be recognized.

These statements leave nothing to be desired as to clearness and explicitness. The author's view could not well be put into more concise terms than he has used. It must be added, however, that he has sometimes described the oil of Pennsylvania and Ohio as indigenous to the Devonian and Carboniferous sandstones which contain it. (Essays, p. 171.)

Professor J. P. Lesley has also urged the view that petroleum is derived, at least in some conspicuous instances, from vegetable remains that are still found associated with it in the rocks; but he does not theorize as to whether it results from primary or secondary decomposition. In a well-known paper on the petroleum of the eastern coal field of Kentucky, he refers this petroleum to the great conglomerate at the base of the coal measures. He says:

"A conglomerate age, or horizon of petroleum, exists. This is the main point to be stated, and must be kept in view apart from all other ages or horizons of oil, whether later or earlier in order of geological time. The rock itself is full of the remains of coal plants, from the decomposition of which the oil seems to have been made. * * * For hundreds of square miles this vast stratum of ancient sea-sand is a thick packed herbarium of coal-measure plants. * * * We can easily conceive of the wide, flat, sandy shores of the coal islands of the ancient archipelago of the coal era becoming completely charged with the decomposed and decomposable reliquiæ of both the plants of the land and the animals of the sea."

Professor I. C. White has also supported the view that the petroleum of the third oil sand of Venango county, Pennsylvania, is indigenous to this rock, basing his belief on the abundance of vegetable remains that he finds in the outcrop of this sandstone in Erie county, Pennsylvania. (See report on Erie county, 2d Pennsylvania Survey, page 239.)

Professor J. D. Whitney has expressed the belief that all of the bituminous minerals of California, including asphalt and petroleum, are derived from the remains of infusoria in mineral limestones, but he has not expanded this view into any formal statement.

The opinions of several eminent American geologists have now been quoted in support of the general view that petroleum and gas originate in the strata in which they are found, and, so far at least as the most extended statement is concerned, by the primary decomposition of organic matter.

The testimony of geologists from other parts of the world could also be adduced to support the above-named view if it were counted necessary at this point. It is enough to say that the opinions of a number are on record which express in the clearest manner a belief in the primary derivation, and thus in the indigenous origin, of petroleum.

II. Theory of Origin from Distillation.

The second of the main theories previously noted, viz: that petroleum and gas are the product of the secondary rather than of the primary decomposition of organic substances, or, in other words, that they are derived from the hydrocarbons of the rocks by a process of distillation, is accepted far more widely than the view previously named. In connection with this theory, it has always been held that these products of distillation are carried upward by hydrostatic pressure to be stored in porous reservoirs or to escape at the surface. This doctrine has, without doubt, aided in giving currency to the distillation theory with which it has always been associated; but it must be observed that it is not incompatible with the first-named theory of the origin of petroleum, and that it has been of necessity recognized, at least by implication, by the advocates of the first theory. Whatever the origin of petroleum, it is certain that it has been accumulated by the method here indicated, at least in many instances. The distillation theory must, therefore, be considered by itself.

That petroleum and gas can be produced from coal, bituminous shales and other rocks, by the process of destructive distillation, is known to all. The same products, we should have a right to expect, if similar rocks should be subjected to volcanic heat while buried deep below the surface.

When, therefore, we find these or other members of the bituminous group present in the rocks of volcanic districts, or in the neighborhood of hot springs, or, in a word, in regions where elevated rock temperatures prevail, or have recently prevailed, we refer them without hesitation to a process of distillation from the strata which the heat has traversed. Conditions are seen to be at hand similar to those which we establish in the artificial production of these substances. It may be added, in passing, that petroleum and asphalt are very frequently found under the circumstances named above.

Such an origin can not, however, be made out for the great supplies of petroleum and gas in the Eastern United States. These are, without exception, drawn from regions which have never been invaded by igneous rocks, and which have been but little disturbed by geological accidents, the uniform and monotonous dip of their formations being only occasionally interrupted by the low arches that traverse them.

b. Statement of Newberry's Distillation Theory.

The theory that has been most elaborately stated, and most widely accepted, of all advanced to account for the oil and gas of the Allegheny field, is that of Prof. J. S. Newberry, who refers the origin of these substances to the extensive deposits of

Devonian and Subcarboniferous shales, and particularly black shales, that underlie the productive districts. He considers petroleum and gas the products of *a slow spontaneous distillation* of the organic matter of the shales, and he regards the process of their formation a continuous one.

In his noted paper on the "Rock Oils of Ohio," published in the Ohio Agricultural Report for 1859, he says:

"The precise process by which petroleum is evolved from the carbonaceous matter contained in the rocks which furnish it is not yet fully known, because we can not in ordinary circumstances inspect it. We may fairly infer, however, that it is a *distillation*, though generally *performed at a low temperature*."

Again he says (Geology of Ohio, Vol. I, p. 192):

"The origin of the two hydrocarbons (petroleum and gas) is the same, and they are evolved simultaneously by the *spontaneous distillation* of carbonaceous rocks."

In Vol. I, Geology of Ohio, p. 158, he says:

"I have already referred to the Huron shale as a probable source of the greater part of the petroleum obtained in this country. * * * The considerations which have led me to adopt this view are briefly these:

"*First.* We have in the Huron shale a vast repository of solid hydro-carbonaceous matter, which may be made to yield ten to twenty gallons of oil to the ton by artificial distillation. Like all other organic matter, this is constantly undergoing *spontaneous distillation*, except where hermetically sealed deep under rock and water. This results in the formation of oil and gas, closely resembling those which we make artificially from the same substance, the manufactured differing from the natural products only because we can not imitate accurately the process of nature.

"*Second.* A line of oil and gas springs marks the outcrop of the Huron shale from New York to Tennessee. The rock itself is frequently found saturated with petroleum, and the overlying strata, if porous, are sure to be more or less impregnated with it.

"*Third.* The wells on Oil Creek penetrate the strata immediately overlying the Huron shale, and the oil is obtained from the fissured and porous sheets of sandstone of the Portage and

Chemung groups, which lie just above the Huron, and offer convenient reservoirs for the oil it furnishes."

So far, at least, as pointing out the sources of Pennsylvania oil and gas, this statement has met with wide acceptance among geologists.

c. Statement of Peckham's Distillation Theory.

There is, however, another statement of the distillation theory that must be briefly considered. It is that of Prof. S. F. Peckham. It is clear and self-consistent, recognizing all the necessary factors and conditions. He refers the oil and gas of Pennsylvania, and adjacent territory, to a distillation effected by the heat that accompanied the elevation of the Appalachian mountain system. He says (Tenth Census Reports, X, 70):

"Bitumens are not the product of the high temperatures and violent action of volcanoes, but of the slow and gentle changes at low temperature, due to metamorphic action upon strata buried at immense depths. * .* * It is not necessary here to discuss the nature or origin of metamorphic action. It is sufficient for our purpose to know that from the Upper Silurian to the close of the Carboniferous periods the currents of the primeval ocean were transporting sediments from north-east to south-west, sorting them into gravel, sand and clay, forming gravel-bars and great sand-beds beneath the riffles, and clay-banks in still water, burying vast accumulations of sea-weeds and sea-animals far beneath the surface. The alteration, due to the combined action of heat, steam and pressure that involved the formations of the Appalachian system from Point Gaspe, in Canada, to Lookout Mountain, in Tennessee, involving the Carboniferous and earlier strata, distorting and folding them, and converting the coal into anthracite, and the clays into crystalline schists, along their eastern border, could not have ceased to act westward along an arbitrary line, but must have gradually died out further and further from the surface.

"The great beds of shale and limestone, containing fucoids, animal remains and even indigenous petroleum, must have been invaded by this heat action to a greater or less degree * * *

"Too little is known about petroleum at this time to enable any one to explain all the phenomena attending its occurrence on any hypothesis, but it seems to me that the different varieties of petroleum * * * are the products of fractional distillation, and one of the strongest proofs of this hypothesis is found in the large content of paraffine in the Bradford oil under the enormous pressure to which it is subjected. * * *

"If this hypothesis * * * really represents the operations of nature, then we must seek the evidences of heat action at a depth far below the unaltered rocks in which the petroleum is now stored."

The statements now presented, inadequate and unfinished as they appear, are the most careful and extended that have been made upon the subject by American geologists. They bring before us two main views as to the origin of petroleum, viz:

(1.) Petroleum is produced by the primary decomposition of organic matter, and mainly in the rocks that contained the organic matter. Of this view Hunt is one of the chief advocates.

(2.) Petroleum results from the distillation of organic hydrocarbons contained in the rocks, and has generally been transferred to strata higher than those in which it was formed. Newberry and Peckham have been quoted at length in support of this general theory. Newberry holds that a slow and constant distillation is in progress at low temperatures. Peckham refers the distillation of the petroleum of the great American fields to the heat connected with the elevation and metamorphism of the Appalachian mountain system.

These three views, as to the date of the origin of petroleum and gas, are seen to cover almost all of the possibilities in regard to the subject. Hunt believes petroleum to have been produced at the time that the rocks that contain it were formed, once for all. Newberry believes it to have been in process of formation, slowly and constantly, since the strata were deposited. Peckham refers it to a definite but distant time in the past, but long subsequent to the formation of the petroliferous strata. He supposes it to have been stored in its subterranean reservoirs from that time to the present.

In these several statements as to origin, two questions are seen to be especially prominent, viz: What particular kinds or classes of rocks are the sources of petroleum, and what is the nature of the chemical processes involved in its production?

In answering the first question, we find the views of Hunt and Newberry distinctly opposed to each other. Hunt counts limestones the principal source of petroleum, and denies that it has been produced by distillation from bituminous shales, while Newberry finds in these shales the main source of both oil and gas, and vigorously opposes the view that limestones are ever an important source of either. (Geology of Ohio, 1, 159.)

It is not necessary to follow the discussion in relation to these points further. It is enough to say that, in the light of present knowledge, each statement is right in what it asserts, and wrong in what it denies. Petroleum is undoubtedly indigenous to, and derived from, certain limestones, as Hunt has so strongly asserted. The Trenton limestone is undoubtedly the most important source of oil and gas in the geological scale of the United States at the present time. On the other hand, Newberry's doctrine, that the great supplies of the Pennsylvania field are derived from Devonian shales, is becoming more firmly established and more generally accepted every year, though it seems likely that he has laid too much stress on *bituminous* shales.

In other words, the theories are not exclusive of each other. Different fields have different sources. We can accept, without inconsistency, the adventitious origin of the oil in Pennsylvania sandstones, and its indigenous origin in the shales of California, or in the limestones of Canada, Kentucky or Ohio.

The double origin of petroleum from both limestones and shales—and it is not necessary to exclude sandstones from the list of possible sources—deserves to be universally accepted. In confirmation of this double origin, it is coming to be recognized that the oil and gas derived from these two sources generally differ from each other in noticeable respects. The oil and gas derived from limestones contain a larger proportion of sulphur than is found in the oil and gas of the shales. Sulphur compounds impart to the oil a rank and persistent odor, from which they can be freed only with great difficulty. In the case of the oil-bearing shales of California, the petroleum is apparently derived from the animal remains with which the formation was originally filled. In composition, this oil agrees with the limestone oils already described. Peckham says of these California oils:

"The exceedingly unstable character of these petroleums, considered in connection with the amount of nitrogen that they contain, and the vast accumulation of animal remains in the strata from which they issue, together with the fact that the fresh oils soon become filled with the larvæ of insects to such an extent that pools of petroleum become pools of maggots, all lend support to the theory that the oils are of animal origin."

He speaks again of this class of petroleums as formed of animal matter that has not been subjected to destructive distillation. (*Ibid.*, p. 71.)

It is possible that the oil and gas derived from animal remains can be distinguished from those of the bituminous shales by the characters above described. Certain it is that the "limestone oils" differ in physical characteristics from the Pennsylvania oils, for example, in a marked degree. They are dark in color; they are heavy oils, their gravity ranging generally from 34 degrees to 36 degrees Beaume, though sometimes rising to 40 degrees, or even 42 degrees. They have a rank odor, arising from the sulphurous compounds which they contain. The oils of Canada, Kentucky and Tennessee, and of the new field in Northwestern Ohio, all agree in these respects, and the oil and gas of the Utica shale and Hudson river group of the State fall into the same category.

The organic matter of the bituminous shales has not been positively referred in the preceding statements to a vegetable source. Such a source is highly probable; but it cannot be said to be fully demonstrated until the origin of the so-called *sporangites* of the shales is finally determined. There are a few geologists who are inclined to refer these forms to hydroid zöophytes (animal) rather than with Dawson to marine plants (rhizocarps). It must be added that there is a growing tendency among German investigators to refer petroleum to an animal origin. Professor Hans Höfer of the K. K. Berg-Akademie, Leoben, Austria, urges this view in his excellent treatise, *Das Erdöl* (Braunschweig, 1888). Professor C. Engler, of Carlsruhe, has also given the results of recent experiments directed to this point. (*Berichte der Deutschen Chemischen Gesell-*

schaft, 1888 (21–1816). He distilled 1,000 pounds of menhaden (fish) oil at a temperature of 350 degrees to 400 degrees Fahrenheit under a pressure of two atmospheres. The distillate consisted of combustible gases, water and 600 pounds of oil, resembling crude petroleum in appearance and reactions, and in fact identical with it, so far as chemical behavior was concerned. While this cannot be considered any thing like a reproduction of the circumstances under which petroleum was really formed, the results are full of interest and significance.

Statements have now been made of three of the most prominent theories advanced by American geologists as to the origin of petroleum, based upon its derivation from organic matter. The statements have been made mainly in the words of their authors.

Which of these theories is best supported? Which, if any, is to be accepted as a probable account of the origin of this important group of substances? If any modifications are required, what are they, and how are they to be applied?

The answers to these questions will come out to view in the discussions of the theories that are now to follow. In these discussions, the order in which the theories have been stated will be reversed, and the last will be considered first

Discussion of Theories of Origin.

a. Discussion of Peckham's Theory.

This theory, it will be remembered, refers the origin of the petroleum of the Pennsylvania field, the only great American field at the time when the theory was first put forward, to the destructive distillation of carbonaceous matter in the rocks, by the heat involved in the elevation of the Appalachian mountain system. It considers higher temperatures than those which are found at or near the surface as necessary to the transformation, and directs us "to seek the source of heat action far below the unaltered rocks in which the petroleum is now found."

How far below? If we descend 1,000 or 1,500 feet below the Berea grit, which is a great repository of oil and gas in Western Pennsylvania and Eastern Ohio, we reach the great series of Devonian and Upper Silurian limestones, upon which the Ohio shale rests, and this latter stratum is the only source that we know in our series of oil and gas of the Pennsylvania type. But the drill has repeatedly gone down 1,000 or 1,500 feet below the Berea grit, and not a trace or hint of metamorphic action is found in the drillings that are brought up. In such drillings from the deep well at Canal Dover, Ohio, 2,700 feet below the surface, and even 1,800 feet below the Berea grit, the microscopic spores that make so characteristic a feature of the black shales were found in normal condition. All observations attest not only the general uniformity of the shale formation throughout the State and at all depths, but also the entire absence of any appearance of metamorphic action.

The same line of facts obtains in regard to the limestones underneath the shales. They have been penetrated to a great depth. The drill in the well of the Cleveland rolling-mill rested at 3,200 feet below the surface, but the limestones at the bottom of the hole showed no signs whatever of metamorphism. The same is true of all the recent deep borings of Pennsylvania and Ohio. The Westinghouse well of Pittsburg is the deepest well that has ever been drilled, but no report of metamorphosed rock comes from its deepest drillings. Nearly the whole of the Lower Silurian system has been penetrated at many points, and new supplies of oil and gas are found in these rocks, but they obviously come from the limestones themselves, and differ in a marked degree from the oil and gas of the shales. In Canada the Trenton limestone bears oil where it is separated by only a stratum of sandstone from the old granite floor of the continent. Still more striking facts in this connection are derived from the experience of some Ohio towns in which wells have been drilled 2,000 feet below the top of the Trenton limestone. Such wells have been drilled in Springfield and Dayton, Ohio, and not a trace of metamorphic action has appeared in even the deepest drillings that have been brought up.

But, in the second place, Peckham demands for oil production "slow and gentle changes at low temperature." We must again ask for a limit. How low a temperature? Must it not be high enough to agree with the facts of observation and experiment as to the production of gas and oil by the destructive distillation of bituminous shales? The temperature at which such changes are effected in the laboratory will scarcely be placed below 350 or 400 degrees Fahrenheit. But the shales could not be brought to this degree without suffering metamorphic change. They contain alkaline solutions in greater or less amount, and both Bischof and Hunt have shown that when such compounds are present, they become powerful solvents of silica and silicates at as low a temperature as 212 degrees Fahrenheit. If, then, the temperature had been raised to even 212 degrees Fahrenheit, there would have been unmistakable evidences of the fact left in the constitution of the rocks.

But if a lower temperature is proposed than that which we are obliged to use in effecting destructive distillation in the laboratory, we are compelled to ask, on what authority? It is of no use to answer that we do not know at how low temperatures this distillation can be accomplished in nature, for this would be an appeal to our ignorance and not to our knowledge. If we reason upon the subject at all, we must be governed by the facts that our experience affords. Any other way of reaching an answer is assumption, pure and simple.

In the third place, it has always seemed necessary to this theory, that a coke or carbonized residue should be left in the rocks which give rise to the petroleum. Inability to point out such a residue seems to have been one of the reasons that led our author to locate the source of the oil-distilling heat at such a great depth. He counts a carbon residue a necessity, but he buries the rock from which the petroleum is derived so deep that we cannot expect to obtain any direct knowledge of it. As has already been shown, in doing this, he drops below the only known source of oil and gas of the Pennsylvania type.

The absence of these residual products has hitherto constituted a real difficulty in the way of any distillation theory, but the recent remarkable researches of Professor Engler, which have been noted on a preceding page, have done something towards meeting this previously unanswered objection. He shows that the products of the fish oil upon which he experimented would, under certain conditions, be entirely changed into gases, water and volatile oil. He further showed that if all the oxygen of these compounds should combine with part of the hydrogen to form water, 87 per cent. of carbon and 13 per cent. of hydrogen would remain. But these percentages are the exact proportions of carbon and hydrogen respectively in crude petroleum, as has been shown in all of the authoritative analyses of this substance that have been made. It must be conceded, therefore, that the objection against the distillation theory, which is based on the absence of a carbon residue, can no longer be counted altogether valid. The first two objections, however, still retain their force, and we are obliged to conclude, after giving them due consideration, that Peckham's theory does not harmonize with the facts of geology in the main oil fields. If it fails to furnish a satisfactory explanation in the fields for which it was especially devised, much less will it serve to explain the new oil field of Ohio, with which no mountain making or considerable disturbance has ever been connected.

b. Discussion of Newberry's Distillation Theory.

Precisely what is meant by the term "spontaneous distillation," in Dr. Newberry's theory, it is not easy to determine, as his statements are not explicit in regard to all the points in regard to which questions would arise. He does not seem to require for oil production any unusual temperature. He speaks of the distillation as "constant," and as going on "at a low temperature." He never uses the term "destructive distillation," and though he sometimes compares the production of natural gas to processes included under the head of destructive distillation, there are other passages in which he seems to make distillation cover the ordinary decomposition of organic matter in stations from which the air is mainly excluded. This is not, however, an authorized use of the word. Distillation, as distinguished from decomposition, requires and depends upon the action of temperatures decidedly above the normal; in other words, of high rather than of low temperatures. In fact, there is no process known under the name of distillation by which the substances under consideration could be produced from organic matter in the rocks, except destructive distillation. Destructive distillation is the heating of organic substances beyond the point of decomposition without access of air.

Those who have criticised Newberry's theory have, in all instances, counted destructive distillation as involved. If it does not involve destructive distillation, then the theory requires to be restated and defined anew. If it could be shown that, under the pressure of great depths, and with the normal increase of temperature due to descent, the transformations in question can go on, then a basis would be supplied for this phase of the distillation theory, but, so far as known, there are no facts to warrant the belief that such a state of things is true. If, instead of distillation, this theory should substitute decomposition of organic tissues at ordinary temperatures without access of air, it would approach the theory of Hunt, that petroleum is due to the primary decomposition of organic matter.

The objections that have been urged against the distillation theory of Peckham apply with equal force to Newberry's theory. Distillation is not accomplished, so far as we know, at a temperature lower than 350 degrees Fahrenheit, and there seems good reason to believe that the petroleum-bearing rocks of the Mississippi Valley have never been raised to this temperature. They do not show the mineralogical characters that we should have a right to expect if they had ever passed the boiling point of water.

c. *Discussion of Hunt's Theory.*

Dr. Hunt's theory, that petroleum originates in the *primary decomposition* of organic substances, remains to be considered. It is the simplest of the theories that have been stated, and it harmonizes well with a great number of geological facts. The author seems to have formed it to meet certain classes of facts that were difficult to explain by the distillation theory. His restriction of oil production to limestones must, of course, be discarded. He denies that the so-called bituminous shales, "except in rare instances, contain any petroleum or other form of bitumen." (Essays, 169.) This statement is singularly wide of the mark so far as the great shale formation of New York, Pennsylvania, Ohio and Kentucky is concerned. It is indeed surprising that any geologist could have expressed such an opinion as this in regard to any of the shale formations, because the proofs of the presence of petroleum in shales are patent, unmistakable and universal. Moreover, chemical analysis of the shales, with reference to this point, has been made, and quantitative determinations of the amount of free oil that they carry have been placed on record. The exact converse of Dr. Hunt's statement is true. Petroleum is present in all fresh samples of bituminous shale, not potentially, but actually, existing in them *as* petroleum, and the amount is susceptible of measurement. (See Geol. of Ohio, VI, 413.)

The highest percentage thus far found is small, it is true, being one-fifth of one per cent.; but, as already shown, when such a percentage is applied to a few hundred feet of shale, their total oil contents become very large. Prof. N. S. Shaler puts the facts in regard to this formation in clear light, in his discussion of the Ohio shale as it is found in Central Kentucky. (Geol. Survey of Kentucky, Sec. Series, III, 169.)

A similar distribution of petroleum is also found in the Shales of the Utica and Hudson River age of the Low Silurian system.

It must not be inferred from these statements, however, that the shales monopolize the petroleum of the bedded rocks of the Mississippi Valley. The claim that the limestones are distinctly petroliferous is abundantly established by examination of the various strata. Every important member of the entire scale contains, disseminated through at least portions of its extent, petroleum in large enough amount to admit of measurement. The Trenton limestone, the Clinton, Niagara, Lower Helderberg, Corniferous and St. Louis limestones, each and all furnish conspicuous examples of its presence in noteworthy amount.

The sandstones of the scale have not been brought into this list of petroliferous rocks, but every one knows that they in fact constitute the great petroleum reservoirs. It is believed, however, that they obtain their stocks mainly at second-hand, and their offices, in the way of the storage of gas and oil, will accordingly be treated under another head.

The limestones and the shales of our geological series are thus seen to agree in these respects. Both of them carry petroleum through all of their substance, and the product of each class has its own characteristics. In other words, these supplies appear to be indigenous to the rocks of both groups.

Dr. Hunt's theory as to the petroleum in these limestones is, that it was formed in them at the time the beds themselves were formed "by a peculiar transformation of vegetable matters, or, in some cases, of animal tissues analogous to them in composition." This is vague, it is true, and the stress is perhaps laid on the wrong element; but why shall it not be extended for what it is worth to the other section of our rocks in which petroleum occurs under precisely similar conditions? If there is good reason for believing in the contemporaneous origin of oil and gas in the limestones, and if there is advantage to be derived from the doctrine as applied to them, the same reason will be found to exist in the case of the shales, and they should be allowed the same advantage.

The main question, however, is this, viz: Can this "peculiar transformation," to which Hunt appeals, be substantiated? Does his theory rest upon processes which are known to be in present operation in the world? Unless proof can be furnished of the reality of the transformation of organic matter *directly* into the bituminous series, this theory makes no better show than the "spontaneous distillation" theory which has already been considered. The latter will furnish a very good account of the facts of petroleum occurrence if no questions are asked in regard to it; but when followed back, it is found to rest upon an entirely unsupported assumption, viz: that distillation of carbonaceous matter will go forward in the rocks at ordinary temperatures, as, for example, at temperatures below 100 degrees Fahrenheit. For such an assumption, as already stated, we have no warrant whatever in the facts of observation.

Dr. Hunt's theory, in like manner, explains in a very satisfactory way all the facts as to the distribution of petroleum in the rocks, but is the theory able to give a good account of *itself?* Are its own foundations properly laid?

The answers to these questions are not all that we could wish, but it is still true that the theory now under consideration is in decidedly better shape in this respect than the theories that have been already examined.

What proof does Hunt adduce that organic matter passes *directly*, by primary decomposition, into some of the compounds of the bituminous series?

One of the most important lines of facts that he presents is derived from the reports of Wall and Krüger (Proc. Geol. Soc., London, May, 1860), upon the so-called asphalt lake of the Island of Trinidad, at the mouth of the Orinoco river. A remarkable passage occurs in Mr. Wall's report which bears directly upon the question before us. It is as follows, two sentences being italicised:

"When in situ, it (the asphalt) is confined to particular strata, which were originally shales, containing a certain proportion of vegetable debris. The organic matter has undergone a special mineralization, producing bituminous in place of ordinary anthraciferous substances. This operation is not attributable to heat nor to the nature of distillation, but is due to chemical reaction at the ordinary temperature and under the normal conditions of the climate. The proofs that this is the true mode of the generation of the asphalt repose not only on the partial manner in which it is distributed in the strata, but also on numerous specimens of the vegetable matter in process of transformation, and with the organic structure more or less obliterated. After the removal by solution of the bituminous material under the microscope, a remarkable alteration and corrosion of the vegetable cells becomes apparent, which is not presented in any other form of the mineralization of wood. * * * Sometimes the emission is in the form of a dense, oily liquid, from which the volatile elements gradually evaporate, leaving a solid residue." (Quart. Journ. Geol. Soc., XVI, 467.)

According to the statements of these observers who appear to be intelligent and discriminating, the facts are as follows:

Beds of shale, formed in comparatively recent times beneath the sea, but now raised above its level, containing in abundance vegetable remains brought down by the Orinoco river, near the mouth of which Trinidad is situated, are yielding petroleum in large amount, by a direct decomposition of vegetable tissues, and the petroleum rapidly passes into asphalt, inasmuch as it is exposed directly to the atmosphere.

This valuable deposit is known as a lake, but the designation is misleading. It has but few characteristics of a lake, except that its surface is level. It is situated about three miles from the sea, and about 100 feet above its level. It has an area of about 114 acres. Its depth has not been reliably ascertained, but on the strength of a few rude borings, it has been reported to be about 18 feet thick at the sides, and 78 feet in the centre. There is said to be a bed of blue clay underlying it. As stated above, the surface is a level tract of brownish material, traversed by cracks or fissures, which are a few feet in depth and width, and which are sometimes filled with rain water. Others of them are filled with soil, blown into them by the winds, and such support a scanty vegetation. A statement relating to this deposit appeared in the "Mineral Resources of the United States," 1883-4, page 937, which is surprisingly erroneous. The statement is in these words, viz: "Near the margin (of the lake) the asphaltum is solid, or nearly so, grading off to a viscous liquid in the center, where it reaches a temperature of several hundred degress centigrade." When it is remembered that 100 degrees centigrade stands for 212 degrees Fahrenheit, and that 200 degrees, the smallest number that could possibly be counted, "*several* hundred," stands for 392 degrees Fahrenheit, and that 300 degrees centigrade is 572 degrees Fahrenheit, the surprising features of the statement come to view.

The fact is, that the deposit is solid throughout, and presumably of one and the same temperature from center to circumference, and this temperature the normal of its location. Carts and mules can be driven anywhere upon its surface. The only fact that could be perverted into a statement of the liquidity of the lake is the observation that the surface of the lake has not been appreciably lowered by the removal of the 200,000 tons, less or more, that have been taken out for the paving of the streets of American towns. It is possible that the mass retains plasticity enough under its normal pressure to fill the excavations that the workings leave, but no explicit statements on this point are at hand. When loaded on shipboard, the separate blocks reunite, and it has to be removed from the hold by pick and shovel, as from the original bed. (See paper on Asphalt, A. I. M. E., Vol. XVII, F. V. Greene.)

There are many other localities, in the countries that border on the Gulf of Mexico, and in the islands that it includes, that furnish bituminous products on a large scale, all seeming to show that petroleum is in process of active formation there at the present time. Barbadoes tar has long been exported to Europe, and Cuban asphalt also has a considerable importance.

Petroleum, rapidly hardening into asphalt, is also recorded as occurring in some of the small tributaries of the Coaxocoalcas river in Central America. The petroleum seems to arise from the decomposition of vegetable remains with which certain beds of shale are stored. (Major J. G. Barnard's Survey of the Isthmus of Tehuantepec, U. S. Government Reports, page 159.)

From the fact that all of the chief bituminous accumulations of recent age belong to the torrid zone, it seems necessary to conclude that a tropical climate, or a climate of 80 degrees Fahrenheit at least, is most favorable, if not essential, to a large production of this class of bodies. The main asphalt deposits of commerce are found about the southern and western shores of the Gulf of Mexico.

The asphalt of Trinidad, which seems to be in constant process of formation, is derived from shales that belong to the later Tertiaries, and though derived from the most recent of all rocks that precede the present geological age, must still be separated from our time by a considerable interval. If, then, the formation of petroleum is made contemporaneous with the rock that contains it, it must be a geological contemporaneity that is meant, in which events that may be separated from each other by many thousands, or even tens of thousands of years, are counted contemporaneous.

Why is it that *shales* are so constantly associated with the recent supplies of petroleum, while the older stocks are largely derived from sandstones? The difference between the two formations in this respect may in part be due to the fact that the shale seals up the vegetable matter more perfectly than the sandstone. In the more porous structure of the latter, ordinary decomposition would have a better chance to go on.

But another fact, and one of very great importance in this connection, is the *affinity of clay for oil of all sorts.*

Illustrations of this affinity are familiar to every one, but an observation of Professor Joseph Leidy's, made a number of years since, has special interest and value for us. He observed that on the bed of the Schuylkill river, for some distance below the Philadelphia gas-works, a deposit of clay impregnated with the petroleum-like oils that are produced in the manufacture of coal-gas was in process of formation. These oily substances, which would otherwise be found on the surface of the river, are absorbed by the particles of fine clay in the water and gradually sink to the bottom with them, there forming a petroliferous clay on the river bed.

If petroleum, arising from such springs as occur in Central and South America, had found its way by rivers to lakes or seas, or had been liberated from sources beneath the sea, the same results would have followed. It would have been absorbed by the fine particles of clay held in suspension in river and sea, as in the case described by Leidy, and the combined clay and oil would have been gradually carried downward to rest on the sea floor, a bituminous or oil-bearing shale.

But if petroleum is a result of the primary decomposition of vegetable tissue, so long as vegetable matter remains undecomposed in the rocks, and so long as the conditions of temperature and pressure remain favorable, what is there to hinder these processes of petroleum formation from going forward. Why limit it to the time of rock formation?

It would seem, however, that in the vast periods that have elapsed since the Paleozoic era, there would have been time enough and to spare for all of these changes to be accomplished, and that the process would be necessarily arrested, either for want of material or for lack of proper conditions.

The essential point in Hunt's theory of the origin of petroleum is, not that it was produced contemporaneously with the rock, nor that it is especially a product of limestones, but that it results from the primary decomposition of organic substances. Discarding these incidental elements of the theory, and applying its central postulate to the explanation of the origin of the petroleum of Eastern Ohio and Pennsylvania we can see what some of the steps in the history must have been.

The shales which constitute its chief source were accumulated in a tropical sea. The Devonian limestone, which immediately preceded them in time, bears witness to most genial conditions of climate. Its massive corals required at least as high an annual temperature as is found in any part of the Gulf of Mexico to-day.

The sedimentary deposits that were laid down on the floor of this Devonian sea consisted of clay and sand, with occasional gravel bars, the sources of which must be sought in the rising Atlantic border, or in the Canadian Highlands, as is proved by all the deposits thickening and growing coarser in those directions. To the western limit of this sea, along the shores of the emerging Cincinnati axis, only fine clay was borne, and this fine and homogeneous material accumulated very slowly, one foot requiring as much time as ten or twelve feet of the coarser and more varied series to the eastward.

In these seas, as we know, there was a vast development of marine vegetation. Some plants of rhizocarpean affinities were especially abundant, and their resinous spores and spore cases, which constituted by far the most durable portions of the plants were set free in enormous quantities. Even now, in some parts of the series, these spores constitute a notable percentage of the shale. In structure and composition, they are but little changed from their original condition. Other portions of this and like vegetation may have been carried to the sea floor in a macerated condition, and have there passed through the coaly transformation resulting in the structureless carbonaceous matter that constantly characterizes the black shales. This carbonaceous substance can still be made to yield the members of the bitumen series through the agency of destructive distillation, and, doubtless, so also can the spores that remain unaltered in the shales, both leaving a carbon residue thereafter.

The shales that were slowly accumulating on the floor of this tropical gulf, thus charged with vegetable remains, must have behaved as similar shales do around the borders of the present gulf. The vegetable matter was turned into petroleum as it is in Trinidad and the West Indies now. The petroleum would have been absorbed by the particles of clay in contact with which it was originated, or, if liberated in the water, it would there have been laid hold of by the like floating particles of clay, to be carried with them in due time to the sea floor, and the work would have gone on until the material was exhausted or the requisite conditions were lost.

The resulting stratum of bituminous shale would have been much more highly charged with petroleum than any portion of these shales is at the present time. Over it, at least throughout the eastern portion of its extent, a bed of sandstone is deposited, which in turn is roofed in by another fine-grained shale. The pores of the sandstone are occupied by sea water, but, under certain conditions, a slow system of exchanges would be established between the rocks by which, at last, the petroleum would be gathered into its final reservoir. The presence of petroleum in considerable amount in a shale might give it a measure of permeability.

Such would appear to be some of the steps in the production of petroleum if Hunt's view of its origin by the primary decomposition of organic tissue is adopted. The result would correspond fairly well with those of the spontaneous distillation theory already discussed. Both would find the petroleum distributed through the substance of the shales, and both would expect its constant escape from outcrops of producing shale or sandstone reservoir. Continuous origination is by no means a necessary conclusion from continuous outflow.

The advantage that the present theory has over others is, that it seems to find more support in the processes of nature at the present time. We find the bitumen series in actual process of formation in many parts of the world to-day, resulting apparently from the primary decomposition of organic matter under normal conditions. On the other hand, we do not find this series, in any cases which are open to observation and subject to measurement, resulting from secondary decomposition of carbonaceous matter contained in the rocks, unless the comparatively high temperatures of destructive distillation are reached.

The several views as to the origin of petroleum that seem best to deserve attention have now been stated as fairly as possible. Some liberty has been taken with the last in the way of removing limitations, but no new theory has been broached, and no real contribution to our knowledge of these very interesting questions is claimed. In subjects which tempt speculation as much as those which are now under discussion, it is well to know the opinions that are most entitled to respect, even where grounds of positive knowledge are wanting. How little real knowledge we have of this subject has been made to appear in this brief review, and it is safe to conclude that, until the boundaries of our knowledge are considerably extended, every theory in regard to the origin of petroleum should be held as provisional only. We must not forget, however, that there is a substantial unanimity among all investigators of the present day as to the organic origin of petroleum. This vital point may be counted finally settled. The chemical theories will flourish mainly among the real estate speculators of new gas fields.

The theoretical views that we hold as to the origin of petroleum will influence our judgment also as to the duration of its supplies. The question is often asked, whether there is any provision in nature by which the supplies that are now drawn upon or exhausted can be renewed? It is to be observed that of the several theories passed in review, only the discarded chemical hypotheses hold out any promise of a perennial supply. Of the three views from which most will feel obliged to take their choice, two answer the questions raised above emphatically in the negative, and the remaining theory gives in reality no more encouragement. Newberry's theory makes the process of oil formation a continuous one, it is true, but it extends it through such vast cycles of time that 1,000 years or 10,000 years would not constitute an important factor. In other words, the reservoirs that we are now piercing with the drill, and that are yielding such vast and valuable stores of light and power, would in all probability have yielded the same supply 1,000 or 10,000 years ago.

Practically, the stock is now complete, as much so as the contents of coal mines and mineral veins. As a result of our interference with natural conditions, small local movements of oil or gas may go on in the rocks, but these would be but insignificant exceptions to a general rule that the reservoirs hold all the oil and gas that they will ever hold, and that when once exhausted they will never be replenished. This question will be still further discussed under a succeeding head.

Gas and oil have been considered together in all the preceding discussions, as if the history of one would cover the history of the other also. There are, however, speculations which dissociate them in origin. By some, gas is counted the first and original product, and it is supposed to be converted into petroleum in the sandstone reservoirs by some unknown process of condensation.

This question, like those that have preceded it, does not admit of a final and definite answer at the present time, but the chemical probabilities do not seem to favor this view. Petroleum is more composite and unstable than gas, and in these respects it seems to stand at less remove from the organic world than the latter. A large percentage of natural gas is light carburetted hydrogen or marsh gas, one of the simplest and most stable products of decomposition. Petroleum readily gives rise to marsh gas when subjected to destructive agencies, but we have no known experience in which the higher compound naturally results from synthesis of the lower. It seems, therefore, safe to count petroleum first in the order of nature.

A few words remain to be said under this head upon another subject. In the preceding discussions, shale and limestone have been considered the chief sources of petroleum, although, as is well known, sandstones are the direct source of the great supplies. There are some who hold that these supplies originate in the sandstones which now contain them. This view can be urged with plausibility, at least, for such sandstones as Lesley describes in eastern Kentucky, or as White finds the LeBoeuf sandstone to be; but the Berea grit, which is the main oil sand of Ohio, and an important horizon also in western Pennsylvania, is singularly free in most of its outcrops from all traces of vegetation. The claim at the best has many weak points, as is well shown by Carll (Penna. Geol. Survey, III, p. 272). Speaking of the Venango sands, he says.

"We find that the largest wells are those which are sunk through the coarsest part of the oil-bearing sand-rock. The drillings show nothing but coarse sand and pebbles. Pieces of the unpulverized rock, one or two cubic inches in bulk, are often brought up after torpedoing, but nothing can be detected in them that could possibly originate petroleum. Could a rock of this character have originally contained a quantity of organic matter sufficient to yield a cubic foot of oil to every ten or twelve cubic feet of rock, and these organic remains be so completely converted into oil as to leave no residual trace of their existence?"

With these questions and suggestions, and many others in the same line, he shows the difficulties of this view. There is much less disposition in the most recent literature upon the subject to insist upon sandstones as original sources of petroleum.

In concluding this chapter, a few of the previously stated propositions in regard to the origin of petroleum that seem best supported, will be repeated in concise terms:

1. Petroleum is derived from organic matter.

2. Petroleum of the Pennsylvania type is derived from the organic matter of bituminous shales, and is probably of vegetable origin.

3. Petroleum of the Canada type is derived from limestones, and is probably of animal origin.

4. Petroleum has been produced at normal rock temperatures (in American fields), and is not a product of destructive distillation of bituminous shales.

5. The stock of petroleum in the rocks is already practically complete.

In the preceding pages, petroleum has been shown to be widely distributed in the rocks of the Mississippi Valley. The limestones and shales of the series, in particular, everywhere contain it. Dr. T. S. Hunt has made a calculation showing the amount of petroleum which the oil-bearing dolomite of Chicago holds to the square mile for every foot in thickness of the stratum. (Essays, p. 173.) If we apply a like calculation to the rocks of the Kentucky scale, we shall find the total amount of oil enormously large. We may take, for example, the Subcarboniferous limestone, which is, in some of its phases, notably petroliferous. Estimating its petroleum content at one-tenth of one per cent., and the thickness of the stratum at 500 feet, both of which figures are probably within the limits, we find the petroleum contained in it to be more than 2,500,000 barrels to the square mile. The total production of the great oil fields of Pennsylvania and New York is, as has already been shown, about 300,000,000 barrels. It would require only 125 square miles to duplicate this enormous stock from the Subcarboniferous limestone alone. But if the rate of one-tenth of one per cent. should be maintained through a descent of 1,500 feet at any point in the State, each square mile would, in that case, yield 7,500,000 barrels, or one-fortieth of the total product of the entire oil field. These figures pass at once beyond clear comprehension, but they serve to give us some idea of the vast stock of petroleum contained in the earth's crust. If petroleum is generally distributed through a considerable series of rocks in any appreciable percentage, it is easy to see that the aggregate amount must be immense. Even 1–1000 of 1 per cent. would yield 75,000 barrels to the square mile in a series of rocks 1,500 feet deep; but this amount is nearly one-tenth of the greatest actual production per square mile of any of the leading Pennsylvania fields.

It is obvious that the total amount of petroleum in the rocks underlying the surface of Kentucky is large beyond computation, but in its diffused and distributed state it is entirely without value.

CHAPTER IV.

GEOLOGY OF PETROLEUM.

In the preceding chapter the leading facts and theories as to the origin of petroleum have been given. Its well-nigh universal dissemination among the various classes of stratified rocks has been described, and it has also been pointed out that as long as it exists merely in this disseminated state, it has no economic value.

There are two groups of questions connected with what may be called the geology of petroleum.

Under what conditions do the valuable accumulations of petroleum, and the inflammable gas that invariably accompanies it, take place? In what kinds of rocks are these substances stored? What determines the storage in one part of a stratum rather than another? What determines the occasional accumulations of gas in large volume in the rocks without the presence of oil? What relation does the salt water, that is almost always present in an oil and gas rock, hold to these substances? What originates the pressure, under which oil and gas are delivered, when their reservoirs are penetrated by the drill? In other words, what are the laws of oil and gas production? The question of the duration of the supplies will also be found closely connected with some of those above stated.

The second group of questions that needs to be answered in this connection pertains to the recognition of the probable existence of oil and gas in advance of the drill. The list embraces questions like the following: What are the most reliable indications of the presence of oil and gas in the rocks? How far can geology aid us in the search for these substances? What is the significance of the so-called "surface indications?"

These groups of questions will be taken up in the order in which they have here been introduced.

I. The Laws of the Accumulation of Petroleum and Gas.

As in most forms of mineral wealth, concentration is an essential feature in the production of valuable stores of petroleum. It has been already shown that petroleum is present in most of the rocks of our shale in quantities large enough to meet the most extravagant demand, but it still remains true that the really valuable reservoirs of it are few and far between.

Our first group of questions is connected with the geological conditions that lead to these valuable accumulations. It may be remarked in passing, that the same, or at least similar conditions, are to be found in every field.

1. *The Reservoir.*

It is obvious that if the storage of petroleum is to be effected on a large scale, there must first of all, at least after a source is provided, be a rock that can serve as a reservoir. How do our ordinary stratified rocks become reservoirs of petroleum and gas? It can be answered that a stratum may serve this purpose if it is cavernous in structure; the caves resulting either from the solution of the rock throughout more or less extensive spaces, or, more rarely, from the underground movements of the rock masses.

Again, the stratum may simply be a porous rock, its porosity resulting from the character of the separate grains that compose it, if a fragmental rock, as sandstone, or from the solution and removal of small portions of the rock-mass through ordinary agencies of change, if a limestone.

In the last named class, only limestones are found; and, at first sight, it might seem as if the case were the same as the cavernous structure above named, for limestone rocks are also those in which cave formation appears. But there are, after all, marked distinctions between the two cases. The action in the formation of caverns is on the masses of the limestone rock. In the other case, it is purely interstitial.

Caves in limestone rocks have been named as furnishing possible storage capacity for oil and gas. The belief that they do so is a quite widespread popular belief in the few districts where gas and oil are obtained from rocks of this class. But there is not a single case on record in which large storage has been traced to any such structure, and there is in reality no more probability that the storage of oil-bearing limestones is due to such structure than there is that the capacity of sandstone can be thus explained. This point will be further discussed under a subsequent head.

For all the facts of oil and gas storage, the porosity of the rocks is abundantly able to account not only in sandstone, but in limestone as well, and no other explanation, therefore, will be invoked in these pages.

In the early history of petroleum in the Pennsylvania field, a notion found access to the minds of many of the operators at that time to the effect that the facts of production could only be explained by the existence of "crevices" in the rocks, and this assumed fact took for a time a prominent place in all theories concerning production. A "crevice-searcher" was invented by some ingenious driller, which, when lowered into a well, would reveal the exact location of any irregularity in a well wall, all of which irregularities were assumed to be crevices. With widening experience, however, and especially with a more careful study of the facts by those whose training has fitted them to form just conclusions from the observations, the whole doctrine of crevices has dropped out of sight. If it survives at all at the present day, it is only among the least intelligent persons connected with the work of drilling.

a. Sandstones as Reservoirs.

The drillers in Venango county, Pennsylvania, in 1859, were not long in learning the facts as to the composition and order of arrangement of the series from which petroleum was obtained. Beginning in the valley of Oil Creek, it was found that the drill first descended through several hundred feet of soft and fine-grained shales, after which a series of sandstones, imbedded in shale, was passed through.

These sandstones were three in number when the series was complete, and from the upper surface of the uppermost member to the bottom of the lowest, the interval was about 350 feet. It was at once learned that the petroleum, for which the drilling was undertaken, was confined to these sandstones, which, accordingly, took the name of "oil sands." They were named in order from above, the first, second and third oil sands. When all three were found in the well section, the oil was confined to the third or lowermost, but gas was sometimes found in the second, or even in the first. When the third oil sand was wanting, the second became the receptacle of the oil and gas, and when both the second and third were wanting, the stock was found in the first. The important fact thus came to light that the first sandstone to be reached in ascending order from the bottom of the series was the oil-containing stratum. The rocks below the oil sands were found at a somewhat later period to be gray or dark shales.

The Venango "oil sands" proved to be sandstones of medium or coarse grain, or even, in some cases, conglomerates. The third or lowermost sand, in particular, often assumed this phase, containing quartz pebbles in abundance. These sandstones were considered, in the course of the development of the field, to be elongated bars of sand or pebbles, their longer axes extending in a northeasterly and southwesterly direction. The productive fields were found to extend in length for a score or more miles in some cases, while their width would be confined to one or two miles. In thickness, the oil sands ranged from a shell to 100 feet. Some of them are described as having no outcrop, never rising to-day in their own characters. Under the interpretation of the oil sands given above, which is substantially that of Carll, these oil-containing reservoirs are seen to be lenticular in transverse section. It is in any case certain that the productive belts showed the relations named above, and further, that production was related in a very definite way to the grain and thickness of the oil sands. The coarser the sand and the more open, the greater the amount of oil, and in like manner the thicker the stratum, the larger was its production likely to be, other things being equal.

It must be noted, however, that all of the facts presented by such a field can be explained without supposing the oil rocks to be ancient sand-bars or submarine gravel ridges. Sandstone strata with an ordinary measure of continuity could present just such phenomena as we are called on to explain, under certain accidents of structure or arrangement. In fact, the sand-bar theory is not only unproved but it is unnecessary. Several of the most famous oil sandstones of Pennsylvania and Ohio, so far from being lenticular in character, are now known to be wonderfully persistent, though varying in thickness and grain from point to point, and occasionally nearly disappearing for short spaces.

The first drillers in Venango county took possession of the valleys, counting the production of oil to be confined to them; but later comers began to try fortune on the slopes adjacent, and little by little the drilling rigs overran highlands as well as valleys, the fact being soon made apparent that the only necessary advantage possessed in the valleys was the shorter distance to be drilled to reach the oil-sand.

The wells drilled on the uplands revealed the presence of other sandstone strata, lying many hundred feet above the oil-sands. To these new strata the name of "mountain sands" was given, and three of these also were enumerated, viz.: the first, second and third mountain sands. Petroleum and gas were sometimes found in these strata to a small extent.

The order that was thus ascertained to exist among the different strata penetrated by the drill in the valley of Oil Creek at the beginning of petroleum production, on the large scale, in this country, has proved to be the universal order, so far as the oil and gas fields of Pennsylvania, New York and Eastern Ohio are concerned. In all of these fields, without important exception, sandstones buried in shales have proved to be the reservoirs of oil and gas, when the latter are found in large quantity. The overlying shale is the cover or roof of the reservoir; the underlying shale appears to be the source from which the bituminous products are derived. We can count on this as the established and essential order for oil and gas accumulation in the territory already named. Several distinct beds of oil-producing sands have been brought to light besides the Venango, the most important of which are the Warren and Bradford sands, both of which underlie the Venango system.

From facts like these, it is apparent that the composition and order of arrangement of a series of strata have a vitally important relation to the accumulation of oil and gas that may take place within it. Some geologists count the composition of the series the main element in oil production. They regard especially the grain and thickness of the oil-sand or reservoir, 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. The practical driller also makes great account of these facts.

Mr. John F. Carll, of the Second Pennsylvania Survey, has discussed these questions at length in his invaluable reports on the petroleum fields of Western Pennsylvania. He claims that an oil-bearing pebble rock may contain, under favorable conditions, one-tenth, or even one-eighth of its bulk in oil, basing his claim upon the indications of experiments made upon the rock. (Second Pennsylvania Survey, I, 251.) He also shows that the pores of the sandstone would serve as channels for the largest supplies of oil that have yet been found, and that we are under no necessity of resorting to hypothetical "crevices" to account for any of the facts pertaining to the yield of oil-wells.

b. Limestones as Reservoirs.

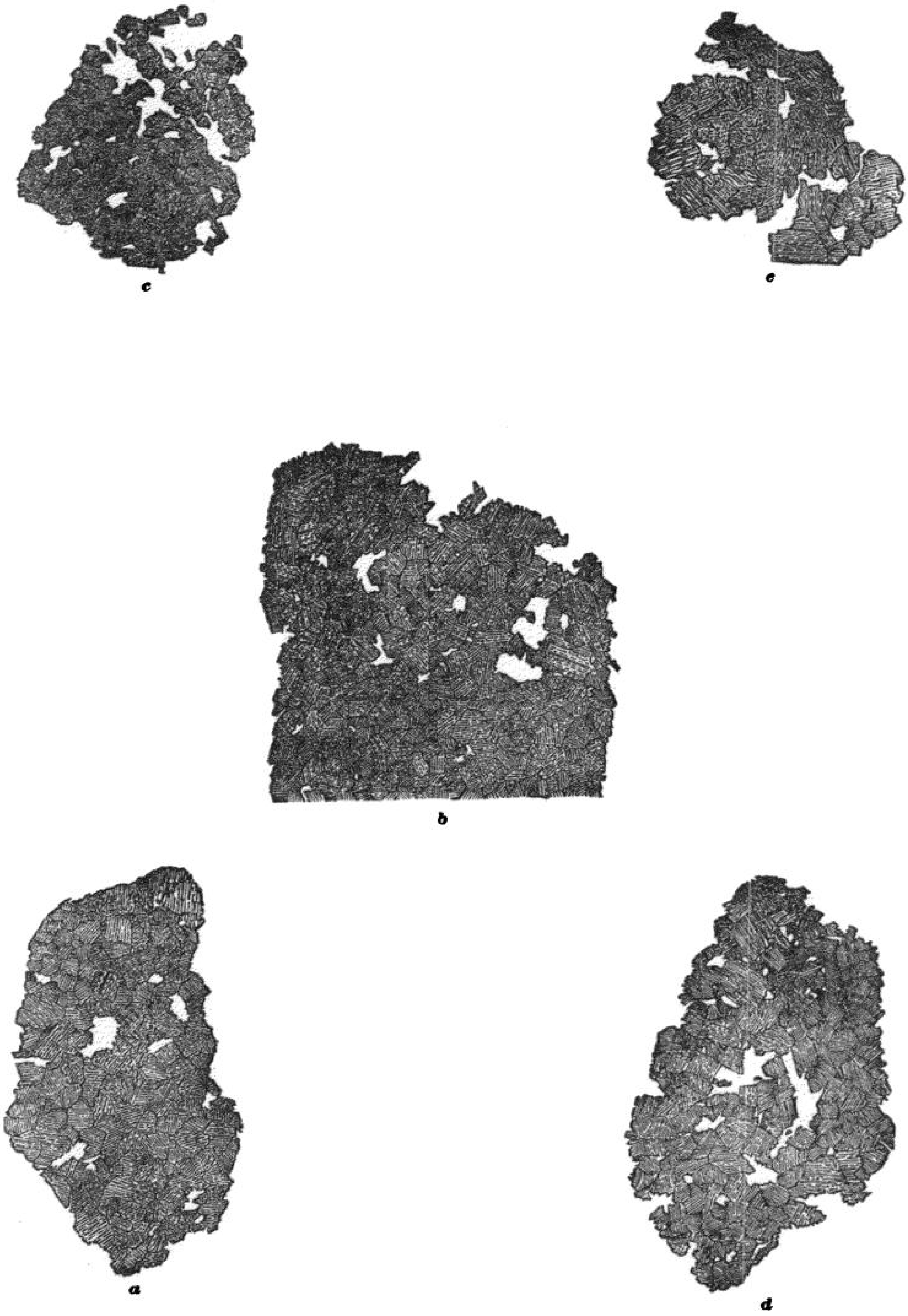
In the experience of the great oil fields of Pennsylvania, New York and West Virginia, the reservoir rocks have been found, without a single exception, to be sandstones of one or another grade. The rock sometimes passes the limits of this name, perhaps, as ordinarily applied, becoming on one side a conglomerate, or on the other a sandy shale ; but sand, coarse or fine, is the essential element in its composition. Whenever oil and gas have been found, therefore, in new locations, or in new positions in the strata within these districts, the first question to be asked is in regard to the *oil sand* or the *gas sand*, as the case may be, its name and place in the general scale, its grain, its thickness, and its extent.

This unbroken experience naturally led the drillers of the main fields to the unquestioned conclusions that oil and gas rocks were always and everywhere sand-rocks. If this conclusion was not distinctly formulated, it was because it was counted so nearly an axiom that it would go without saying.

When, then, at Findlay, Ohio, in November, 1884, drillers from Bradford, Pennsylvania, struck high pressure gas in large volume at a depth of eleven hundred feet, the rock in which it was found was unhesitatingly pronounced a gas sand. Its crystalline grain matched well enough in appearance to this view, but chemical analysis failed to sustain it, and the surprising fact was presently discovered that the rock was in no sense a sand-rock, but the gas was derived from a dolomitic or magnesian limestone of exceptional purity, so far as the best examples of it were concerned.

It was a year or more before the full significance of this discovery was recognized. But at last the facts were brought out, and the following state of things was established: The Trenton limestone is, in the main, a fairly homogeneous rock, composed of 80 to 90 per cent. of carbonate of lime, but for considerable areas in Northwestern Ohio, Michigan, Northern Indiana, Illinois and Wisconsin, its uppermost beds for five to one hundred and fifty feet have been metamorphosed. At some time in its history, the carbonate of lime has been replaced by the double carbonate of lime and magnesia. It is probable that the rock which has been thus replaced was an exceptionally pure carbonate of lime. At any rate, small portions of unchanged rock are found in the cap of the Trenton having such a composition. The porosity of the Trenton results from this replacement. The dolomite is highly crystalline, and its crystals interlocking imperfectly, leave vacant spaces between them. This is shown in the microscopic section of the gas rock, highly magnified for this purpose. The vacant spaces of this rock are seen to be much more conspicuous, and probably, on the whole, much larger than the spaces between the grains of any sandstone. The facts of the present development of the fields agree well with these conclusions. Foot for foot, the Trenton limestone has probably greater capacity of storage, and thus of production, than the best of the Pennsylvania oil-sands.

It is important to note that this replacement of the uppermost beds of the Trenton limestone is by no means a universal phenomenon. It is, on the other hand, decidedly local and exceptional, although the limits of the change as stated are quite wide. The failure of the Trenton limestone to respond to the drill in Southern Ohio, Southern Indiana and Kentucky, where



MICROSCOPIC STRUCTURE OF THE TRENTON LIMESTONE.

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other conditions seem favorable, is plainly due to the want of porosity in the upper beds of this great stratum. In other words, its failure results from its physical state, and this in turn is based upon its chemical composition.

There are other cases beside that already named in which oil and gas are found to be derived from dolomitic limestone, but thus far the Trenton limestone easily stands at the head of these sources of oil. It is by no means certain, however, that the oil production of limestones is altogether limited to those that have undergone the dolomitic metamorphosis. Crinoidal limestone, made up of broken stems and plates of stone lilies, may easily be porous enough to act as a reservoir, but no conspicuous examples of this sort have thus far been reported.

c. *Shales as Reservoirs.*

There is a third group of rocks that sometimes acts the part of oil and gas reservoirs, namely, shales. The best, and in fact the only example of large production from shale, is found in the new Meade county field of Western Kentucky. A somewhat exceptional structure is to be inferred for the shale of this field, from the very fact above noted, namely, that there is but one example of the sort known. It is true that shales have long been recognized as sources of weak flows of gas and oil. Along the extensive northern and western outcrops of the great Ohio shale through Western New York, Ohio, Kentucky and Tennessee, oil and gas springs are everywhere found, but the supplies are invariably small in quantity, and there are no indications of storage on the large scale such as would justify the application of the term "reservoirs" to the formation. In Northern Kentucky, however, the sole representative of the great Ohio shale is a mass of black shale, commonly called slate, from 30 to 90 feet in thickness, which, when found at a depth of 300 to 500 feet, and possibly at much greater depth, shows all the characteristics of the reservoir rocks. Its storage must, however, depend on the open joints of the stratum rather than on its porosity in any strict use of this word.

Shale is a rock in which the joint structure is displayed to exceptional advantage as a general rule. The black shale of the Kentucky series here referred to certainly furnishes an excellent example.

A few words remain to be said as to the extent, permeability and total production of the strata that serve as reservoirs.

Extent of the Reservoirs.

As to the first point, namely, the extent of reservoirs, it is obvious, if the account already given of them is correct, strata having a wide distribution, occupying not only many hundreds, but many thousands and tens of thousands of square miles, answer this purpose and deserve this name. But are they reservoirs throughout their entire extent? They are by no means reservoirs of oil and gas, but their failure to serve this purpose does not rise from any change in the composition or character of the strata. In point of fact, the gas and oil occupy only insignificant portions of the whole extent of this porous rock, all of the remainder being charged with water, and generally with salt water. Bituminous reservoirs, for reasons that will presently be explained, are limited to the summits of low anticlinal folds, or broad terrace-like uplifts that answer the same purpose as anticlines.

Permeability of the Reservoirs.

The fact that different portions of the oil-sands communicate with each other with more or less freedom was early established in the history of oil production in Pennsylvania. Adjacent wells were often found to affect each other's yield, and the locations of wells at once began to be made in consonance with this view. Wells were especially multiplied along boundary lines, under the selfish purpose of obtaining oil from the lands of others and in the attempt to protect rights of ownership against such unjust invasions.

The descent of surface water into the oil-sands, through abandoned wells, proved disastrous to entire fields, and it became necessary to invoke stringent legislation to guard against this source of danger by requiring wells to be securely plugged before being abandoned. In these various ways it came to be seen that there was a fairly free communication through the oil-sands, at least in some cases, for intervals of one or more miles. So, also, in thick and gently dipping strata, like the Bradford oil sand, the division of the rock into gas, oil and salt water territories, respectively, the gas holding the highest and the salt water the lowest levels, made the conclusion well-nigh irresistible that the entire rock is permeable, and that, in the course of ages, its various contents have been differentiated as we now find them, under the influence of gravitation.

But, on the other hand, it became equally clear that there was no necessary and absolute connection between different portions of an oil-sand, but that in many instances this stratum exists in lenticular masses, the several divisions of which may be nearly or even entirely disconnected. This conclusion is based on facts like these, viz: that contiguous wells often show no connection with each other, and that in what are supposed to be exhausted oil fields, small pockets of sand are sometimes subsequently discovered that furnish considerable supplies of oil. The rapid changes in thickness of the oil-sand in adjacent wells furnishes conclusive proof upon this point. We can follow the stratum down to a feather-edge by these records.

As to the degrees of permeability which characterize the rock in question, it is thus seen there are wide variations. The same stratum may differ greatly in different portions of its extent. The subject is of great practical importance. The number of acres to be assigned to a single gas well or oil well, in a wise and economical administration of a field, depends altogether upon this factor; but the qualification above made asks more than can be rendered. There *is* no wise and economical administration of a gas field or oil field. The nearest approach to such a thing thus far made is found in the working of the great corporation that obtains control of gas land or oil land in solid blocks of large extent. The experience of these corporations is, however, of comparatively recent date, and but little of it has been made public as yet. In many fields, it is certain that the number of wells required to drain the rocks is not only duplicated, but in all probability is multiplied many times. In some fields, five acres are counted a fair allowance for a well; in others fifty would better meet the facts; and in still others a single well will doubtless drain a still larger area if time enough is granted to it.

Total Production of the Oil Rocks.

Under this head also there is a great dearth of facts. The only figures that command consideration are those derived from some portions of the Pennsylvania field. Mr. Charles A. Ashburner, of the Pennsylvania Geological Survey, has calculated that a total production of 900,000 barrels of oil to the square mile has been realized from very limited areas in the best parts of the Pennsylvania fields.

II. The Cover of the Reservoir.

The three kinds of stratified rocks to which, so far as present experience goes, the large accumulations of oil and gas are limited, have now been passed in brief review. They are as follows: First, sandstones of various grades as to grain and purity; second, limestones generally dolomitic in composition; third, shales which owe all the storage capacity that they may possess to their jointing.

A factor in the large production of oil and gas that is common to all these reservoir rocks, must next be mentioned, namely, the cover or roof of the porous stratum. It is obvious that reservoir rocks must have more or less impervious roofs to retain their contents. The same upward tendency of oil and gas, by which the porous rock has itself been charged from lower sources, would empty it in due time, unless the ascent of its contents were prevented by a stratum that forbids their passage. The most common, and, at the same time, most perfect cover of an oil rock, is a stratum of fine-grained shale. This order was discovered in the drilling of the first wells in the Oil Creek field of Pennsylvania, as shown on a preceding page, in which the three sandstones that were found to be possible sources of oil are buried in a mass of fine-grained blue shale, incorrectly termed soapstone by the driller.

So common is the occurrence of petroleum in stratified rocks, that wherever a close-grained shale occurs, there is almost always at least a small accumulation of oil directly underneath it. The same thing occurs when an impervious stratum of any other composition than shale occurs in the series. From such facts, it may almost seem that the proper cover of an oil and gas rock is harder to find in nature than an adequate source of gas and oil.

That these investing rocks are not entirely impervious is evident from the fact that oil and gas find their way through them to the surface. These escapes are often facilitated by breaks in the continuity of the stratum resulting from flexures. When the rocks of any series have been flexed to the breaking point, it seems useless to look for oil and gas within them. No valuable accumulations have been reported under such circumstances, unless the California field may prove an exception. The details of the structure here, however, have not been given fully and clearly enough to warrant important inferences from this field alone. The entire absence of oil and gas from Central and Eastern Pennsylvania and adjacent territory seems well enough explained by the broken structure of the strata. Easy ways of escape have been abundantly provided for all the bituminous accumulations that may have been gathered here.

III. The Structure or Arrangement of Oil-bearing Rocks.

If an adequate source of petroleum is found in the deep-lying rocks of any district, as, for example, in the great series of shales of Pennsylvania, Ohio and Kentucky, and if overlying this series, one or more porous strata are found, as, for example, the Berea grit of Western Pennsylvania and Northern Ohio, and if this porous stratum is in turn roofed over by a heavy bed of fine-grained and fairly impervious shale, as, for example, the Berea and Cuyahoga shales of the district last named, will valuable accumulations of oil and gas, or both, certainly be found throughout the porous stratum? The conditions of accumulation thus far insisted upon appear to have been met. There are source, reservoir and cover, all in due order, and, according to the supposition, in proper state for the offices respectively assigned to them.

The question is easily answered. The rock series already named meets all the demands thus far announced over many thousand square miles, but the areas of oil and gas territory cannot even be counted within these limits by tens of square miles. Oil and gas would lose all their market value by reason of their abundance if the above stated question could be answered in the affirmative. While the order above named is insisted upon by nature, this is not all that she demands. What additional requirements must be made to constitute an oil or gas field? The question is an important one. The answers to it deserve to be carefully noted. To the facts already named, a *particular structure* or *arrangement of the rocks* must be added. The reason why oil and gas territory is so rarely met, and therefore so valuable when it is found, is because the last of these conditions occurs in so few instances. The primary conditions of source, reservoir and cover are coextensive with entire districts, but the accessory condition of favorable structure is limited to very small and definite areas.

To understand the nature of the last element, a brief review of the conditions under which the strata have reached their present state and arrangement is necessary. The strata of which Kentucky is built up were all successively deposited on the sea floor. The sea floor can be safely assumed to have been approximately level at the time of this deposit. For, if any depressions or irregularities at any time existed, the first work of nature would be to obliterate them by filling these depressions and smoothing over the irregularities. We see that work like this must be going on upon the sea floors at the present time. But the strata that constitute the state are no longer horizontal. They are bent and warped in various ways. If originally deposited in a horizontal plane, how have they acquired their present dispositions?

It must be remembered that all of these strata go back for their origin to the paleozoic age, and that periods of time, vast beyond conception, have passed since they were laid down upon the ancient sea floor. But the earth, we know, is a cooling, and therefore a contracting globe. It is to the shrinkage or contraction in size from its volume when these strata were formed that all the folds and irregularities of its beds are due.

This shrinkage has often taken place with a considerable measure of regularity, as is seen in the parallel folds of a mountain system like the Appalachians, for example, occupying hundreds of thousands of square miles in extent, and built up on a symmetrical plan. In other cases, however, there are single breaks or lines of disturbance limited to comparatively small districts.

Both of these cases occur in Kentucky. The eastern extremity of the State has been invaded by the long ridges of the Appalachian chain. In Central and Western Kentucky, on the other hand, there are small and isolated regions of disturbance sometimes marked by the dislocation of strata.

In addition to both these main and striking forms of movement, there is a more important class than either, because more widespread, revealed in the very slow and uniform descent in a given direction of the strata for large areas. The fall of the rocks may be but a few feet to the mile, entirely too small to be measured by instruments when applied to any single section, and susceptible of determination only when widely separated outcrops are considered. This peculiar structure is characteristic of large areas of the Mississippi Valley. It is undoubtedly due to the slow and long-continued rise of the sea floor in an extended axis or ridge while the strata were in process of deposition. This last feature distinguishes it from the mountain folds. The latter were formed by bending into arches strata that had already been completed.

But even these regions of uniform and gradual dip are occasionally crossed by slight irregularities of their own, which become of great interest in connection with oil and gas accumulations.

a. *Anticlines or Arches.*

There are two forms of structure that have been found connected in a very influential way with the storing of gas and oil, namely, anticlines and terraces. The anticline or arch is the most frequent, and, at the same time, the simplest form of rock disturbance. The strata of a particular section are required by the secular contraction of the earth to adjust themselves to a shorter horizontal extension than they have heretofore had. They do so by an exchange of horizontal for vertical extension. The strata that constitute the section, together with the foundations on which they rest to a great depth, are flexed into an arch or into a series of parallel arches, the height of which depends on the amount of contraction for which provision must be made. The arches are often broken at the top, in which case they apparently lose all value in this connection, through the escape of these hydrocarbons; but, in other cases, the rise and fall of the strata are so gentle that the continuity of the beds remains unbroken. The porous rocks already described, as the reservoirs of gas and oil, share necessarily in all these movements, and, as they are lifted into arches, a differentiation of their contents necessarily follows, the gas, of course, claiming the highest chambers of the rock, the oil succeeding it, while the troughs are filled with water.

The influence of anticlines on the accumulation of petroleum and gas has been discussed ever since the discovery of these substances in this country on the large scale. Definite theories as to the influence of such disturbances as have occurred in the oil-producing territory were early propounded, some of which have been maintained to the present day.

The "oil-break" of West Virginia, in the neighborhood of Burning Springs, furnished, in the early days of the search for petroleum, an example of the effect of structural disturbance on oil production that he who runs might read. There is an uplift there at once considerable and conspicuous, viz: the White Oak anticlinal, and the productive oil wells, out of the great number of wells which were drilled in this region, were found to be strictly confined to the region of the anticline or axis. These facts were brought out in a very clear manner by the late Professor E. B. Andrews, in a paper published in the American Journal of Science (2, XLIII, 33). The discovery of the axis in its relation to oil production seems to have been made by General A. J. Warner, in connection with Professor Andrews, in 1865. Beyond the structural disturbance shown in the anticlinal, Professor Andrews also claimed the existence of crevices or fissures on the large scale in the rocks from which the oil was derived. To effect the separation of water, oil and gas in the supposed crevices, he invoked the force of gravitation, showing that these substances would necessarily be arranged in the order of their densities in any space which they should occupy in common.

The clue that was thus given as to the location of successful wells was, of course, promptly followed. The anticline was traced throughout its entire extent, and test wells were put down at numerous points, but of these a large percentage failed. To account, if possible, for these failures, Mr. F. W. Minshall, of Parkersburg, West Virginia, undertook at a later date a careful determination of the levels of the axis. He found that instead of either keeping a horizontal plane, or of dipping regularly and uniformly, it advanced by a series of pronounced undulations, having domes or summits at some points, and sinks or sags at others. All of the productive oil and gas wells had been located on the domes, and the failures were to be found in the depressions. (10th Census Reports, X.)

Dr. T. S. Hunt, at a still earlier date, viz: in 1863, 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 taught that the anticlinal structure is a necessary condition for a large production of petroleum, referring its accumulation in such portions of the series to hydrostatic laws. (American Journal of Science, March, 1863.)

Dr. Newberry seems also to accept the anticlinal theory, though his statements on this point are less explicit than those already quoted. In speaking of the Canada oil-field, he says:

"This district is in the line of the Cincinnati arch, which here, as in the islands of Lake Erie, shows evidences of disturbance long subsequent to its original upheaval."

In speaking of the Pennsylvania oil-fields, he says:

"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 in a great mass of carbonaceous strata below, more or less disturbed and loosened, from which oil is supplied in a constant and relatively copious flow; above this, strata of porous, jointed sandstone, serving as reservoirs, where the constant product 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." (Geology of Ohio, I, 159.)

Elsewhere, he says:

"The facts I have observed lead me to conclude that the disturbed 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 up 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, we find the rocks more undisturbed, and the escape of oil and gas, through natural or artificial orifices, gradually diminished." (Ibid, 183.)

This reasoning, as will be seen, is in harmony with the anticlinal theory. From the statements already quoted, it is shown that distinct theories and claims have been advanced during the last twenty years, connecting the accumulation of oil and gas with anticlinal structure.

Within the last few years, since natural gas has attained such prominence in Pittsburgh, its sources and the conditions of its occurrence have been studied anew with sharpened inspection, by both geologists and practical men, and some real advance seems to have been made in our search for it. The anticlinal theory has been revived and extended, and has been used successfully in the location of many productive wells. For the new statement, we are indebted to Professor I. C. White, of the University of West Virginia, and recently of the Pennsylvania Geological Survey. Professor White, in turn, gives credit to Mr. W. A. Earseman, an oil operator of many years' experience, who had noticed in 1882-3, "that the principal gas wells then known in Western Pennsylvania were situated close to where anticlinal axes were drawn on the geological maps. From this he inferred there must be some connection between the gas wells and the anticlinals."

Professor White goes on to say:

"After visiting all the great gas wells 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 synclines 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 to one 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 location 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 are found on the anticlinal axes, the converse of this is not true, viz.: that great gas wells may be found on all anticlinals. In a theory of this kind, the limitations 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 three or four general rules, which include practically all the limitations known to me up to the present time, that should be placed on the statement that large gas wells may be obtained on anticlinal folds, viz:

"(*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 (500 to 2,500 feet). 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 traverse 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 anticlines, provided the dip be sufficiently rapid, and especially if it be irregular or interrupted with slight crumples. And even in regions where there are no marked anticlines, if the dip be somewhat rapid and irregular, rather large gas wells may occasionally be found if all other conditions are favorable." (Science, June 26, 1885.)

To the qualifications already made, Professor White would probably add, at this time, one to the effect that gas wells shall be located on the domes of the axis, rather than its depressions, recognizing the same line of facts in regard to them that Minshall had already established in the case of the White Oak anticlinal of Ohio and West Virginia, to which reference has previously been made.

The facts cited by Professor White as to the gas supply of Pittsburg are conclusive. Every foot of it comes from anticlines, but not from them because it has been sought nowhere else, but because, if found in other stations, it is speedily overcome and extinguished by salt water. Where anticlines of the type here referred to traverse an oil-bearing series, it may be considered demonstrated that they exert a decided effect on the accumulations of oil and gas in this series. So rational is such a conclusion, so directly does it result from the facts already stated, that it is hard to see on what grounds it can be called in question.

While there is no element of the theory, as stated by Professor White, that differs from the theory as heretofore stated, his applications of it are bold, original, and, best of all, successful, and they mark a new period in our study of the geology of oil and gas.

The entire gas production of the new fields of Ohio and Indiana furnish the clearest proofs of the truth of the doctrine above stated. The facts are not only entirely consistent with the theory, but they are inconsistent with any other, and they may be counted as completing the demonstration in its favor.

b. The Terrace Structure.

Nature sometimes begins to build anticlines which she does not finish. In a region of uniform dip, for example, the upheaving force may go no further than to arrest the steady descent of the strata. If the whole had lain horizontal at the beginning, the force exerted would have been sufficient to bend them into a low arch; but, as the strata were descending, the force has all been used in arresting the descent and bringing the beds up to an approximately horizontal position for a small space. This peculiar structure has been designated "arrested anticlines." (Geology of Ohio, VI, 94.)

Mr. F. W. Minshall, of Marietta, was the first to bring this terrace structure into distinct notice. He discovered it in the famous Macksburg oil field of Southern Ohio, and here it was worked out under the Ohio Geological Survey by a careful series of instrumental measurements that left no question as to its reality; while, at the same time, the economic development of the field showed the controlling influence of structure on oil and gas production throughout the territory involved. Since that time similar structure has been discovered in other oil fields of Ohio, and it is probable that adequate series of facts would reveal it as a frequent, if not a universal, element in oil production. It is much to be regretted that the great oil fields of Pennsylvania and New York have not been studied in such a way as to bring out the laws of their production. If the figures pertaining to even a small portion of the 50,000 wells which have been drilled here, had been reduced to some common datum, as the sea level, it is certain that generalizations could have been gathered from each field that would have made all the results of these explorations thoroughly intelligible. All the facts of the great fields in this line that are available point unmistakably to the same conclusion that the Ohio fields have established, namely, that oil is likely to be gathered in terrace-like expansions of the reservoir rock. It is not necessary to insist on absolute horizontality in our definition of a terrace. If the dip is reduced to five, or even ten feet to a mile, it is perhaps all that need be asked in this respect. Such hints as we have as to the structure of the great Bradford field, for example, render it certain that it would have furnished a magnificent example and confirmation of this view, if only the facts had been adequately gathered and tabulated.

It must not be forgotten, however, that the terraces are in reality parts of anticlinal systems, and follow the same lines of geographical direction that sharper folds exhibit. The sketch map of the oil fields of Pennsylvania and New York, which is found on the succeeding page, renders it clear beyond the possibility of doubt or question that the oil fields have been developed along the great structural lines of the regions to which they belong.

In the now famous field of Findlay, Ohio, the terrace structure has proved itself equally efficient in both gas and oil accumulation. The two products are separated here by sharp boundaries following persistent lines, and the drill has demonstrated the existence of two terraces arranged side by side, and connected by a monocline, the upper terrace being occupied exclusively by dry gas, the lower by oil and salt water. The interval between the two terraces at their line of juncture is about 150 feet. The new gas field of Central Indiana exhibits similar terrace structure.

The structure of the new gas field of Meade county, it will be seen hereafter, comes under this head rather than under the preceding division. The productive arch is so low and flat that it may better be called a terrace than an arch.

In concluding this division of the subject, it may be said that the high pressure gas of the Pennsylvania fields is derived from pronounced anticlines, and the oil is apparently accumulated on terrace-like expansions of these arches, while the terrace structure, pure and simple, predominates in both oil and gas production of the new fields of Ohio and Indiana.

IV. The Presence of Salt Water in Oil Rocks and Gas Rocks.

Oil rocks and gas rocks have been shown to be porous rocks, covered with impervious shales, and in some way connected with underlying sources of petroleum. Are there any porous strata that are entirely and exclusively devoted to the storage of these fossil hydrocarbons? None such are known. All the gas rocks and oil rocks that have ever been worked have, without exception, contained in some part of their extent water, and, in the great majority of instances, salt water. When the rock lies at comparatively small depth, as, for example, less than 500 feet, it often contains fresh water, but generally at greater depths, and sometimes at less as well, it is for the most part occupied with salt water in all portions of it that are not filled with oil and gas. Even when occupied with fresh water at shallow depths, the same stratum, when followed to a greater depth, generally becomes a salt-water rock. This association of salt water and oil has been conspicuous from the first. It will be remembered that the original discovery of oil and gas in deep wells came from drilling that was undertaken in the search for salt water. It is certainly true that all the strata which have yielded brine for salt manufacture have, in some portion of their extent, yielded gas and oil also. It is not only true that all gas and oil rocks are salt water rocks, but the converse has but very few exceptions; namely, all salt water rocks carry gas and oil as well.

What is the source of the salt water that the oil rocks contain? No other source than the sea in which they grew need be looked for. It is not necessary to find beds of rock salt at great depth to account for the enormous supplies of salt water with which all porous rocks are generally filled. They have been charged with this from the date of their formation.

These deep brines sometimes vary widely in composition. Hunt has suggested that the Silurian brines may represent the composition of the sea water of an earlier day, and notably different from the composition of salt water at the present time. An important fact in this connection is, that the quality of the brines varies with the rock from which they are derived. Limestone, for example, carries sulphurous and otherwise impure brines. The best brines are derived from sandstones.

Do these rocks reach the surface at any point? Certainly they do. They form constituent parts of the general series, and share all its fortunes. When found in outcrop, they necessarily receive their portion of the rain-fall of the regions to which they belong. This fresh water follows the stratum downward through its various flexures, blending at length with the salt water that fills the great mass of the rock.

When the porous rock in its salt water areas is penetrated at considerable depths by the drill, the brine invariably rises a greater or less distance in the well. Sometimes it overflows, but in other cases it falls short of reaching the surface by 50, 100 or 500 feet. The elevation that it reaches in one well it is likely to reach in others drilled near, indicating a common source and common pressure for all. What causes the salt water to rise in the wells? The answer is plain. The water is simply responding to artesian pressure, and thus is governed by the elevation of the outcrop of the porous stratum. The latter may be carried in mountain folds to considerable elevations, and thus give high pressure even when the wells are not excessively deep. But this porous stratum that we are considering has a small amount of oil and gas distributed through it; and it must be remembered that the rock never lies horizontal for any great distance, but has been variously flexed by the accidents of its geological history. Numerous folds, greater or less, are sure to be found in it. Where shall we look for the stocks of gas and oil above referred to? Under such circumstances as we have supposed, gravitation would have been sure to effect a separation of substances that differ as greatly in weight as the three that together fill the pores of this reservoir rock. Gravity, in other words, will drive forward the gas to the highest point or arch of the stratum. The oil will take its place next below, while to the salt water the remainder of the rock, or, in reality, almost its entire volume, will be surrendered. All the low-lying regions of the porous stratum in particular will be flooded with salt water.

If now a well be drilled to the stratum along one of these lines where all three substances are located in close proximity to each other, it is plain to see that any one of the three substances, gas, oil or salt water, may be yielded to the drill, according to the location of the drill hole. If we drill into a trough of the rock, we find the salt water following the drill as soon as the reservoir is reached, and very likely it will overflow the well. The cause of this ascent of the salt water we have already seen, and we must keep it clearly in mind. It is an artesian flow. But if the drill descends into the oil space, what is the result? The oil may rise and overflow the well with great force. Gas is sure to be mingled with it in such a case. Let us make one more supposition. Suppose the drill reach the gas area of the porous rock upon the summit of one of the unbroken arches we have already described. What are we to find now?

The phenomena of a high pressure gas well are among the most striking in the whole range of mining enterprise. The gas issues from the well head with a velocity twice as great as that of a ball when it leaves a minie rifle. The noise with which it escapes is literally deafening. Exposure to it often results in loss of hearing on the part of those engaged about the well.

What is it that originates this indescribable force? What else do we need but the force we have just left, acting on the salt water which lies, it may be, but a few rods away from the gas well, and but a score or two of feet below in absolute depth?

It seems impossible to escape the conclusion that the pressure of the water column contained in the rock is responsible for all the effects of the outflows of gas and oil. Natural gas is compressed in the arch of the reservoir rock under ths pressure of a water column, just as artificial gas is compressed in the gasholder of the city works.

What other explanations of these remarkable facts have been offered? But two have been put forward that deserve special consideration. Both will be briefly stated here.

One of them teaches that the rock pressure of gas is derived from its expansive nature. Solid or liquid materials in the reservoir are supposed to be converted into gas as water is converted into steam. The resulting gas occupies many times more space than the bodies from which it was derived, and in seeking to obtain the space demanded by the change through which it has passed, it exerts the pressure which we note.

This view has, no doubt, elements of truth in it, even though it fails to furnish a full explanation. For the pressure of shale gas, it may be that no other force is required. But the theory is incapable of verification, and we are not able to advance a great ways beyond the statement of it. Some objections to it will also appear in connection with facts that have been already stated.

The second of these explanations is, without doubt, more generally accepted than any other by those who have begun to think upon the question at all. It is to the effect that the weight of the superincumbent rocks is the cause of the high pressure of gas in the reservoirs. In other words, the term rock pressure is considered to be descriptive of a cause as well as of a fact. That a column of rock 1,000 or 1,500 feet deep has great weight is obvious. It is assumed that this weight, whatever it is, is available in driving accumulations of gas out of rocks that contain them whenever communication is opened between the deeply buried reservoir and the surface.

Is this assumption valid? Can the weight of the overlying rock work in this way?

Not unless there is freedom of motion on the part of the constituents of the rock, or, in other words, unless the rock has lost its cohesion, and is in a crushed state. If the rock retains its solidity, as Professor Lesley has shown, it can exert no more pressure on the gas that is held in the spaces between the grains than the walls of a cavern would exert on a stream of water flowing through it. The distinguished geologist named above has discussed this theory at some length, and has shown its entirely untenable character. (Annual Report, Penna. Survey, 1885.)

The claim that the Trenton limestone, for example, where it is an oil or gas rock, exists in a crushed or comminuted state, is negatived by every fact that we can obtain that bears upon the subject. The claim is, in fact, entirely inadmissible and preposterous, but without this condition the theory fails.

Neither of these explanations of the rock pressure of gas and oil is found to be valid when subjected to any adequate examination, and we are left, therefore, to rely altogether upon the theory first stated, viz: that the flow of gas and oil depends upon the pressure of a water column, or, in other words, every flowing gas well or oil well is in reality an artesian well. With the principles involved in ordinary artesian wells, all intelligent persons are familiar, and it will, therefore, be easy for such to extend the applications of these laws to the cases now under consideration. An artesian water well obtains its supply from the syncline or trough of a folded section of rocks. Gas and oil, on the contrary, must come from the anticlines of the same or similar series.

Demonstration of the Artesian Theory.

The facts, recently accumulated in the great gas-fields of Northwestern Ohio and Central Indiana, afford a demonstration of the truth of the artesian theory of the rock pressure of natural gas, so far as these fields are concerned, and at the same time they render it probable that the cause, which is found present here, is equally operative in all other gas-fields as well.

The facts that enter into the demonstration come under the following heads, viz: (*a*) the height to which the salt water rises in wet wells; (*b*) the density of the salt water; (*c*) the depth below the surface at which the water is found in drilling the wells; (*d*) the initial rock pressure of the gas when it is reached by the drill.

(*a*) As to the height to which the salt water rises in wet wells, there is not as much *exact* information as could be asked. A salt water well is, by its very nature, a failure, and the driller loses all interest in it from the time that its real character is made apparent; but we can sometimes obtain from his statements some clue as to the height to which the water ascends. The level at which the casing stands is an important point in the record of every well. When, therefore, the salt water is reported as rising 100, 200 or 300 feet in the casing, we can learn from such a record its approximate absolute height. The casings in the Findlay district are set at an elevation of 300 to 400 feet above tide. Salt water that ascends 100 or 200 feet into the casing is thus seen to have an absolute elevation of 400 to 600 feet above tide. When the surface of the ground in which the well is drilled is lower than in the field last named, it becomes easier to get accurate figures. Along the shore of Lake Erie in Ohio, and in the Wabash Valley of Indiana, we obtain our most reliable data. The salt water rises nearly to the surface in the former district, and flows out in true artesian fashion from wells drilled in the last-named region, the surface of the valley being lower than that of the shore of Lake Erie.

As a result of all the observations made, it can be stated that the strong and free flow of salt water from the Trenton limestone in the new gas-fields rises to approximately the same height in all wells, viz: to a level of about 600 feet above tide, whatever the elevation of the surface. or the depth below the surface, at which the gas or oil is found.

This rise of the salt water must represent the height of some outcrop of the Trenton limestone in its porous condition. Such an outcrop is found on the shores of Lakes Huron and Superior, and at approximately the same elevation as that to which the salt water rises in the new gas-fields, viz: 600 above tide. Fresh water finds access to the limestone in these outcrops; but its influence, while available for pressure, would not go far towards changing the character of the peculiar bitterns or brines that occupy this great sheet in its subterranean expansion.

(*b*) The specific gravity of the salt water of the Trenton limestone is high. Several determinations show a gravity of 1.1, and some samples are even heavier. A column of fresh water, one foot high, and having a one-square inch for the section, weighs .43285 lbs. avoirdupois. The weight of such a column of average sea-water is .445 lbs.; but twelve cubic inches of the Trenton brine, counted at 1.1, weigh .476 lbs. The weight may go as high even as .5 lbs.

(*c*) The depth at which the gas or oil is found is the one element in the calculation that can, as a rule, be definitely ascertained. Coming, as they do, from the surface or near the surface of the Trenton limestone, the depth at which this great stratum is reached is a fact of universal interest and record in all the subdivisions of the fields.

(*d*) The remaining inquiry, that, namely, pertaining to the original rock pressure of the wells, does not admit, as a rule, of determination or observation at the present time; and to learn the facts, we must go back to the records of the earliest wells drilled in each portion of the productive territory. The pressure of a gas-field is reduced, and generally promptly, as soon as wells are multiplied to any considerable extent in it, and when we inquire for the facts of the pressure at the opening of the fields, we frequently find more or less uncertainty. Gauges are not always reliable, and, more than that, they are not always promptly applied. Exaggeration also finds place in these early records, to some extent.

In the list of early pressures, reported from the different portions of the gas-fields, the following figures are counted fairly trustworthy and fairly representative to the districts to which they belong:

Tiffin, Ohio	650 lbs.*	*(NOTE.—The gauge used in this well read only to 600 lbs., but the index indicated an excess of 50 lbs.)
Upper Sandsky, Ohio	515 "	
Bloom Township, Ohio	465 "	
Findlay, Ohio	450 "	
St. Mary's, Ohio	390 "	
St Henry's, Ohio	375 "	
Kokomo, Indiana	328 "	
Marion, Indiana	323 "	
Muncie, Indiana	300 " †	†(Rep'd as "less than 300 lbs.")

These figures will now be combined with other data from the respective wells, and to them will be added, for comparison, a column, containing calculations of the pressure that should result from the following factors, viz: (*a*) an assumed ascent of the salt water to 600 feet above tide; (*b*) an assumed specific gravity of 1.1 for the salt water, which gives .476 lbs. to the foot in pressure. If the gas rock is found below tide, the figures, representing this depth, must be added to the 600 feet above tide, to which the water rises. These sums will represent the effective water column. The rock pressure should be, according to theory, the product of the numbers thus resulting, and the weight of a column of Trenton limestone brine, one foot in height and one inch in section, which is .476 lbs.

Location of Wells.	Depth to Gas.	Relation of Gas Rock to Sea Level.	Original Pressure.	†Calculated Pressure.
Tiffin, O.	1,500 ft.	747 ft. below tide.	650 lbs.	1,347×.476=641 lbs.
Upper Sandusky, O.	1,280 "	478 " " "	515 "	1,078×.476=513 "
Bloom Township, O.	1,145 "	395 " " "	465 "	995×.476=476 "
Findlay, O.	1,120 "	336 " " "	450 "	936×.476=445 "
St. Mary's, O. . . .	1,159 "	238 " " "	390 "	838×.476=399 "
St. Henry's, O. . . .	1,156 "	200 " " "	375 "	800×.476=476 "
Kokomo, Indiana. .	936 "	98 " " "	328 "	698×.476=332 "
Marion, Indiana . .	870 "	78 " " "	323 "	678×.476=323 "
Muncie, Indiana . .	900 "	*0 " " "	—300 "	600×.476=286 "

*At tide level.

†Add 600 to figures in third column, and multiply by .476 lbs.

The agreement between the last two columns of the tables affords a demonstration of the principal cause of the rock pressure of Trenton limestone gas. It is due to the weight of the salt water that occupies the porous rock jointly with itself, though by a very unequal partnership, and the water pressure in turn is unmistakably of artesian origin.

A few obvious conclusions that follow the acceptance of the artesian theory will find appropriate place at this point, and will conclude the discussion of this particular subject.

1. The supplies of gas and oil are seen to be definitely limited by this theory of rock pressure. If a salt water column is the propelling force, it is idle to speculate on constantly renewed supplies. The water advances as the gas or oil is withdrawn, and the closing stage of the oil rock is, as already pointed out, a salt water rock.

2. Other things being equal, the rock pressure will be greatest in the deepest wells. The deeper the well, the longer the water column.

3. Other things being equal, the rock pressure will be greatest in districts the gas or oil rock of which rises highest above the sea in its outcrops. The 800 pounds of rock pressure in Pennsylvania gas wells, as contrasted with the 400 pounds pressure of Findlay wells, can be accounted for on this principle.

4. Where both oil and gas are found in a single field, the first sign of approaching failure will be the invasion of the gas rock by oil, or of the oil rock by salt water. Salt water follows the gas directly, however, in a great many fields without the intervention of an oil horizon.

5. This explanation shows the lack of all foundation for the views advanced from time to time by sciolists, wrongly called scientists, as to imminent dangers that are to result from air entering the gas rock, and there forming an explosive mixture, or from extensive subsidence of the regions from under which the gas has been withdrawn. Such notions, whenever advanced, are sure to obtain wide currency through the newspapers, but they are utterly foolish, and, so far as they disquiet the minds of the ignorant, are mischievous.

II. The Discovery and Development of Oil Fields and Gas Fields.

We have seen that immense accumulations of oil and gas are sometimes found in the stratified rocks of the earths' crust. They occur in various kinds of strata, and at depths below the surface ranging from 100 to 2,500, or even 3,000 feet. We have also seen that these reservoirs are the source of enormous wealth to the individuals or companies who find access to them. A single one of these pools of oil or store-houses of gas may prove to be one of the great prizes of the modern mining world.

How are these reservoirs discovered? Are they found accidentally, or as a result of definite search? If the latter is true, what is there to guide the search? Are there natural signs of the presence of petroleum and gas that will lead us to their places of concealment, or are there geological indications that can be profitably followed in locating wells? These are the kinds of questions that are to be considered under this general division.

1. Discovery of Petroleum and Gas.

Most of the early discoveries of petroleum and gas were made accidentally, as has been shown in Chapters I and II. In the search for brine to be used in salt manufacture, both of them were first brought to light in this country. But since the modern utilization of these substances, a direct and costly search by the drill has been instituted and carried forward on a large scale throughout many parts of the world. Our recent supplies, including all the largest ones that have been thus far obtained, are the result of this search. In this country, where by far the greatest development has taken place, the search has, until quite recently, been guided by a few facts and a great many theories. Most of the latter have been crude generalizations from an insufficient number of inadequate observations, but they have served to meet, for the time at least, the natural and imperative demand of the mind for some rational basis of action.

In answer to the question, how are these stocks of oil and gas brought to light, it can be said that the new stocks are frequently fonnd in the drilling of trial wells, commonly known as "wildcat" wells, which are located outside of all the boundaries of known production. When once a new district is indicated, by reason of such a well yielding gas or oil in noteworthy amount, the aim of outside parties is to secure territory as near to the successful well as possible, so as to make its experience available for their own use, and possibly to divide its supplies of oil and gas. The discoverer of a new source of oil was, in the earlier times, often robbed of most or all the value of his discovery by the crowding upon his lines of drillers who would avail themselves without scruple of his good fortune. To guard against such results the driller, in entering upon new territory, has been obliged to secure by leases the exclusive right to drill upon large and connected bodies of land, so that if any value is found in the property, the discoverer will be able to appropriate at least a fair share of it. The leasing of oil and gas territory, therefore, becomes the first stage in the development of a new oil field. Leases vary greatly in form, and also in the advantages which they give respectively to land-owners and oil-producers. A form that is in common use in Kentucky at the present time is given below:

"That for and in consideration of one dollar paid, the receipt of which is here acknowledged, and the other considerations hereinafter mentioned, the parties of the first part have, and by these presents do bargain, lease and convey unto the said parties of the second part the gas, oil, mineral gases and waters on, in and under the following described land, viz: * * * * * *

"As well the right and privilege to dig, bore and prospect for same on said land, and the right to such use of said land as may be necessary to produce said gas, oil or waters, and transport same to market, and the right to produce same and prospect therefor, and to open wells for same and to operate them; to have and to hold unto the parties of the second part and their assigns all of said rights and privileges.

"The parties of the second part agree and promise to pay to the parties of the first part fifty dollars per annum for each well they dig or open on said land and which they operate, for each year they so operate same, and one-sixteenth of all gas, oil or waters taken by them from wells on said land, to be taken by parties of first part at such wells, and all of same at well that the parties of first part may use for domestic purposes.

"Unless the parties of second part, or their assigns, shall begin to bore or prospect for said oils or gases on said land within three years from this date, this lease shall be null and void."

The greatest variety in leases is in the proportion of the production that is assigned to the land-owner. The form above given allows $\frac{1}{16}$, but others $\frac{1}{8}$, $\frac{1}{6}$, and even $\frac{1}{4}$ of the total product. Their provisions also vary as to the cash rental of the wells. In some cases entire farms are leased at a cash rental per acre as long as they are held. In some recent instances, the land-owner reserves for his own use a certain part of every tract or farm which is leased. He is much better able to secure a fair share of the profit of a successful field in this way. This modification of the old form of lease, has every thing in its favor so far as the interest of the land-owner is concerned.

In locating these trial wells, the driller is sometimes guided by the lines of direction which have been established upon the wells previously drilled in the nearest fields. In such cases he simply extends the lines for a considerable distance beyond proved territory. In other cases, and these constitute by far the larger number, the driller locates his venture with sole reference to the surface features of the country within which he is to operate. But during the last few years the most extensive explorations have grown out of the ambition or the supposed necessities of cities and towns, scattered far and wide, to find natural gas for themselves, in order to compete with their fortunate neighbors, who have already secured a supply. Drilling has been carried on over entire States in this search, and, as a result, numerous important additions have been made both to the fields and the horizons of gas and petroleum.

2. *Surface Indications.*

Reference has already been made to the fact that the driller is guided, to a greater or less degree, in his selection of territory to be tested by some of the superficial phenomena of the country. What are the kinds of facts he employs in this way?

He sometimes finds a clew, as he imagines, in the ordinary surface features of the country. He is familiar, for example, with the oil-producing territory of Western Pennsylvania or of Northern Ohio. The former is a high-lying plateau, much dissected by the long-continued agencies of erosion; the latter is a drift-covered plain that departs in but small degree from a horizontal surface. Such surface features as are here indicated will of course be duplicated in many regions, the geological sections of which may be entirely distinct from the sections of the districts named. But often, for lack of any other guidance, the driller will seize upon some ravine or valley or some extended plain for the location of his trial well, because of its accidental resemblance to a point that may have proved productive in his former experience. To be able to say, this location "looks like Western Pennsylvania," or "looks like Findlay," is with some a sufficient justification of the location of a well. When, from some new and hitherto unknown horizon, stumbled upon in this way, and perhaps a mile distant in the vertical scale from any stratum that was ever found productive in the fields which are taken as the standards of comparison, gas and oil are found abundant, the prescience of the practical man is counted fully justified and is, to say the least, duly celebrated. The failures of such predictions are, however, never counted against their authors; for these, an explanation can always be given.

It is obvious that all such guidance as this is entirely destitute of value, and, as a matter of fact, it is only the least intelligent location that is now made in this way. When the prospector has nothing more than this to offer in behalf of his location, it is obvious that he has no valid ground whatever for it. But, as in new fields, one location is as good as another, so far as these surface features are concerned, for all that any one knows, it must be added no great harm is done by following these illusive resemblances. The main mischief comes when the location happens to prove successful. The confidence inspired by one success of this sort will often lead to the wasting of a great deal of money. It can be set down with all assurance, therefore, that the superficial resemblances of untested territory to territory that has been proved productive, have no significance or value whatever. It is not worth while to try to find ravines like those of Western Pennsylvania, nor drift-covered plains like those of Findlay, in or upon which to locate wells. The closest of such resemblances would not have the smallest possible significance.

There are, however, surface indications of another kind that are much more widely appealed to, and that in reality may have a great deal of significance and value in leading us to the great reservoirs. These indications are found in the escape of gas and oil from the rocks, either with or without the presence of water. In the latter case, they are known as gas springs, oil springs or tar springs, according to their special production. These escaping products, in reality, monopolize the name "surface-indications." Oil Creek, Pennsylvania, where petroleum was first discovered in this country as a commercial product, obtained its name from the oil that oozed out from many springs along the banks of the stream, and which kept its surface always discolored with their floating films. Findlay, Ohio, the center and source of the most wide-spread drilling excitement that has swept through the country since the first development of Oil Creek, had "surface-indications" of the most pronounced character in the escaping gas that spoiled the springs and wells of the town, and found its way into cisterns, cellars and sewers, from the first occupation of the country. It was the "surface-indications" that led in both these instances to the astonishing developments that have followed. That surface indications may have very great value and significance in this direction, therefore, goes without saying. Do they always have such significance and value? Do all escapes of gas and oil stand for great reservoirs underneath? This is an assumption that is often and most positively made, in connection with surface indications; but it is most baseless, mischievous and misleading. The truth is, that by far the greater number of such surface shows of gas and oil, probably 99 out of every 100, stand for no large accumulations whatever. Can those indications that do not lead to large accumulations be distinguished from those that may so lead? As a rule, they can be distinguished. There is one formation in particular that is given to "surface indications" of small significance, along the whole line of its out-crop, namely, the Ohio Black Shale. It occupies a very conspicuous belt across the whole width of Kentucky, from Louisville on the north to Burksville on the south, and along this belt, and near it, as the shale dips under shallow cover, "surface-indications" of both oil and gas are always and everywhere in order. But, as a rule, they reveal all there is in the formation, namely, the possibility of weak, but long-continued outflows of gas. There is a single and very important exception that will be described in a succeeding chapter, in the case of the Meade county gas field; but the statements already made apply to the formation as a whole.

The tar springs of the State, which issue from the great sand rocks of the Chester group, and the Carboniferous Conglomerate, are examples again of "surface-indications" that probably lead to nothing larger than themselves.

It needs, therefore, to be distinctly recognized that there are various kinds of "surface indications," and that by far the larger portion of them are in no ways derived from great reservoirs of oil and gas. In fact, no example has been afforded, in the recent history of Kentucky, of any other sort of "surface-indications" than those already described, for the reason that no great accumulations of oil and gas have been recently found within the State. The great American well of Burksville, which dates back to the year 1829, if we can rely on the accounts of its production that have come down to us, must have furnished a case in which "surface-indications" were connected with a really great reservoir.

The so-called surface-indications of oil in marshy ground need to be alluded to in this connection, because they often mislead the untrained observer. The iridescent film that mantles the stagnant water, found in such situations, is not due to the presence of oil, as is commonly held, but is a thin scale of iron ore formed from the oxidation of the iron dissolved in the water which feeds the bog.

When we call to mind the facts of the preceding chapter as to the almost universal presence of petroleum and gas in the varied members of the series of stratified rocks, we shall not find ground for wondering that these widely diffused stores make so many natural exhibitions of themselves in the way of "surface-indications."

III. Geological Indications.

Is the geologist any better off in this search than the untrained prospector? Are there any clues to the great production that he can find and follow, which another would not see? Has the geology of oil and gas reached such a stage of scientific development that it can safely undertake the work of predicting results to any extent?

In answer to these questions, it can be said, considerable progress has been made within the last decade, and the position of the geologist in this respect is improving every year. It must also be borne in mind that the most valuable guides of the most sagacious operators are facts that are strictly geological in their nature and bearing. The lines of compass-bearing, which he follows from one successful well to another, are, in reality, nothing but the lines of direction of the uplifts or arches upon which the geologist lays so much stress; and if a superficial knowledge of the facts can be turned to some economic account, a larger and more systematic knowledge would seem likely to be still more valuable. It will be found that this is proving true to some extent.

The geological indications that can be made serviceable belong to two main lines of facts, viz: First, the order of the series at any particular point, involving the probability of reservoir rocks at suitable depths; and second, the structure or arrangement of the strata at any point with reference to favorable or unfavorable physical conditions for the storage of gas and oil.

a. Order of the Series.

It can easily be seen that the order of the underlying geological series is a main factor in the possibility of oil production in any locality. There must be a certain relation of the strata, as has been already pointed out, to admit of any accumulation of petroleum or gas. Cover, reservoir and source must be found, once, at least, in every productive section, in the order herewith named, to render an oil field possible. Such a collocation of strata *may* be found several times repeated in long sections, in which case there may be more than one oil horizon. The geologist is able to determine approximately, from an examination of the rocks that constitute the surface, what the underlying order is for a few hundred, and often for a few thousand feet. He studies the strata at their nearest outcrops, and finds their composition. He learns their prevailing dip, its direction and amount, and from these factors he can predict, often considerably in advance of the drill, at what depths rocks suitable to become store-houses of these coveted bituminous productions can be found. Whoever does this work is making use of geological data, and is obtaining geological results, whether he calls himself a geologist or not. The more thoroughly and systematically the work is done, the better it will of course be.

But the strata found in any particular section cannot be supposed to extend indefinitely in all directions, with thickness and character unchanged. Sometimes, it is true, they show great steadiness and persistency, but sometimes again they undergo rapid alterations in the particulars above-named. From the nature of the changes that are found to be in progress at any particular point, the sagacious observer may sometimes infer, with considerable confidence, what the conditions will be at some locality well in advance; but, after all, there are serious limitations to our theoretical forecasts in these fields, and a *probable* order is all that can be affirmed. It often happens that the stratum is porous in one condition, and thus able to answer the purpose of an oil or gas reservoir, while in another condition, it loses this porosity altogether. If these changes take place capriciously, or without any apparent regularity or order, as they sometimes appear to do, it is evident that no prevision can extend to them; but if the transformation appears to be progressive and regular in any given direction, we, in such cases, obtain the right to assert with confidence, far in advance of the drill, what the character of the stratum will be found to be. This state of things is well exemplified in the case of the Trenton limestone of Ohio and Indiana, the bituminous stores of which have proved so remarkable and valuable during the last few years. Where it attains the character of a reservoir rock it is a pure dolomite; but through a considerable part of Northwestern Ohio, for example, the stratum plays fast and loose with this characteristic, abandoning the dolomitic composition in a single well or neighborhood, while showing it in wells or neighborhoods on all sides around. Here, no predictions can be safely made for new wells or localities. But, on another hand, as the Trenton limestone is followed southward from the Lima field, it loses steadily and finally its dolomitic composition, and thus all power of bituminous storage is withdrawn from it. We are able, on such grounds, to say, with all confidence, that the Trenton limestone is not an oil or gas rock for large areas, in which it constitutes a well-known element in the geological scale.

But when the most is said for geological prediction of thi particular sort, it is freely acknowledged that the final answer in every new section must come from the testimony of the drill. The work of the geologist makes the work of the driller intelligent, and this is an immense gain in and of itself. It cannot be dispensed with in any proper development of a new field: but there are too many possibilities of change in an extended series to allow us to base large outlays with full confidence on the most sagacious geological prevision.

b. The Arrangement or Structure of the Rocks.

The services that can be rendered by the geologist under the head now to be considered are, without doubt, the most valuable he can render in the eager search for oil, and especially for gas, that is going forward on every side. In fact, geological guidance is now recognized as indispensable to success in the most important gas districts of the country. It will be remembered that the leading gas fields have been classed under two main heads ; those, namely, that are found upon the summits of low anticlines, as in Western Pennsylvania, and those that occupy the terraces of the Trenton limestone of Northwestern Ohio and Central Indiana. In the latter, the gas is distributed in such broad and continuous areas that the geologist has only to concern himself with the main boundaries of the gas fields. But, in Western Pennsylvania, he is called upon to mark out for the driller the flattened summits of arches never more than a mile or two miles in width, and sometimes holding up to a uniform level for ten or twelve miles in length, the directions of which are not constant, as the practical man is wont to assume, but are often found to curve and bend in a perplexing manner.

How can these summits of the arches be recognized? I answer, by the relative levels of the strata that compose them. Some particular element, a coal seam or a well-marked limestone, for example, can be followed by the level or the barome ter, in its multiplied outcrops across the country ; and when two or three sections have been run on properly selected lines, and have been platted on a proper scale, the arch, if there be one, in the territory that has been traversed, will come into distinct view.

As stated on the preceding page, it is to Professor I. C. White, of West Virginia, that we owe the great progress of the last few years in the possibility of geological predictions of this kind. His successful location of gas wells has done more to commend geology to the great interest concerned in the production of gas and oil, than all other scientific investigations combined, that have been undertaken in this field.

In this division of the geologist's work, he is entirely independent of the driller, and it is his place to go before him and point out, with a good degree of precision, where the most promising possibilities are to be found. As has been shown in a previous section, he is powerless to predict the condition of the reservoir rock when reached, as to grain or thickness ; but its relative altitude he can positively determine; and this has already been seen to be a point of vital importance.

In all this, it is assumed that all the strata of an extended series have been flexed together, and that the disposition of a single bed 1,000 or 2,000 feet below the surface will agree perfectly with the disposition of the surface rocks, rising and falling with them. These conclusions have not been rashly taken for granted, but have been submitted to, and have been found to be fully supported by the tests of extensive series of measurements, carried from the surface by the level, and underground by the drill. The best results of this sort come from the Macksburg oil field of Southern Ohio. (Geology of Ohio, VI, 94.)

There are many cases, however, in which the results of movements, originating at different ages of the earth's history, are now combined in a single section. Such cases might give rise to anomalies; but in one important instance in Ohio, they have furnished strong corroborative testimony as to the efficiency and necessity of a proper relation of the gas rock in whatever way brought about.

These, then, are the methods in which the geologist can render aid in the discovery of gas and oil. He can indicate the strata that are likely to prove reservoir rocks in any section the elements of which have been already worked out, and he can also indicate the probable depth at which such strata will be found; and he can determine, with precision, by doing work enough, what are the best points in any field in which to locate trial wells; or, what is equally important, he can determine that certain districts are entirely destitute of geological promise in this regard. He can also make the driller's work intelligent, and this is one of his not least important services. In a word, he is now able to render to a well-driller the same general sort of guidance and aid that he has long rendered to the mining engineer. But as in mining, so in drilling, there will always be room for surprises. Unique phenomena, like a Comstock Lode, a Carbonate Hill, a White Pine Chamber, or a petroliferous phase of the Trenton limestone, he can never imagine in advance of their discovery.

It must be also added that he is pledged to conservative views, and must not be relied on to lead investigation in new fields or institute a search for new horizons of mineral wealth of any sort. On the very supposition that is made, there is no geological warrant for such investigations. There are only geological possibilities involved. Many of the most valuable discoveries in the line of oil and gas of recent years, have been made in the face of all known geological probabilities as they were understood at the time. Such was the discovery of high pressure gas in the Trenton limestone at Findlay, in 1884, and in the Clinton series at Lancaster, Ohio, in 1888. If the world had waited for the geologists to point out and unlock these fountains, it would, without doubt, have waited long—been waiting still. But when these sources of wealth are once discovered, it is the geologist's work alone that can make their true significance and relations appear.

CHAPTER V.

UTILIZATION OF NATURAL GAS, INCLUDING METHODS OF TRANSPORTATION AND MEASUREMENT.

No form of mineral wealth has awakened as widespread interest in our day as natural gas. Certainly, there is no other mineral production in the search for which so many people are directly or indirectly engaged. Villages, cities, counties, vote upon the expenditure of large amounts of public money in the work of exploration, and the propositions to use public money in this way almost always prevail. Millions of people in the Mississippi Valley may be safely said to be actively interested at the present time in the various questions pertaining to this subject.

The steps that have led to this universal interest have been briefly described in the preceding chapters. It is not more than ten years since natural gas began to be counted, by any considerable part of our people, as worthy of our consideration as a source of domestic and manufacturing fuel. Pittsburgh taught the world this lesson, that natural gas is the most perfect and most desirable form of fuel that we can possibly secure. But Pittsburgh gave little ground to other sections of the country for entertaining the hope that they also might obtain a supply of the new fuel for themselves. It was universally believed by geologists and oil-producers alike, ten years ago, not only that the conditions for the large production of oil and gas were exceedingly limited in their distribution, but also that these substances were scarcely to be looked for below the Devonian series in which the Pennsylvania oil and gas are found.

It fell to Findlay to teach a lesson, of at least equal importance with that taught by Pittsburgh, that the stocks of gas and oil are not limited to Devonian rocks, but may be found in vast volume, almost to the bottom of the great series of stratified deposits. It was this revolutionary discovery of gas and oil in the Trenton limestone that kindled the excitement far and wide throughout the country, and that led so many thriving towns, in a half dozen States, to inquire as to their own possibilities in this matter, and, finally, to test these possibilities by the drill. It seemed, indeed, for a little while to many as if natural gas were likely to become the universal fuel. Had not the geologist been completely surprised by the experience of Findlay? Could his forecasts be longer counted of any value? If a well, drilled in the drift-covered plain of Northwestern Ohio, to a depth of a thousand or 1,200 feet, had found so unexpected and so vast a supply of the best of fuel, what reason could be given why a thousand other localities should not, by a proper search, find as valuable resources beneath their own foundations? Of course, no satisfactory answer but that of the drill could be given to such questions. These practical answers were rapidly multiplied during the next two or three years throughout the Northern Mississippi Valley; and though additions of immense importance have been made to the known storehouses of bituminous products by this widespread and enthusiastic search, it still remains true that they are very far from being universal. On the contrary, they are still seen to be as sharply limited and restricted in all their productive areas as of old. In Central Indiana, the largest gas-field of the world has been brought to light; and, as a direct result of this search, in two counties of Central Ohio, the Clinton formation has been added to the Trenton limestone as a valuable source of gas. Many thriving towns, lying outside of the limits of gas production, are supplied from the more favored territory by pipe lines. In Ohio, Toledo, Dayton, Columbus, Springfield, and a score of other cities and towns, are now supplied, or are soon to be, from one or other of the two new sources already named. In like manner, Indianapolis, Fort Wayne, and numerous other towns of Indiana, are bringing in natural gas, to the exclusion of all other fuel; and this, in addition to all the thriving towns within the limits of the gas territory, that are now supplied.

The cause of this widespread excitement and interest, which has been referred to in the preceding paragraph, is not hard to find. It is the money value of the gas that leads to the extraordinary interest that pertains to good territory.

A gas well, the drilling of which will cost $1,000 to $5,000, will pour forth, for a series of months, and often years, a flood of gas, which, even at the lowest rates that ever prevail, may be worth to its owner $100, $1,000, or even $2,000 a day. As already shown, the charm that invests a gas field is precisely the same as that which invests a mining district of phenomenal richness. The great advantages of natural gas are found in the support which it gives to manufacturing industries of various sorts. To certain lines of manufactures it is so happily adapted that competition, without it, is almost out of the question. Its presence invites and stimulates manufacturing enterprises to a wonderful degree. In addition to the direct value of a gas-field, our alert business men have not been slow to recognize the fact that no other element, in the list of the natural advantages of a town, can be made to exert half the attractive power that the possession of a good supply of the new fuel can give. Real estate speculation, consequently, of the most violent and unreasonable sort, has sprung up in many of the favored towns of Ohio and Indiana during the last few years, based wholly upon the presence of this new element.

Natural gas is valued, because it is the best of fuel. What makes it the best of fuel; or, in other words, on what does its adaptation to all the purposes of fuel depend? Obviously, upon its chemical composition. This subject will be first considered; but before taking it up, a few facts pertaining to the physical properties of natural gas will find appropriate mention.

Physical Properties of Natural Gas.

All forms of natural gas are colorless and transparent. Some of the varieties have a well marked and even offensive odor, derived from their sulphurous constituents. A small percentage of the latter group goes a good way in advertising the presence of the gas. The discoloration of compounds of lead and silver, by the sulphuretted hydrogen of this variety of gas, are familiar but troublesome phenomena in the new fields of Ohio and Indiana.

The gas of many districts, and of Western Pennsylvania in particular, is counted odorless; but this claim needs qualification. The odor is not pronounced, and certainly not offensive; but natural gas is seldom free from the characteristic odor of some of the chemical compounds represented in it.

As to the specific gravity of natural gas, there is, of course, considerable range arising from the well-marked differences that are found in its composition. The direct determination of the specific gravity of gas is a somewhat difficult problem, requiring delicate instruments and nice manipulation. So far as known, no such determinations have thus far been made. All the figures that we have are, with a single exception, derived from calculations made upon the chemical composition of the gas. But, as will presently appear, there are some minor questions as to its exact composition, that cannot be definitely determined. Our figures, therefore, must rest upon an assumed composition of the gas, and variations in them are likely to result from different opinions, on the part of chemists, as to the manner in which the elements are combined.

Professor Howard's determination of the Findlay or Trenton limestone gas makes its gravity practically .57 (air being 1.00). Professor Robinson, by the application of an ingenious and original method, deduced a specific gravity of .60 for it. For purposes of comparison, the following figures may prove interesting:

Pennsylvania natural gas	51 to .54
Coal gas	.40
Water gas	.57 to .60
Producer gas	1.00

Some varieties of natural gas have been figured as high as .87. It is probable that the gas of Meade county will show a high specific gravity.

CHEMICAL COMPOSITION OF NATURAL GAS.

Chemistry is counted an exact science. To the uninitiated, it would seem an easy enough task to determine, with absolute precision, the composition of a substance like natural gas. But the chemist has found great difficulty in the problem. In the first place, natural gas sweeps through as wide a range of composition as coal does, without losing its name. The fire damp of the miner is natural gas; the marsh gas of the stagnant pool is natural gas; and the inflammable gases, released by the drill from their deep reservoirs, though varying much in quality from each other, are all known by the same name.

But, aside from the fact that no one analysis can possibly cover the ground, there are, in the second place, difficulties of another sort in the way of the chemist as he attempts to answer the question, what is natural gas? He can determine accurately and easily enough the proportions of the organic elements, carbon, hydrogen, oxygen and nitrogen, that are present in any gas; but these absolute proportions give us comparatively little of the information that we desire. We need to know how these elements are combined in the gas; and its value, as fuel, is dependent, to a great extent, upon the particular form of combination. But to obtain the results of the chemist, the original organic compounds of the gas must be decomposed and destroyed; and, consequently, there is more or less uncertainty in his restoration of these compounds. There is, at the present time, a growing accord among the best chemical authorities as to the interpretation to be placed upon the results of analysis. Natural gas is now believed to consist of about 90 per cent. of hydrocarbons of the paraffine group, with varying proportions of other elements. The first series of results that established this conclusion was obtained by Professor C. C. Howard, of Columbus, Ohio, for the Ohio Geological Survey. He analyzed, in 1886, Findlay gas, with great care, and showed its composition to be as follows:

Marsh gas	92.61
Olefiant gas	0.30
Hydrogen	2.18
Nitrogen	3.61
Oxygen	0.34
Carbonic acid	0.26
Carbonic oxide	0.50
Sulphuretted hydrogen	0.20

After an interval of several months, a new analysis was made, and the figures were found to agree with those previously obtained within the limits of error involved in the processes themselves. More significant still are the results of Professor

Howard's re-determination of Findlay gas, for the United States Geological Survey, in the summer of 1887. To these results, which agree as closely as could be desired with the figures originally obtained, are added the composition of Fostoria gas, St. Mary's gas, and the gas of four well-known centers of production in the Indiana field, viz., Muncie, Anderson. Kokomo and Marion. The very important fact is brought to light that all of this production is of one piece. The differences in results would all be included within the limits of error in the processes, and as wide a range could be obtained from analyzing one and the same specimen of gas at different times. without any change whatever in its composition.

The figures are given below:

	1	2	3	4	5	6	7
Hydrogen	1.89	1.64	1.74	2.35	1.86	1.42	1.20
Marsh gas	92.84	93.35	93.85	92.67	93.07	94.16	93.58
Olefiant gas	.20	.35	.20	.25	.49	.30	.15
Carbonic oxide	.55	.41	.44	.45	.73	.55	.60
Carbonic acid	.20	.25	.23	.25	.26	.29	.30
Oxygen	.35	.39	.35	.35	.42	.30	.55
Nitrogen	3.82	3.41	2.98	3.53	3.02	2.80	3.42
Sulphuretted hydrogen	.15	.20	.21	.15	.15	.18	.20
	100.00	....	....	....	....	....	...

1. Fostoria, Ohio.
2. Findlay, Ohio.
3. St. Mary's, Ohio.
4. Muncie, Indiana.
5. Anderson, Indiana.
6. Kokomo, Indiana.
7. Marion, Indiana.

These are remarkable and instructive results. From one end of the new field to the other the composition of the gas is the same, and all the popular judgments, as to differences in this or that particular district, are seen to be baseless.

Although natural gas was in large and very successful use in Western Pennsylvania for at least five years before it was discovered in Findlay, we were left without any adequate knowledge of its chemical composition until long after the results above given were established. In fact, the first authoritative announcement of its composition proved to be most incorrect and misleading. In 1885, the Pennsylvania Geological Survey published, on the authority of a well-known chemist of that

State, a series of results of a most surprising character. These results were widely reprinted in the scientific and practical journals of the day, and did a great deal to bring confusion into the minds of those who were studying the subject. The conclusions were as follows: The natural gas of Western Pennsylvania is an exceedingly unstable compound, varying greatly on different days, and even on different hours of the same day. No single analysis would have any great value in showing its average character. In the following table, the figures of the first column show the average of six analyses, and the second, third and fourth columns show the composition of the gas taken on different days:

	1	2	3	4
Marsh gas	67.00	49.58	57.85	75.16
Hydrogen	22.00	35.92	9.64	14.45
Ethylic hydride	5.00	12.30	5.20	4.80
Olefiant gas	1.00	0.60	0.80	0.60
Oxygen	.80	0.40	2.10	1.20
Carbonic oxide	.60	0.40	1.00	0.30
Carbonic acid	.60	0.40	0.00	0-30
Nitrogen	3.00	0.00	23.41	2.89

It was noted, however, that those who were using the gas found no differences in it from day to day at all corresponding to the figures given above. The subject remained in this anomalous condition for several years, until it was again taken up, and this time by the Geological Survey of the State. Prof. Francis C. Phillips, of Western University, Allegheny, Pennsylvania, began a series of examinations that has superseded entirely the results quoted above. His investigations appear to have been carried on in accordance with the best methods known to science, and his report bears upon its face the marks of scrupulous care and conscientious painstaking.

The anomalous features of the results before announced all disappear, and Pittsburgh gas is seen to be a steady and self-consistent product. It agrees, very closely, in composition with Findlay gas, as determined by Prof. Howard, two years since. Both contain about 90 per cent. of hydro-carbons. The main difference is in the presence of a small amount of sulphuretted hydrogen in one, and its absence from the other.

A few of Prof. Phillips's analyses are herewith given. In them we see, for the first time, the true constitution of the natural gas of the most famous fields of the country. The analysis of the shale gas of Fredonia, N. Y., is added to the list:

CONSTITUENTS.	Sheffield.	Kane.	Wilcox.	Lyon's Run. Murrysville.	Fredonia, New York.
Nitrogen	9.06	9.79	9.41	2.02	9.54
Carbon dioxide	0.30	0.20	0.21	0.28	0.41
Hydrogen	0.00	0.00	0.00	0.00	0.00
Oxygen	Trace.	Trace.	Trace.	Trace.	Trace.
Sulphuretted hydrogen	0.00	0.00	0.00	0.00	0.00
Paraffins	90.64	90.01	90.38	97.30	90.05

The last analysis is of special interest in this connection, because the gas is derived from the same formation that supplies the new field in Meade county, of this State.

FUEL VALUE OF NATURAL GAS.

Whatever will burn will produce power. The value of natural gas lies in the fact that it will burn, and thus generate power. For a standard of fuel value, we take some fixed form of fuel, as coal. What is natural gas worth, as compared with Pittsburgh coal, for example? In the following calculations, round numbers will be used, as it seems unnecessary to burden the general reader with exact figures on such a subject; moreover, the calculations made in such a way will apply fairly well to all the varieties of natural gas.

Coal is sold by weight in pounds and tons. Gas is measured in cubic feet. What relation does a pound of coal bear to a cubic foot of gas? We shall best learn this relation by finding the heat units in each. The latter depend entirely on the chemical composition of the substances examined.

One pound of Pittsburgh coal holds about 13,500 heat-units. We can get a better idea of what is meant by this by considering that this pound, burned in one hour's time, will prove the equivalent of about six horse-power. A horse-power is an arbitrary measure of work done. It stands for the raising of 33,000 pounds one foot high in one minute. A ton of Pittsburgh coal, burned in an hour, is the measure of about 12,000 horse-power.

Coming now to natural gas, we find that about 15 cubic feet of it are theoretically equivalent to one pound of Pittsburgh coal, or 30,000 feet to one ton. Practically, the relation is very different. Most of the heat of the gas can be readily utilized, while a large but varying proportion of the heat of the coal is lost in the process of burning. Experience seems to show that 15 feet of gas will, on an average, do the work of two pounds of coal; or, in other words, 15,000 feet of gas are the practical equivalent of a ton of coal, instead of 30,000 feet. There are gas wells that produce in 24 hours one million, five million, ten million, fifteen, twenty, twenty-five, and, perhaps, even thirty million feet. The lowest well in this list would be the equivalent of 33⅓ tons of coal per day; the highest would be the equivalent of 1,000 tons of coal in a day. If a ton of Pittsburgh coal is counted worth $3.00, the production of the first well would be worth $100.00 in a day, and the last $3,000.00 in a day.

Such figures explain very clearly why natural gas is so highly valued.

Various Uses of Natural Gas.

When gas is once obtained, to what purposes is it applied? The answer is, to almost all the uses in which heat is employed. So far, it has not been used in smelting iron ores (except to a very limited extent in a direct process of steel manufacture lately introduced), and it does not appear probabie it can be turned to profitable account for this purpose. But there is scarcely another use of fuel in the districts in which it is most generally introduced in which it does not replace coal. A few of the leading applications will be enumerated.

First in the list will be named its employment as *domestic fuel* in grates and furnaces, for warming houses, and in cooking-stoves and ranges. All its best properties are seen in these applications. It is a source of unspeakable convenience to the housekeeper, saving a vast amount of time and labor. The fuel is always at hand; and, with intelligent management, the temperature of house or stove can be held exactly at the point desired for any required period of time. The never-ending burdens of ashes and soot, that necessarily go with the burning of bituminous coal, all disposed of when gas becomes the fuel.

There are some drawbacks that usually accompany the use of gas as household fuel; but they are not necessary to its use. Gas-heated houses are generally kept too warm, and the air is too dry in them for comfort and health. The wood-work of the house shrinks and warps; furniture is often injured by the dry heat; but none of these evils are necessary. With proper care all can be avoided.

Can the use of gas as fuel be made safe? The answer is, that only ordinary intelligence and care are required to make its use perfectly safe; but, at the same time, it must be confessed that, as human nature is constituted, a larger element of danger is brought into the community when gas is introduced. Mixed with eight to ten times its volume of air, natural gas forms an explosive mixture, and we may be sure that in every neighborhood into which gas is brought there will be some one who will strike upon these dangerous proportions.

Natural gas is so admirably adapted in all ways to this particular use, viz.: household fuel, that it ought to be kept by every community that obtains it largely for this special application. The factories may well enough forge along on the old system. The comfort of life for the many is certainly to be preferred to the undue business advantage of the few.

To the *production of steam* gas is also most happily adapted. It works to this end with extreme regularity. The flow can be so arranged as to regulate the steam pressure automatically. Boilers last longer with gas as fuel, and there is much less liability to explosions. Great economy also results in the reduction of labor in hauling and handling coal and ashes.

Of all the applications of natural gas to manufactures, its use in *glass-making* is, perhaps, the most successful. The perfect control of the heat which it allows, the freedom from dust in all stages of the manufacture, give to the companies that use the new fuel advantages which can not possibly be met by those who are obliged to depend on raw coal.

In *rolling-mills and steel works*, in *lime-burning*, and in *brick and tile manufacture*, natural gas is also used with complete success. But all of these industries make immense draughts upon the gas-fields that supply them, and it would clearly be to the general good if they should, one and all, be entirely cut off from the lines. The fuel is altogether too good for these coarser and more common purposes, and these now take the lion's share of every field with which they are connected. If they were all relegated to producer gas or to oil-burning, for example, the life of the natural gas-fields would be greatly lengthened.

As a source of *artificial light*, natural gas takes no such place as it does in furnishing heat; but there are great differences in this respect in the gas of different fields. Its light, when burned in the ordinary gas-burner, generally has about one-half the candle power of good artificial gas. But the gas of some fields answers a much better purpose.

In its use as fuel, natural gas is giving to the world a lesson of great value. It is demonstrating the enormous advantages that result from the use of gaseous, as contrasted with solid fuel, and it is thus preparing way for a most beneficent and important economic revolution, in which all of the fuel employed in our cities and towns will be converted into gas before being burned in grate, stove, furnace or boiler. Such a result would lengthen immensely the life of all those accumulations of power with which the progress of civilization is so intimately connected. The stored power of the world is by no means inexhaustible. It is certainly inadequate to endure for more than a few centuries at the furthest the reckless demands and wanton waste to which we are now subjecting it. All the supplies that we now know are certain to be exhausted within the limits above named. Every ton of coal converted into gas and used under a properly regulated system will do the work of many tons as used at the present time. All the supplies of natural gas that we have thus far found, and all that we shall hereafter discover, will apparently be exhausted in a few decades at the longest. But the communities that have once enjoyed the luxury of gaseous fuel will never willingly go back to the barbarism of raw coal. The failing supplies of the natural gas-wells will certainly quicken the process of invention and discovery in furnishing an artificial substitute. The work, in fact, is already well begun, and its consummation is, on every account, most earnestly to be desired.

THE TRANSPORTATION OF NATURAL GAS.

Since 1873, when the first pipe line for the conveyance of natural gas from wells, a few miles distant, was constructed, and especially within the last eight years, vast amounts of money have been expended in this line of work, and a great deal of valuable experience has been gained. The conveying of enormous volumes of gas from wells that, in some instances, have an initial pressure of at least 800 pounds to the square inch, in pipe lines, which sometimes reach well nigh a hundred miles in length, and its perfect distribution throughout the streets and dwellings of a great city for every use to which fuel is applied, are giving rise to what may be called a new branch of mechanical engineering. Serious difficulties have been overcome, and threatened dangers have been obviated, and the problem of a safe and successful introduction of the new fuel can be said to be fully solved.

It is not within the scope of the present chapter to give any extended account of this new art; but a few of the general facts in regard to it will be stated.

Of what materials are the pipes which are used in the lines constructed? They are made of lap-welded wrought-iron, or of steel, when used in the high-pressure portions of the lines. Cast-iron pipes of large size, twenty, thirty, forty inches in diameter, have been introduced of late, in good practice, on the low-pressure sides of pipe lines, where the pressure does not exceed ten pounds to the square inch. Cast-iron is too treacherous to admit of its safe introduction into those portions of the line that are exposed to the full pressure of strong wells; but it must be added, that since the pressure of the Pennsylvania fields has fallen off materially; cast-iron lines have been laid in a few instances, for the entire distance, from the wells to the points of consumption.

In the construction of pipe lines, what sizes of pipes are employed? Naturally, the sizes vary greatly, according to the demand to be made upon them. They generally range from two to twelve inches in diameter, never falling below the former figure, and in but few cases passing beyond the latter. The usual sizes range between four and ten inches. A two-inch pipe is inadequate to any thing but short distances and small supplies. There is a great advantage, especially in feeble wells, in having pipes of large diameter. It is to be observed that the capacities of pipes vary with the squares of their diameter; for example, a six-inch pipe carries two and one-fourth times as much gas as a four-inch pipe. The practical rules, used in the distribution of artificial gas, may prove serviceable in this connection.

From a pipe four times as long as another, one-half as much gas can be obtained, other things being equal.

From a pipe one fourth as long as another, twice as much gas can be discharged, other things being equal.

The longest gas lines in use are those which supply Buffalo, New York, and some of the villages of Northern Pennsylvania. The length of the first is about 90 miles, and of the second a little more than 100 miles. The gas furnished by the Buffalo line is not introduced into the city for general use, but is sold at a price that makes it regarded as somewhat of a luxury. The pipe line that supplies Dayton, Ohio, is more than 50 miles in length; the Toledo lines are nearly 35 miles in length; the Columbus line is 30 miles in length; the Pittsburgh lines do not exceed 35 miles in length. The original lines that supplied the city were none of them more than 20 miles long. When a pipe line exceeds 30 miles in length, rates for the gas, approximating or exceeding the cost of coal, are to be expected. If the company bringing in the gas is wise, it will be very slow to give to iron or steel mills, or other like large consumers, a supply, at least, at such rates as will make it practicable for these establishments to use fuel from the line.

Pipe lines should always be laid below the reach of frost. More or less water finds access to the line. The expansion of the gas, as it reaches the surface, considerably reduces the temperature of the pipe; and, consequently, it is an easy matter for any water in the line to freeze, if low atmospheric temperatures can affect it.

Great difficulties and dangers were originally encountered in the introduction of gas into towns, arising from the enormous pressure of the wells; but all the trouble from this source has now been overcome. Regulators of various patterns have been invented that exercise perfect control over the flow of the strongest wells. The pressure is reduced to any required amount at any point on the line. Great ingenuity has been displayed in this field, and the results leave little to be desired.

The increase of the pressure of weak wells, by the introduction of compressors or blowers along the line, has been attempted in a number of instances. As the supply of a pipe line weakens from natural causes, it often happens that there is no longer force enough in the wells to send even the gas that is produced to its destination. Sometimes, also, the initial pressure of the wells is too low for what is required of them. Attempts have been made at various points to supplement this low pressure by the use of pumps of the same sort as those employed in forcing air into deep mines. That such a re-enforcement of pressure appears practicable to engineers and superintendents of pipe lines is evident, from the fact that so many trials have been made in this direction; but the number of failures resulting makes it evident also that there are some serious difficulties in the way. Full success, however, is claimed in some of these trials, and the introduction of one of these systems into the pipe line of the Kentucky Rock Gas Company, which is now bringing natural gas to Louisville, will be watched with great interest.

There is a growing disposition to introduce meters into all the distributing systems of the natural gas companies. As is well known, when natural gas was first brought into use, the supply was abundant, and the most reckless waste was tolerated. Five years ago, a calculation showed that 60 million feet per day were burning from waste pipes connected with the Pittsburgh supply alone. The prices for gas at that time were fixed for the use required; as, for example, so much for every ton of iron or steel worked with gas; so much for every glass pot; so much for a steam boiler, with and sometimes without regard to its horse-power, and on the same basis prices were fixed for stoves, grates and furnaces. No inducement was offered to the users of gas to adopt economical methods. As the use of gas has rapidly extended, while at the same time the original supply has been rapidly reduced, a new state of things has been brought about, and the gas companies are now using all means in their power to effect an economical consumption of fuel, and to avoid all forms of waste. Nothing works more efficiently in this direction than the introduction of meters.

Meters are now constructed so as to be adapted to every demand of the new fuel; and wherever natural gas is introduced, it ought to be sold, from the outset, by measured volume.

In concluding these statements in regard to the piping of natural gas, it needs only to be added that it is to the decided advantage of every town that is fortunate enough to find a supply, to use only the best methods in introducing it. All the problems of a safe and economical distribution have been solved by the leading companies that are engaged in this work, and it is a great mistake on the part of any town to fail to avail itself of this experience.

There are, it is true, many parties ready to underbid the rates of the great companies; but the money saved by the substitution of inferior and unskillful work will, in all probability, be lost several times over, in attempting to remedy the defects of a line laid in such a way. Indeed, the defects are generally irremediable, and lines of this sort are sure to be sources of constant annoyance, danger and waste. To provide supervision of the entire work of piping and distributing the gas by a thoroughly skilled and experienced pipe-line engineer is the very least that can be asked of any town into which natural gas is being introduced.

Measurements of Gas Wells and Pipe Lines.

An important subject remains to be treated in this chapter, namely, measurements of gas wells and pipe lines.

It is a matter of surprise that some system of measurement, at once reliable and easy of application, was not originated in the remarkable experience of Western Pennsylvania for the last fifteen years. In all the buying, selling and leasing of gas lands and gas wells that have gone forward there, only crude, empirical and misleading observations were introduced into the transactions. In 1886, an engineer of one of the great gas companies devised a system that, for the first time, made it possible to approximate the production of the gas well in measured volume. But the process was not only one of difficult application, but it was not even made public, being reserved entirely for the private use of the company. It is possible that there are other instances of the same sort that have not chanced to come to light; but certain it is that in 1885, when the great gas wells of Northwestern Ohio were being drilled, there was no published system of determining the actual volume of these remarkable outflows. That one of two wells was larger than the other was made obvious by unmistakable signs; but how much larger was a matter of guess-work in the main; and, as might be expected, estimates were very discordant.

It is much to be regretted that this state of things existed so long. If measurements had been applied to the gas wells and gas fields in the beginning of their development, we should have a much better basis for our conclusions as to many interesting facts connected with the gas supply; and especially as to its duration. Even since an adequate system of measurements has been promulgated, it has not been found possible to apply it as widely as could be desired. The companies who control the great gas supplies count it to their interest to hold the facts pertaining to the wells as business secrets; and if they themselves have learned, with any accuracy, how these wells are maintaining themselves, they do not share this knowledge with the public at large. There is no question, however, but that it would be to the public interest to have all the facts on record, so that the true nature of the supply of the new fuel could be generally understood.

The measurement of the small gas wells of the shale series was accomplished a score or more of years ago by the use of the ordinary gas meter; but such a meter was not to be thought of in connection with the great wells that were pouring forth millions of cubic feet a day. The first attempts to ascertain the relative values, used in the volumes of such wells, were made by marking the rate of increase of pressure when the flow of gas from the wells was arrested. One well, for example, would gain a hundred pounds pressure in one minute; another well would require five minutes to reach the same pressure. It is obvious that a sort of clue to the relative volumes of the wells could be reached in this way; but, from such data, it is not possible to obtain definite information as to their production. The apparent relations would, in fact, be quite likely to mislead.

The Use of the Anemometer in the Measurement of Gas Wells.

The anemometer is an instrument used in determining the velocity of the wind and measuring the volumes of air that are used in the ventilation of mines and buildings. The instrument consists of an easily revolving wheel, which is made to register its revolutions. It is constructed for a certain sized orifice, through which the current of air must pass; as, for example, a square foot. If used in a larger or smaller orifice, allowance for this fact must be made. The time during which the wheel is allowed to revolve is to be carefully noted, and the volume for the day can be deduced from these observations. This instrument, if properly constructed, is admirably adapted to the measurement of moderate-sized wells.

We owe the first suggestion of its use for this purpose, as well as the first practical application of the instrument, to Emerson McMillin, Esq., President of the Consolidated Gas Company, of St. Louis. In May, 1885, Mr. McMillin determined, for the Ohio Geological Survey, by the use of this instrument, the daily product of the Adams well of Findlay. This is the first case, so far as known, in which the anemometer was used in measurements of this sort.

The product of the well was found to be 1,296,000 cubic feet per day. The gas was escaping from the casing (5⅝ inches in diameter); but a funnel-shaped box was adjusted to the casing, expanding at the outer extremity to an area of one square foot. In using the anemometer on pipes smaller than the instrument itself, a funnel of a foot or two in length must be provided, which shall fit accurately to the delivery pipe at one end, and expand to the exact size of the anemometer at the other.

Allowance must be made for the superior force of the central portion of the gas current. A measurement, based on the velocity of the central flow, would be in excess of the true production. Judgment and experience are required in making this allowance. As a general thing, the largest figures that can be obtained are used.

For all wells, producing a million feet or less in 24 hours, the anemometer, in proper hands, leaves little to be desired. Still, it must be remembered, it is an instrument of the same general character as a watch, and, like a watch, it is liable to get out of order. If thoroughly trustworthy results are required, the instrument must be frequently tested, and its rate of correction determined. The anemometer, it will be observed, simply gives the velocity of the gas current.

The Use of the Pitot Tube in the Measurement of Gas Wells.

The anemometer, as described above, answers an admirable purpose for a large class of wells; but there are many wells to which it cannot be applied, by reason of the extreme violence of their flow. The gas stream of a large well goes through the instrument in very much the same fashion that a ball, fired from a Minnie rifle, would go through it. For all such wells, an entirely different system of measurements must be employed. But one adequate system for this purpose is known, and that we owe, both in its theoretical statements and in its practical applications, to Professor S. W. Robinson, of the department of Mechanical Engineering, in the State University, Columbus, Ohio. The investigation of the subject was taken up by Professor Robinson, at the instance of the Ohio Geological Survey, in 1886, and the problem was successfully worked out upon the famous Karg well of Findlay. This method has already come into universal use. It leaves nothing to be desired, and can have no competitor. It is so easy of application that the flow of the strongest gas well ever discovered can be absolutely determined by observations requiring only a fraction of a minute. The only essential is, that access shall be given to the unobstructed flow of the well, either from the casing or tubing.

The discussion of the theoretical principles involved is given at length in Professor Robinson's formal statement of the method in Chapter IX, Vol. VI, Geology of Ohio. The reader, who desires access to the full discussion, must consult this chapter. At this point, little beside the practical applications will be given.

The Pitot tube obtains its name from its inventor, Pitot, who made it known to the French Academy in 1732. It is shown, in all its simplicity, in figure 1.

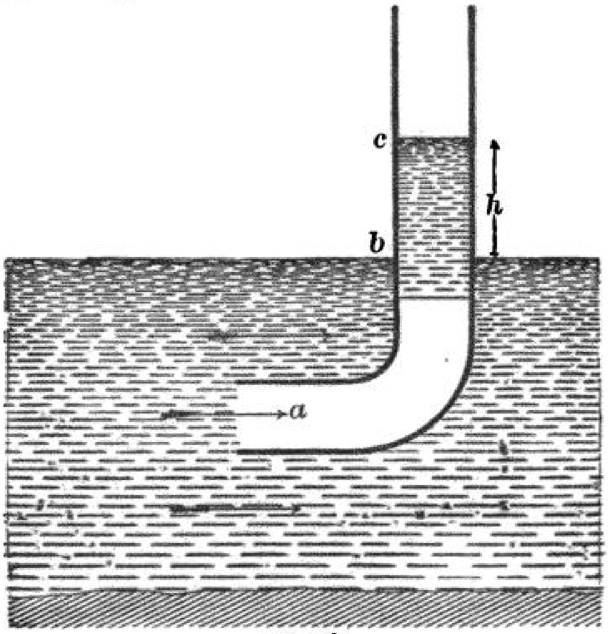


Fig. 1

As here represented, the instrument consists simply of a glass tube, opened at right-angles, and placed with an open mouth, a directly presented toward the water current, while the other end rises above the surface at b. The water, driving against the open end, causes the column to rise in the branch b c to the height h. This height is to be used in the calculation of the velocity. Pitot taught that this height was simply that due to the velocity, V, of the current, and from this construction deduced the law, $V^2 = 2\ g\ H$, g being the acceleration due to gravity. This formula is recognized as that belonging to falling bodies. The conclusion of Pitot has been abundantly substantiated by later investigators. Greatly to their surprise, the instrument has proved itself to be an instrument of precision. Professor Robinson was the first to extend its use from liquids to gases. In 1873, he applied it to the determination of the velocity of air-jets under compression, and he worked out at the same time the modification in the formula required by the change in the medium.

In figure 2, the instrument is seen in a simple form, ready for use in a gas well. The casing is represented in section as

A. B B is a metallic tube of any convenient diameter, ground sharp at the lower end, which is presented to the gas current.

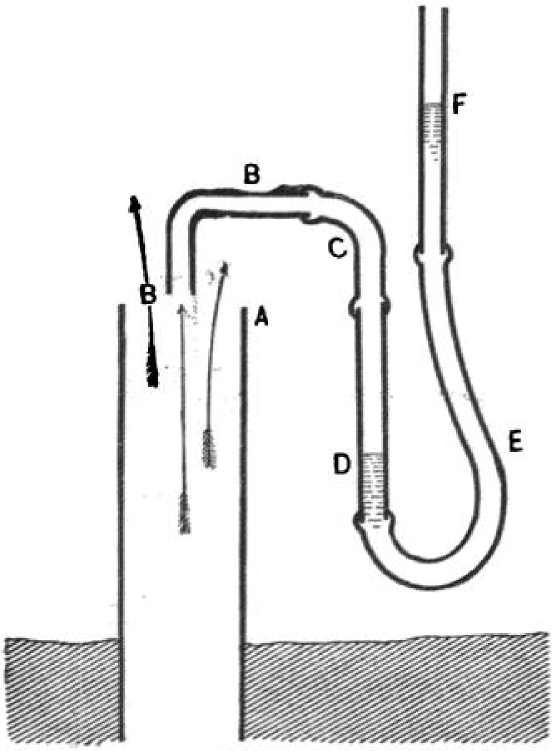


Fig. 2

C and E are pieces of rubber tube, fitting closely to the metallic tube B, and the glass tubes D and F. By making the rubber tube E several feet in length, a considerable value can be obtained for H. In working, the tube is to be partly filled with water, the level of which will, of course, be the same in both arms, until the force of the gas current breaks the balance and raises the water on the side E F. The amount of displacement measures the velocity of the gas stream.

No glass tubing is required in connection with the steam gauge. The size of the pipe is immaterial in all these cases; but care must always be taken to have the end of the metal pipe presented to the gas stream well-sharpened by the file. In the use of the steam-gauge, it is always to be borne in mind that the instrument is very likely to give inaccurate readings, especially after long-continued and severe use. To insure the accuracy of the results, the gauge employed must be frequently tested, and proper allowance must be made for its errors.

In the use of the gauge, the same caution needs to be observed that was given in connection with the use of the anemometer, viz: that the average of the pressures of the discharge pipe must be taken. Generally, the highest figure that can be read is adopted for the entire area of the pipe. Results obtained in this way are always in excess of the real production.

Three modes of measurement have now been described under the last head, viz.: measurement by a water column, by a mercury column, and by a steam gauge. The two former are to be preferred wherever they can be applied, as all sources of error can easily be avoided in their use. The water and mercury columns are read in inches, and the steam gauge in pounds. In Table I, which is to follow, no provision is made for the mercury column; but this is easily, and, with sufficient accuracy, converted into pounds by counting two inches of mercury equal to one pound.

Table I, that is found below, explains itself. The pressure must be read in one or other of the ways that have now been described, and is to be found in one of the two left-hand columns of the table. The size of the pipe from which the gas flows is also indicated in the table, under a proper heading. By combining these two observations, the volume of the gas flowing from the well is read in cubic feet from the table.

It must be observed that the volume of the gas, as reported in the table, is counted at 32° F. This is a commonly observed temperature in high-pressure wells; but, in case the temperature varies from this, calculation must be made as to the true volume by the use of Table II.

How is the temperature of the flowing gas to be determined? *Not* by inserting the naked thermometer into the gas current, as is commonly done. Such a mode of procedure involves serious errors. The most practicable way is to make a dam of moist clay against or upon the delivery pipe, in which a small quantity of water can be held in direct contact with the pipe. The water will soon reach a constant temperature, and this can be taken as the temperature of the flowing gas. When the temperature is determined, correction can be made of the results obtained from Table I by the use of Tables II and III. These tables will sufficiently explain themselves.

By the rules that have here been laid down, and by means of the appended tables, any intelligent person can determine the flow of any ordinary gas well. Still, as in other arts, there are many minor points that are learned by experience only, and that cannot be laid down in any set of directions. Where large interests turn on the results of measurement, it will be advisable to call in experts to do the work.

In all of the processes above described, it is assumed that the gas to be measured is dry gas. If either water or oil are delivered with the gas, the use of the anemometer and of the steam gauge are excluded, and either the water or mercury column should be employed. There will be chances for considerable error under such circumstances.

TABLE I.

Cubic Feet of Gas Reckoned at 32° F., Discharged by Well per Day of 24 Hours of Continuous Flow, by Pitot Tube Measurement; the Specific Gravity of the Gas being taken at 0.6, (air=1.): and the Temperature of the Flowing Gas at Well-mouth being taken at 32° F.

Cubic Feet per Day Reckoned at 32° F., given by this Table, may be regarded as a Quantity of Gas in a Gas-Holder at the Temperature of 32° F., or the "Temperature of Storage. For other Temperature of Storage, or for other Temperature of Flowing Gas, or for other Specific Gravity than 0.6, Correct the Cubic Feet of Gas obtained from this Table by aid of Table II, or Table IV. See Examples.

Observed pressure by water gauge, as in fig. 3.	Observed pressure by pressure gauge, as in fig. 4	Diameter of Orifice, or of Well mouth, where observed, as in Figures 3 or 4; in Inches.										
		d = 1/2 in	d = 1½	d = 2	d = 2½	d = 3	d = 3½	d = 4	d = 4½	d = 5	d = 5⅝	d = 6 in.
Inches.	Lbs. per sq. in.											
.1	.0036	12,390	27,880	49,556	77,440	111,510	151,780	198,220	250,890	309,750	392,000	446,040
.2	.0073	17,560	39,510	70,260	109,750	158,040	215,110	281,040	355,590	439,000	555,910	632,160
.3	.0109	21,480	48,330	85,940	134,250	193,320	263,130	343,760	434,970	537,000	679,630	773,280
.5	.0182	27,720	62,370	110,880	173,250	249,480	339,570	443,520	561,330	693,000	877,080	997,920
.7	.0254	32,820	73,840	131,260	205,100	295,380	402,000	525,050	664,610	820,400	1,038,500	1,181,520
1.0	.0364	39,210	88,230	156,830	245,100	352,890	480,400	627,310	794,030	980,400	1,240,700	1,411,600
1.5	.0545	48,030	108,070	192,120	300,200	432,270	588,400	768,480	972,600	1,200,800	1,517,900	1,729,100
2.0	.0727	55,340	124,520	221,360	345,900	498,060	677,960	885,440	1,120,600	1,383,600	1,751,000	1,992,200
3.0	.109	67,910	152,800	271,630	424,500	611,190	832,020	1,086,510	1,375,200	1,698,000	2,148,800	2,244,800
4.0	.145	78,410	176,420	313,660	490,100	705,690	960,600	1,254,620	1,587,800	1,960,400	2,480,900	2,822,800
5.0	.182	87,670	197,260	350,070	548,400	789,030	1,074,860	1,402,670	1,775,310	2,193,600	2,733,900	3,156,100
7.0	.254	103,500	232,880	414,000	646,900	931,500	1,267,900	1,656,000	2,095,900	2,587,600	3,274,800	3,726,000
10.0	.3630	123,000	276,750	492,000	768,800	1,107,000	1,506,750	1,968,000	2,490,800	3,075,000	3,890,900	4,428,000
13.75	.50	146,220	328,990	584,880	913,880	1,316,000	1,791,200	2,339,500	2,760,900	3,655,500	4,626,500	5,864,000
20.62	.75	175,350	394,540	701,400	1,096,000	1,578,150	2,148,160	2,805,600	3,550,900	4,384,000	5,548,200	6,312,600
27.5	1.00	201,800	454,010	807,200	1,261,200	1,816,050	2,471,900	3,228,500	4,086,100	5,044,600	6,384,600	7,264,200
41.25	1.5	247,840	557,650	991,370	1,549,000	2,231,000	3,036,000	3,965,000	5,019,000	6,196,000	7,842,000	8,922,000
55.0	2.0	285,130	641,540	1,140,500	1,782,000	2,566,200	3,493,000	4,562,000	5,774,000	7,128,000	8,921,000	10,265,000
....	2.5	316,500	712,130	1,266,000	1,978,000	2,848,500	3,877,000	5,064,000	6,409,000	7,913,000	10,014,000	11,394,000
....	3.0	344,350	774,780	1,377,400	2,152,000	3,099,100	4,218,000	5,510,000	6,973,000	8,609,000	10,895,000	12,397,000
....	3.5	370,000	832,500	1,480,000	2,313,000	3,330,000	4,532,500	5,920,000	7,493,000	9,250,000	11,707,000	13,320,000
....	4.0	393,000	884,250	1,572,000	2,456,000	3,537,000	4,814,200	6,288,000	7,958,000	9,825,000	12,435,000	14,148,000
....	4.5	415,270	934,350	1,661,100	2,595,000	3,737,400	5,087,000	6,644,000	8,409,000	10,382,000	13,139,000	14,950,000
....	5.0	436,200	981,450	1,744,800	2,726,000	3,925,800	5,343,000	6,979,000	8,833,000	10,905,000	13,802,000	15,703,000
....	5.5	450,200	1,020,500	1,824,800	2,851,300	4,105,900	5,589,000	7,299,000	9,238,000	11,405,000	14,435,000	16,423,000

. . . .	6.0	473,750	1,065,900	1,895,000	2,961,000	4,264,000	5,803,000	7,580,000	9,593,000	11,844,000	14,990,000	17,055,000
. . . .	6.5	489,840	1,102,100	1,959,400	3,062,000	4,409,000	6,001,000	7,837,000	9,919,000	12,246,000	15,499,000	17,634,000
. . . .	7.0	505,920	1,138,300	2,023,700	3,162,000	4,553,300	6,198,000	8,095,000	10,245,000	12,648,000	16,008,000	18,213,000
. . . .	7.5	522,010	1,174,500	2,088,000	3,263,000	4,698,000	6,395,000	8,353,000	10,571,000	13,050,000	16,517,000	18,792,000
. . . .	8.0	538,500	1,211,600	2,154,000	3,366,000	4,846,000	6,597,000	8,616,000	10,905,000	13,462,000	17,038,000	19,386,000
. . . .	9.0	565,970	1,273,200	2,263,000	3,537,000	5,093,000	6,932,000	9,054,000	11,459,000	14,147,000	17,905,000	20,371,000
. . . .	10.0	589,270	1,325,900	2,357,100	3,683,000	5,303,000	7,219,000	9,428,000	11,933,000	14,372,000	18,645,000	21,214,000
. . . .	12.0	633,340	1,425,000	2,533,300	3,958,000	5,700,000	7,758,000	10,133,000	12,825,000	15,833,000	20,040,000	22,800,000
. . . .	14.0	675,000	1,518,800	2,700,000	4,219,000	6,075,000	8,269,000	10,800,000	13,669,000	16,875,000	21,357,000	24,300,000
. . . .	16.0	713,550	1,605,500	2,854,200	4,459,700	6,422,000	8,741,000	11,415,000	14,449,000	17,839,000	22,577,000	25,688,000
. . . .	18.0	748,650	1,684,500	2,994,600	4,679,000	6,738,000	9,151,000	11,978,000	15,160,000	18,716,000	23,977,000	26,951,000
. . . .	20.0	779,350	1,753,500	3,117,400	4,871,000	7,014,000	9,546,000	12,470,000	15,782,000	19,484,000	24,659,000	28,057,000
. . . .	25.0	845,150	1,901,600	3,381,000	5,282,000	7,606,000	10,353,000	13,522,000	17,114,000	21,129,000	26,741,000	30,425,000
. . . .	30.0	902,180	2,029,900	3,609,000	5,639,000	8,120,000	11,054,000	14,435,000	18,269,000	22,555,000	28,894,000	32,478,000
. . . .	35.0	954,820	2,148,300	3,819,000	5,968,000	8,593,000	11,697,000	15,277,000	19,335,000	23,870,000	30,211,000	34,373,000
. . . .	40.0	998,680	2,247,000	3,995,000	6,242,000	8,988,000	12,234,000	15,979,000	20,223,000	24,967,000	31,599,000	35,952,000
. . . .	45.0	1,036,700	2,332,600	4,147,000	6,479,000	9,330,000	12,700,000	16,587,000	20,993,000	25,918,000	32,802,000	37,321,000
. . . .	50.0	1,072,000	2,412,000	4,288,000	6,700,000	9,648,000	13,132,000	17,152,000	21,708,000	26,800,000	33,919,000	38,592,000
. . . .	55.0	1,106,880	2,495,000	4,428,000	6,918,000	9,962,000	13,539,000	17,710,000	22,454,000	27,672,000	35,023,000	39,848,000
. . . .	60.0	1,137,600	2,559,600	4,550,000	7,110,000	10,238,000	13,935,000	18,101,000	23,036,000	28,440,000	36,000,000	40,953,000

TABLE II.

Sp. Gr. gas. Air=1.	Temperature of flowing gas for point observed at well mouth. 25°	30°	35°	40°	45°	50°	55°	60°	
.40	.234	.227	.221	.215	.209	.203	.197	.191	Add for quantities above line.
.45	.163	.157	.151	.145	.140	.134	.129	.123	
.50	.103	.097	.092	.085	.081	.076	.071	.066	
.55	.053	.047	.042	.037	.032	.027	.022	.017	
.60	.007	.002	.003	.008	.013	.018	.023	.027	
.65	.032	.037	.041	.046	.051	.056	.060	.065	Subtract for quantities below line.
.70	.068	.073	.077	.081	.086	.091	.095	.099	
.75	.099	.104	.108	.113	.117	.122	.126	.130	
.80	.128	.134	.140	.143	.145	.149	.153	.158	
.90	.178	.184	.189	.192	.194	.198	.202	.206	
1.00	.220	.225	.230	.233	.235	.239	.243	.247	

TABLE III.

For Temperature of Storage of 50° F., Correction Multipliers to use the same as those of Table II.

Sp. Gr. gas. Air 1.	Temperature of flowing gas for point observed at well mouth. 25°	30°	35°	40°	45°	50°	55°	60°	
.40	.278	.272	.266	.259	.253	.247	.240	.234	Add for quantities above line.
.45	.206	200	.194	.188	.182	.176	.170	.164	
.50	.143	.137	.132	.126	.121	.115	.110	.104	
.55	.091	.085	.080	.075	.069	.064	.059	.053	
.60	.044	.039	033	.028	.023	.018	.013	.008	
.65	.004	.002	.006	.011	.016	.021	.026	.031	Subtract for quantities below line.
.70	.033	.040	.043	.048	.053	.057	.062	.067	
.75	.066	.073	.076	.080	.085	.090	.094	.099	
.80	.096	.102	.105	.110	.114	.118	.123	.127	
90	.148	.154	.157	.161	.165	.169	.173	.178	
1.00	.192	.197	.200	.204	.207	.211	.215	.219	

CHAPTER VI.

GEOLOGICAL SCALE AND GEOLOGICAL STRUCTURE OF WESTERN KENTUCKY

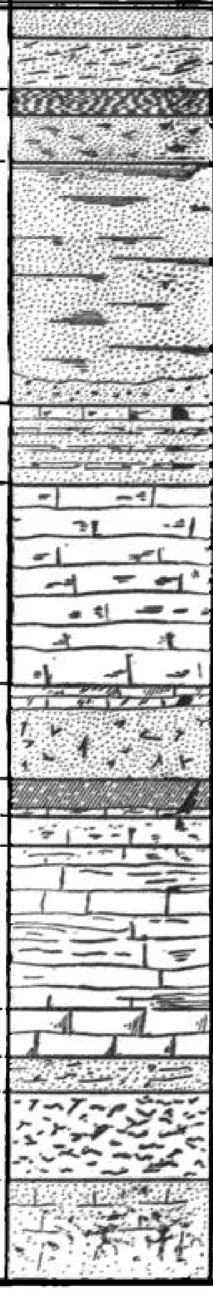
In making application of the facts and principles discussed in the foregoing chapter to the western half of Kentucky, it becomes necessary to furnish a brief review of the geological series that can take part in the origination and storage of petroleum and of its production within this geographical area. In the present chapter such a review will accordingly be undertaken, and, in connection with it, the leading facts of the geological structure of the region, as at present understood, will be noted, involving the accidents that the strata have suffered in the way of uplifts, depressions, and faults during their past history.

A. *Geological Series of Western Kentucky.*

Dividing the State by a meridian passing through Frankfort, the western half of Kentucky consists of the following formations, which either make the surface of its different sections, or lie buried at various depths below the surface. We can be excused from considering, in this connection, the formations that still underlie those that are to be here named, as it is scarcely possible that such can take any important part in the origination of petroleum. None of these lower formations come to the surface within the limits of Kentucky. The formations are named in descending order, and the thickness assigned to each is given on the authority of the Kentucky Geological Survey, being based on measured outcrops and on well records, taken from within the limits named.

In describing briefly the character of these formations, the order here given will be reversed, and the lowest formation will be first considered. The accounts of the lower formations will be mainly taken from the reports of the late W. M. Linney, of the Kentucky Geological Survey.

FORMATION.	GROUP.	FEET.
RECENT	RIVER DEPOSITS	100
QUATERNARY		200
TERTIARY	EOCENE	100
CRETACEOUS		200
CARBONIFEROUS	LOWER COAL MEASURES	950
SUB-CARBONIFEROUS	CHESTER	800
	ST. LOUIS	800
	KEOKUK WAVERLY	375
DEVONIAN	BLACK SHALE CORNIFEROUS	150
UPPER SILURIAN	NIAGARA &C.	100
LOWER SILURIAN	HUDSON RIVER	650
	TRENTON L. S.	175
	BIRDSEYE	150
	CHAZY	350
	CALCIFEROUS	



GEOLOGICAL SERIES IN WESTERN KENTUCKY.

(*1.*) *The Chazy Limestone.*—This great formation, which is the lowest that appears in the surface rocks of the State, is shown only in the valleys of the Kentucky river in the central portion of the State, and in the districts tributary to the valley; consequently it gives rise to no soils. It consists of heavy-bedded, compact, tough, more or less impure limestone, the range of which, in color, is considerable—gray, blue, and dove-colored tints being the prevailing ones. Sometimes a small amount of shale or carbonaceous matter intervenes between the layers. The stone is very strong, and would answer an excellent purpose for bridge stone, or for foundations where unusual strength is required. It has been used to some extent for such purposes.*

The Chazy beds are sparingly fossiliferous. In the massive walls of the valleys that constitute the natural exposures, it is difficult to find any fossils in such a state that they can be identified, but the forms found under the more favorable conditions are counted sufficient to establish the paleontological equivalence of these beds with the Chazy limestone of the New York scale. Among them the coiled univalve shell, *Maclurea magna*, is conspicuous in the upper portions of the beds. Other fossils that are counted on to establish this identification are *Orthis costalis*, *Rhynchonella plena*, *Asaphus marginalis*, and *Leperditia Canadensis*

Whether the lowest beds of this series all belong to the age of the Chazy has not been definitely proved, but no lithological differences are found by which any divisions can be suggested.

(2.) *Bird's-eye Limestone.*—A stratum of limestone in eastern New York, belonging to the lower portion of the Trenton division, is characterized by the occurrence of small spots of crystalline limestone, which suggested the name "bird's-eye" for the formation. They seem to occur as a replacement of marine vegetation. The same peculiarity is found well defined in rocks of the Kentucky scale at the same point in the geological column. The identification seems sufficiently established. It here consists of about 10 feet of buff or gray limestone, with patches of blue limestone included in it. In composition it is magnesian, containing from 32 to 40 per cent. of carbonate of magnesia. It is fine-grained and homogeneous in structure to such a degree that its use as a lithographic stone has been repeatedly suggested, but good results have not yet been obtained

*This stone, from quarries on the Kentucky river near Clay's ferry, was used in the construction of the Old Capital Building at Frankfort, erected in 1836. The buff stone in the pediment and entablature of this portico demonstrates the superior quality and beauty of this stone for architectural purposes. J. R. P.

from it in this line. It makes an attractive building stone, and is locally known as Kentucky marble. The Old Capitol at Frankfort is built of it, in large part.

Associated with this Bird's-eye bed is a large series of fine-grained, dove-colored, brittle limestones, the beds separated occasionally from each other by intervening layers of shale. Some good courses of building stone occur in this series. The upper portion is characterized by cherty beds. The entire series owes its origin in large part to fossils.

(3.) *TrentonLimestone.*—This series in the main consists of thin-bedded blue and gray limestone, but in the lower portions of this division there are sometimes a few feet of dark-colored, or blue, heavy-bedded limestone, separated by shales and marked by oblique lines of deposition. As the limestone and shale are highly bituminous, they suggest the Black river division of the New York scale, and are said to contain some fossils that are characteristic of this division.

Mr. Linney, in his report on Mercer county, divided the Trenton into four main divisions, as follows:

Upper Bird's-eye limestone.
Granular limestone.
Blue grass beds.
Silicious limestone.

The lowermost of these divisions comes in the place of the bituminous beds last described. The rocks belonging to it are impure, containing silicious and argillaceous materials in large quantity. They decay rapidly, and in their decay their characteristic chert nodules and silicious particles are set free.

The Blue grass beds constitute the leading element of the Trenton limestone. These beds are separated from each other, to a greater or less degree, by sandy shales, and both limestone and shale decompose rapidly when exposed, and are converted into the famous soils that characterize what has long been known as the Blue Grass District of Central Kentucky. These soils are found to contain all the elements required by the growth of the plants that we value most, and their fertility and enduring qualities are proverbial.

The rocks of this division are generally composed of fossils

The number and varieties are very great. With the associated forms above and below they exhibit one of the most characteristic assemblages of the life of the early world—that division of it called Lower Silurian being shown here at its best. It is unnecessary to occupy space with a catalogue of those that are already known and described. In Mr. Linney's report on the rocks of Central Kentucky, 1882, an extended list is to be found.

The granular limestone of Linney is not universally distributed. It is mainly found in the Blue Grass country, occurring as a heavy-bedded, gray, granular limestone, which carries a good deal of sand in its composition. The limestone is readily soluble on account of its granular structure, and comparatively small masses of it still appear above the surface of the most characteristic Trenton. This limestone gives rise to caves and underground drains to some extent, and many strong springs issue from them on the outskirts of the Blue Grass District. They are said to occupy the place of the Capitol limestone of Tennessee, from which the State House at Nashville is built. They are locally used to supply a fire stone for chimney backs and jambs.

The upper Bird's-eye beds are by the same token, the dove-colored limestone of the Nashville series of Safford. The beds of this division closely resemble the formations several hundred feet below them which have been already described. They are fine-grained, brittle, pure in composition, and take a fine polish. This particular series is by no means of universal occurrence, but still its presence in the scale deserves to be noted. These beds do not weather into soils as easily as those that underlie them.

(4.) *Hudson River Group.*—There should be found in the geological column, at this point in the scale, place for a division that is not distinctly identified in the Kentucky series, viz., the Utica shale. This is, however, pre-eminently a northern formation. It extends across the whole breadth of New York, and is also well developed in Pennsylvania. In the underground geology of Northern Ohio it has been found to take an important part, but followed southward through this State, it is seen to lose its thickness and distinctive characteristics below the parallel of Springfield. In Southern Ohio, it seems to be represented by a stratum of dark blue limestone, interstratified with dark blue shale, and not more than 40 to 60 feet in thickness. No equivalent of this bed is reported from Kentucky, and it is probable, therefore, that the interval is lost here by overlap of the Hudson river beds.

The last named formation has an important development in Kentucky, both in thickness and the extent in which it constitutes the surface rocks of the State. This series is divided by Mr. Linney into three divisions, viz., lower, middle and upper, but it is unnecessary to insist on these divisions in this review. The entire series consists of interstratified limestone and calcareous shales, all crowded with organic remains. Sometimes a mass ten to twenty feet in thickness will be found, consisting almost entirely of one sort of coral or shell. In thickness, the limestone beds vary from an inch or two to a foot or two. The thinner beds are often separated from each other by a few inches of shale, the thicker beds being succeeded by several feet of shale. Different portions of the series have different compositions, so far as the proportions of limestone and shale are concerned.

The series gives rise in its decomposition to highly productive lands. It forms soils readily and renews itself perpetually, even on steep hill-sides, but in such stations the resulting soils are generally stony.

(5.) *The Upper Silurian and Devonian Limestones.*—The limestones representing these two important divisions of geological time are named together in this enumeration, for the reason that it is difficult to draw a boundary line between them. The lower portion of the series contains beds that are unmistakably of Niagara age, while the reference of the uppermost beds to the Corniferous period of Devonian time is equally clear and unequivocal. When the middle portion of the column is studied, however, as in the immediate vicinity of Louisville, it becomes evident that there is a complete intermingling of the most characteristic forms of both divisions. This is especially true of the fossil corals. It is evident, therefore, that the life of the Upper Silurian was continued without interruption at these points until Devonian time had begun. It cannot, therefore, be proper to name the rocks of this period Niagara, even though they contain characteristic Niagara forms; they must rather represent the Lower Helderberg series.

The most interesting member of the series, economically considered, is the famous Louisville cement rock, which belongs near the center of the combined series of limestones. It consists of a stratum eight to ten feet in thickness in which sand and clay are naturally mingled with the lime which makes the bulk of the mass, in such proportions as to form, when burned at proper temperatures, a natural cement. The business of manufacture is large and strong in every way, and Louisville is by far the greatest center of natural cement manufacture in the United States.

The scientific interest of this formation is as pronounced as its economic interest. The corals that the Devonian division contains are preserved in wonderful perfection, the skeletons being silicious, so that the inclosed rock can be removed by treatment in acids. It is safe to say that the Devonian corals in the collections of Louisville, and especially in the magnificent collection of Major W. J. Davis, surpass in perfection of preservation any fossils of this group and age that have been obtained in any other portion of the world. The Devonian limestone is a source of oil and gas at a few points in the country, and notably at Terre Haute, Indiana.

(6.) *The Black Shale.*—This extremely well characterized formation makes a much more important element in the geological scale of the State than its area and thickness would lead us to expect. Its thickness does not exceed 100 feet, at least in the western half of the State, and its area is consequently of small size. The formation, however, gives rise to very numerous outcrops. It is well shown at New Albany, Indiana, opposite Louisville, and at countless points through the central counties.

The black shale is a part of a very widely extended formation. Its largest development in outcrop is in those portions of Ohio, Pennsylvania and New York that crop out on the shore of Lake Erie, between the mouth of the Huron river in Ohio, and Eighteen-mile Creek in New York. The shale formation has a thickness in this district of 1,200 to 1,500 feet. Under cover in the Ohio Valley it reaches twice the figures given above.

A three-fold division of the series, as it is shown in Ohio, has been urged by Professor Newberry, the several members being respectively designated the Huron, Erie, and Cleveland shales. Professor Newberry draws the line between Devonian and Carboniferous time at the base of the last named division. To other geologists it seems decidedly preferable to count the entire shale series as belonging to the Devonian division. There was evidently no great change in the physical geography of the division, wherever it is found, during the entire period of its deposition.

What portion of the great shale series of Ohio is it that is continued into Kentucky, or is the entire series reduced and represented in the thin division which we are now considering? The answer is clear and positive. It is the uppermost division of the scale, and is probably all included in Newberry's Cleveland shale. This is proved by its fossils, which, though not very abundant, are exceedingly interesting. The skeletons of the great fishes of this period constitute its most striking forms of ancient life.

This formation is especially interesting in connection with gas and oil springs that occur along the line of its outcrops across the State; and it is also found a source of these substances when it descends below moderate cover, as has been recently proved on the large scale in the gas well of Meade county. When found in an unweathered condition, it everywhere contains a considerable amount of desseminated petroleum. In addition to its bituminous contents, it also contains a notable percentage of organic matter that has passed through the anthracitic or coaly transformation.

(7.) *The Keokuk Series, or Knobstone Group.*—As shown in the New Albany section, this considerable division is made up largely of shale or mudstone. Towards the upper portion sandstone courses occur to a considerable extent, and probably some limestone beds are also included within its limits. This series is the equivalent of the Waverly group of Ohio, the lowermost 250 feet representing the Cuyahoga shale, and the upper or sandstone beds the Logan group. The most characteristic fossils of these two divisions are the same in both States, viz: *Conularia*, in the lower beds, *Hemipronites crenistriatus* and *Productus semi-reticulatus* in the upper. The shales are the most characteristic part of the series, and in the exploration that has been carried on in the State for oil and gas they are easily identified when their horizon is reached. The soils derived from this formation are, as a rule, very thin and poor.*

(8.) *The St. Louis Group, or Mountain Limestone.*—This great series of limestones, lying at the heart of the Sub-carboniferous division, constitutes one of the most important elements in the surface of Western Kentucky. Hundreds of admirable natural sections occur in the escarpments of Muldraugh's Hill. The series consists of limestone beds interstratified with calcareous shales. The proportions vary greatly. Many of the limestone courses are massive, and they also show false bedding to an unusual degree for limestones. The base of the series is everywhere marked by the presence of the well-known coral, *Lithostrotion canadense*, and also by abundant and easily recognized cherty concretions or nodules. A massive oolite of great economic importance as a quarry stone may be taken as practically the upper boundary. The St. Louis division gives rise to soils of unequal value in different portions of its extent; but the red lands derived from the decomposition of its uppermost beds are remarkable for their fertility, ranking among the very best lands of the State.

The solubility of the limestones of this section of the scale is attested not only by the abundant soil that results from their decay, but also, and especially, by the underground drainage channels that have been established in them. It was known in the early geological work of the State as the *cavernous limestone*, because of this fact. The most striking examples of these underground channels are to be found in the famous caves of the Green River Valley, including the Mammoth Cave.

(9.) *The Chester Group.*—Separating the mountain limestone series from the coal measures, a group of sandstones, shales and limestones occurs that it is difficult to characterize and describe because of its changeable composition. The most prominent elements in the series are two or more heavy sandstones, one of which attains a maximum thickness of 150 feet, and which ranges from 60 to 100 feet in long lines of outcrop. It is known in the

*The upper member of this group is more calcareous to the Southwest, producing a better soil than that derived from the shales and sandstones of the Waverly in Eastern Kentucky, where the limestone members are very thin or absent. J. R. P.

Kentucky Reports as the Big Clifty sandstone. A section taken in the banks of Big Clifty, four miles from Grayson Springs Station, near the Pearl Ford, is as follows:

Upper Chester sandstone, thin bedded and shaly	30 feet, seen.
Chester limestone with *Archimedes*, *Pentremites* and Oolite	36 "
Big Clifty sandstone, massive and uneven bedded	75 "
St. Louis limestone, blue, fossiliferous	15 " seen.

A section of the Chester series at Tar Spring, south of Cloverport, Breckinridge county, as represented in Vol. I of the Reports of the Kentucky Survey, is as follows:

Limestone	25	feet.
Shale.	15	"
Thin limestone	1	"
Shale, upper part marly	8	"
Limestone, very silicious	10	"
Dark shale	11	"
Limestone	4	"
Shale	6	"
Green marly shale	14	"
Shale	25	"
Covered space	20	"
Sandstone	25	"
Covered, probably sandstone	15	"
Limestone	25	"
Covered, limestone seen at intervals	45	"
Red and green marly shale	4	"
Covered space	25	"
Sandstone at base	278	"

This formation, when well developed, gives rise to bold and rugged features, and, as a rule, the soils derived from it are thin, excepting those derived from the limestones above the massive sandstone.

(*10.*) *The Coal Measures.*—This system is composed of shales, clays, marls, sandstones and limestones interstratified with seams of coal, the latter constituting but a small proportion of the entire series. It is not necessary to attempt an analysis of this complicated division. So far as known, the only element of it likely to be concerned in petroleum accumulation, is the massive sandstone which lies at its base and which is known as the Carboniferous Conglomerate. This sandstone has the general characteristics of the great Chester sandstone named in the preceding paragraph, and, like it, is a massive formation.

The soils derived from the coal measures are decidedly inferior in quality to those derived from the St. Louis limestone, as a rule, but there are some districts in Western Kentucky in which coal measures land shows great excellence. An example is found in the soils of Union county, which take rank with the best in the State.

B. Geological Structure of Western Kentucky.

A few paragraphs must suffice in this connection for the discussion of the subject to which the present section is devoted. The subject is in reality a large and difficult one, and an adequate treatment of it would involve a large amount of labor in field and office not only, but a large amount of text and illustration as well. When properly worked out, the facts will be found to include all the great divisions of Paleozoic time, including the Lower Silurian, Upper Silurian, Devonian, Subcarboniferous, and Carboniferous ages, and the history will be co-extensive with the history of this entire portion of the Mississippi Valley.

The geological work herewith reported gave no opportunity for original investigation in such subjects as these. In the nature of the case, it was even impossible to acquaint one's self with all the facts already gained by the geologists who have devoted much patient study to the several divisions of the field. A few general statements can be made, however, that will render the subsequent discussions more intelligible, and, in addition, a few details in regard to the most striking lines of uplift in Western Kentucky will be given.

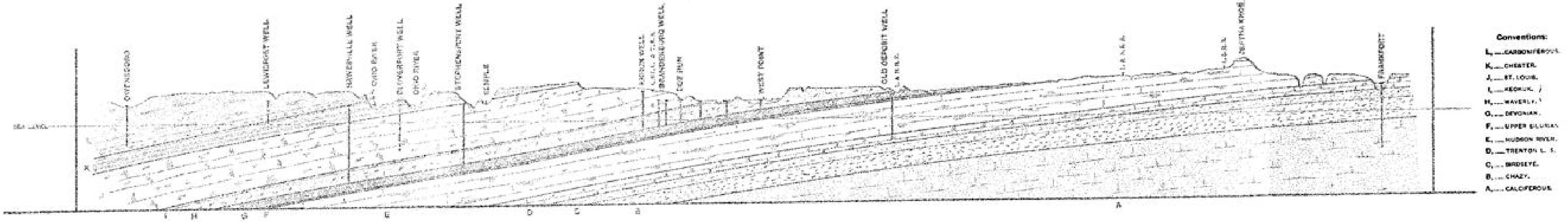
The order of succession of the several formations that constitute the surface rocks of the western half of the State, indicate clearly the underlying structure, so far as its leading features are concerned. The central counties are occupied by the Lower Silurian limestones. On the western edge of this formation, in Trimble, Oldham, Jefferson, Bullitt, Nelson and Marion counties, an outcropping band of Upper Silurian and Devonian limestones is found, varying in breadth from five to twenty miles. The surface rocks of this division have no greater geographical elevation than the older beds upon which they rest. Their presence, therefore, makes it certain that a westerly dip has set in, carrying these older rocks under cover.

The occurrence of the narrow outcrop of the Black or Ohio shale, which succeeds the limestone belt above described, bears out and extends this conclusion. And so, also, does each succeeding division of the great Sub-carboniferous system which constitutes the surface rocks of the next two or three counties to the westward. The Sub-carboniferous limestone, in turn, dips below the coal measure rocks that cover, in whole or in part, sixteen counties of the State, constituting the western coal field. From beneath these rocks the last named division rises again to the surface, to the west of the Tradewater Valley. This western coal field is thus seen to present the unmistakable features of a basin or broad syncline.

From the southern tier of counties of this part of the State the rocks are seen, by inspection of the geological map accompanying this report, to descend to the northward. The coal measures that overlie the Sub-carboniferous limestone, which occupies this southern tier, require such a descent of the latter to explain their occurrence. Their entire thickness of one thousand feet does not bring the surface of this area to any higher level than the underlying rocks attain in their respective outcrops. The general section on the State map, from the Mississippi river to the mouth of the Big Sandy, represents the facts to which attention has now been called.

Throughout the entire area that is under consideration there is no part of the surface that attains an elevation of one thousand feet above tide,* and very few points, if any, that rise to a level of 800 feet above tide. The descent or dip of the strata is in keeping with this elevation. It does not, as a rule, exceed 20 to 30 feet to the mile. Through the Ohio Valley, the direction of the dip is apparently south-west. This direction presents an unexpected confirmation of the surprising fact discovered in the Ohio and Indiana gas field, viz.: that the main line of uplift of the Cincinnati axis bears to the north-west, in-

* In the south-eastern part of the field under discussion, in Russell, Wayne and Clinton counties, a few points attain an elevation of more than 1,000 feet above tide. J. R. P.



GENERAL SECTION FROM FRANKFORT TO OWENSBORO.

HORIZONTAL SCALE, 10 MILES = 1 INCH. VERTICAL SCALE, 2000 F. = 1 INCH.

stead of to the north-east, as previously believed. The facts already stated show that the direction of the dip cannot be uniform throughout the entire territory, and even where the direction is maintained, the rate is found to change abruptly in some places.

The account thus far given sets before us a territory of something more than ten thousand square miles, the structural features of which seem exceedingly simple. The main feature in this connection is a gentle dip to the south-west from the great Lower Silurian area of Central Kentucky, which is commonly known in geology as the Cincinnati anticline. A sag or depression in the western portion of this district gave rise to the coal basin of Western Kentucky.

All of these movements of elevation and depression, as thus far stated, seem to have been of the continental type. That is, they were of low intensity, were continued through long periods of time, and involved large areas in the same movement. There is nothing in them of well-marked axes of elevation, such as result in the formation of mountain ranges.

If we could stop here, it would be impossible to justify the remark with which this section was introduced, viz.: that a considerable complication of structure is to be found in Western Kentucky. But we cannot stop here. Simple as its geology appears, and small as any of its surface elevations are found to be, a more careful examination shows that the rock series of Western Kentucky is traversed by many extensive and deep-seated fractures, and that these fractures are, in numerous instances, accompanied by the dislocations of the strata which are termed faults. While none of these faults are of very great vertical extent, they are still large enough to add considerable complication to the record, and to present problems in the identification of strata in many instances for which our present knowledge is not fully adequate.

The accompanying section, constructed by Prof. R. H. Loughridge, between Frankfort and Owensboro, represents one of these faults cutting the strata at Hawesville, Hancock county. It was brought to light in the working of the coal seams that are present in the series at this point. The amount of this displacement is supposed to be about 90 feet. The direction and horizontal extent of the fault have not been followed out as yet.

Again, in Livingston, Crittenden and Caldwell counties, there are several well-marked and extensive fractures, accompanied with frequent dislocations of the series. These fractures are occupied in part by considerable deposits of fluor-spar, through which lead ores, and, to a smaller extent, zinc ores are sparingly disseminated. These masses of spar constitute true fissure veins, their contents being undoubtedly derived from deep sources. Considerable expenditures have been made in these counties in the development of these veins in the search for lead, especially in the vicinity of Smithland, Livingston county. Thus far no returns have been obtained from such investments.

Another, and a much more important line of disturbance than either of those already noted, extends across a half dozen counties from Grayson Springs to Shawneetown, in the Ohio Valley. It is not less than 100 miles in length. Its general direction is north 80 to 82 degrees west. While the disturbance along this general line has not been strictly proved to be continuous, there seems good reason for believing that it is so practically, but the line certainly does not pursue a straight course. It has been recognized by all the geologists who have worked in the western field. Dr. Owen gave considerable attention to it in his reports, and he recognized the points already named as probably belonging to a single line of uplift.

No name has thus far been applied to the entire series, but saveral of the most marked areas of disturbance have been connected in designation with the localities where they occur. The famous Grayson Springs owe their existence to an extensive fault that is found in this line. Leitchfield shows a well-marked line of uplift without distinct fracture or fault. From the crossing of the Spring Fork of Rough creek, on the road from Leitchfield to the Falls of Rough, the strata are much disturbed. At the Sulphur Springs, in Ohio county, uplifts and faulting both occur, and the springs undoubtedly derive their strong sulphur water from a considerable depth. At many points in and near the valley of Rough creek, within the limits of Ohio county, these disturbances are well-marked. The line can be traced, in fact, across the entire county with perfect distinctness, The disturbance can be followed through McLean county, still further west, by several exposures of broken stratification, the most striking of which occurs in the valley and vicinity of Long Falls creek, three miles north of Calhoun. The break is less distinctly marked in this county, however, than in any other in the line. The Sub-carboniferous limestones are here thrust up to the level of the coal measures. At Sebree, in Webster county, one of the most striking exposures of the uplift is to be found. Again, at the Highland Lick, on the west margin of Webster county, a striking exhibition of the same disturbed structure is found. Further westward still better and more continuous exhibitions of uplift occur. The Chalybeate Hills to the south-east of Morganfield, and the Bald Hills to the west of the town, furnish together several miles of rocks, outcropping at high angles, and rising above the general level of the country in elevations recalling, though not equaling, mountain structure. Finally, at the famous locality known as "The Rocks," in the Ohio Valley, opposite Shawneetown, Illinois, the same disturbed condition of the strata appears in very striking form.

Probably the best name to apply to the entire line is that by which one of the more important sections is now designated, viz.: the Rough Creek Anticline.

How much influence a break in the stratification, of the kind here described, would have upon petroleum or gas accumulation, is an interesting question. There are portions of the line in which all the requirements of geology would seem to be met, so far as the structure is concerned; and the results of the tests, that are to go forward in these districts, will prove instructive in a high degree. In the most disturbed portions of the uplift drilling could not be advised; in fact, it would be found impracticable to drill in hard limestone strata that are pitched at angles of 15 to 30 degrees. But, upon the borders of the uplift, it is certainly possible, and almost probable, that favorable conditions would be found.*

Traversing the district, which the monotonous dip to the

*At Leitchfield and a few other points along the uplift, the rocks are horizontal immediately on the axis of the anticline, and afford favorable conditions for drilling. J. R. P.

southwestward, already named, has been shown to characterize, there are more or less minor arches or terraces interrupting the irregularity of the descent. In a single important instance account has been taken of this feature in the location of a gas-field, and other more or less successful gas-wells attest the presence of favorable structure of this sort that is not distinguishable, or, at least, that has not been distinguished in the surface rocks.

The general structural features of the portion of the State included in this report, so far as these facts are at present known, have now been very briefly pointed out. In the succeeding and final chapter, a brief history of the development of petroleum and its products at the present date will be attempted.

CHAPTER VII.

THE PRODUCTION OF PETROLEUM AND ITS DERIVATIVES IN WESTERN KENTUCKY.

The universal distribution of petroleum and its derivatives. including natural gas, asphalt and mineral tar, throughout the stratified rocks of the Paleozoic scale, which was asserted in the earlier chapters of this report, is abundantly demonstrated in the surface rocks of Western Kentucky. Practically but two divisions of the geological scale constitute the surface rocks of this entire territory, viz.: the Sub-carboniferous and the Carboniferous divisions. Both of these series, but especially the former, abound in one or another form of petroleum. The great sandstones of the Chester division, and the massive conglomerate that underlies the coal-fields, furnish the most important examples of this accumulation; but it is impossible to go amiss of the facts that fall under this head, especially in the first named of these groups of surface rocks. In the coal measures proper there is, however, comparatively little evidence of any notable amount of bituminous production, outside of the coal seams and black shales that they contain. But the surface rocks can, with more or less ease, be pierced by the drill; and thus the characteristics of the underlying strata, an account of which, in their proper geological order, is contained in the preceding chapter, can be tested, so far as this line of substances is concerned. When these tests are applied, each of the following underlying divisions, viz.: the Devonian shale, the Devonian and Upper Silurian limestones and the Hudson river group, has been proved, in some part of its extent, to be petroliferous in an important sense.

The accumulations referred to consist of petroleum proper and of the gas derived from it on the one side, and at the other extreme, of the tar and asphalt that result from its oxidation.

These last named substances are in all cases found in the outcropping rocks of the scale. The gas and oil are the products of the strata under cover when reached by the drill.

These several divisions of the geological series of the State, in their relations to the varied forms of bituminous production named above, will be briefly considered in the following pages. As far as practicable, they will be treated in their proper geological order, the older or lower strata being named first; but there are some fields in which more than one division is found productive, and in describing these we shall be obliged to pass from one formation to another. It will, accordingly, be best to treat of the production with reference to the geographical boundaries.

THE CUMBERLAND COUNTY OIL FIELD.

A small area in southern Kentucky holds a prominent place in the history of the petroleum production of the continent. At Burksville, Cumberland county, in the valley of the Cumberland river, the first great flowing fountain of oil ever opened in this country was struck in 1829. The well giving rise to it was drilled for salt water, and was begun and finished in strata of the Hudson river age. The well was but 300 feet in depth, but it proved to be possessed of great energy, and it made a remarkable impression upon the country at large. It was, at the time, counted one of the wonders of the new world. The drilling tools were lifted out of the well by the force of the gas, and a column of oil was thrown to the top of the trees around the derrick. The stream flowed away from the well into the Cumberland river near by, and covered the surface of the river for many miles. In the course of a few days this film of oil was accidentally ignited at a point about forty miles below Burksville, and the flames spread rapidly along the surface of the water, presenting the astonishing sight of a river on fire. The trees along the banks were scorched and killed, and great alarm was experienced throughout the entire region. The quantity of oil that escaped must have been large, but it is vain to attempt to estimate it in exact terms. The phenomenon was altogether unfamiliar, and no proper standards of comparison were possessed by any of the observers by which they could be aided in gauging the surprising production. The fire upon the surface of the river continued to burn as long as the flow of oil was maintained from the well, but this ceased in about three weeks. The well still remained full of oil, and many years afterwards, when a somewhat more intelligent interest in regard to petroleum was beginning to be developed, pumping was resorted to for the purpose of obtaining as much oil as could still be secured, the product being bottled and sold extensively through the State for medicinal use under the name of "American Oil." At Burksville, as already stated, the Hudson river rocks constitute the surface. All along the margins of the valley the Upper Silurian limestones make their appearance, and a little higher the Devonian slate is found with its well-marked and persistent characteristics.

A good deal of drilling was done in and around Burksville after the modern period, in the development of petroleum, had been entered upon; but nothing at all comparable with this early experience was then encountered, though small oil-wells were found in numerous cases.

Whether the stratum that served as a reservoir in this case was a limestone or a sandstone has not been brought to light. There are occasional courses of sandstone in the Hudson river series of this part of the country that might, under favorable conditions, prove to be oil rocks. The structure necessary for production is manifestly to be found here, the entire Lower Silurian area of the valley being the eroded summit of a low axis of elevation.

The earlier promise of the geological series, now under consideration, has never been fulfilled, and no definite horizons of oil or gas have been made known in it by any of the explorations that have been carried forward or that are now in progress, though small production has been obtained at several other points from rocks of the same age.

THE ALLEN COUNTY WELLS.

The later history of petroleum, as has been previously shown, goes back to the year 1855. During the five succeeding years, rock oil was making its way to general recognition, especially among the Northern States, as a valuable addition to our available sources of artificial light. The general conditions under which it had thus far been found were made familiar to all well-informed persons in the parts of the country from which it was derived. The possible clews to its presence in the rocks that were furnished by "surface indications," so called, were also understood in a general way. The Civil War broke out at this time, and during the next four years there were many persons connected with the Federal armies passing across Kentucky, whose interest in petroleum production had been already awakened, and who, consequently, were sure to notice all the oil and gas springs along their various routes, and who also gathered up more or less of the traditions of the country in regard to these substances, as they had been brought to light in the search for salt water during previous years. When the war was over the results of these observations were to be seen in an invasion of Kentucky by representatives of the rapidly growing oil interests of the country, and drilling was begun at many points with great energy, and with large expenditure of money, most of which came from the Northern oil fields. The shrewd prospector saw, or thought he saw, many a new oil field among the secluded valleys of Southern Kentucky, and made haste to secure for himself a proper share of the wealth that lay hidden here. The period was one of great speculative excitement. The prospector was, by no means, a trained observer. Slight and unimportant resemblances to the productive oil fields of the East were seized upon and magnified into sure promises of fortune. An oil seep or a feeble gas spring was regarded as an infallible guide to a new Oil Creek.

Of this varied and enthusiastic exploration there remain but small, and, in the main, unimportant results. Not a single valuable oil field was brought to light by all this outlay of money and energy. Even the records of the work done have been mainly lost, or, surviving only in the traditional form, they have already become indistinct and unreliable.

One of the districts that attracted great attention at the time, and that was counted of unusual promise, was the central portion of Allen county. Oil springs had been known in the region from the occupation of the country. They generally occur in the lower part of the St. Louis limestone. One spring of this character is found in the valley of the Trammel Fork of Drake's Creek, a branch of Barren river. It is located on the A. S. Walker land, a few miles to the south-west of Scottville. The oil of this spring had long been collected in a small way, after the Indian fashion, by spreading a blanket over the surface of the spring and by wringing out the oil that was thus absorbed. A few barrels were saved every year in this crude way. The Younglove Brothers, druggists of Bowling Green, bought a barrel of the oil some time before 1850 and shipped it to Pittsburgh. The oil was prepared for the market by putting it up in pint bottles, and it found a ready sale throughout the country, as already noted, for an external application in the case of wounds of both man and beast. A few barrels only of the oil from this region found their way to the regions outside. Another oil spring was known on Little Trammel creek, near what is now designated as Petroleum Station.

During the war, while the Confederate army had possession of Bowling Green, fifteen miles to the north-west, account was taken of these native sources of oil, and all that could be got was wagoned across the country and shipped to Memphis. It would appear that several shallow wells were drilled near the spring at this time, each of them yielding, daily, five to six barrels of heavy oil, but the accounts as to these occurrences are not entirely clear. The wells are said to have been from 600 to 700 feet deep.

At the close of the war, the district in which these oil springs were situated was leased by "prospectors" on the large scale for drilling purposes; but nothing more important than the results already named was secured, except in the single locality next to be described.

The Uriah Porter farm, three miles to the west of Scottville, was long counted the finest and best improved farm of Allen county. It consisted of a thousand acres of land, much of it highly productive. In 1866 or '67, Mr. Porter and his sons began the drilling of a well in the search for oil, in the bottom lands to the south-west of the residence. At a depth variously reported in the traditions of the country, the range of the figures being between 75 and 300 feet, and the smallest figure being obviously nearest the facts, a flow of oil of extraordinary volume for this region was found. The production of the well was estimated by people who had never seen an oil well before, as 500 barrels, 300 barrels, 200 barrels, 100 barrels per day. Large abatements from such estimates are generally required. At the outset some oil was wasted, but provision was forthwith made for the flow, and a total production of the well of not less than a hundred barrels, and probably twice or three times this amount, was secured. The oil was shipped to Louisville and St. Louis for refining, but it was rank with sulphur and could not be deodorized by the means then at the refiner's command, and it was therefore counted of no value. Transportation was also very expensive, no railroad being reached within 15 miles. The horizon from which this well obtained its supply must have been the Keokuk group of the Sub-carboniferous age.

This well naturally caused great excitement in the county and the surrounding region. It is said that an offer of a hundred thousand dollars was made by responsible parties for the farm, and that this amount was refused. Two other wells were drilled by Mr. Porter, but both of them were failures. Another well was drilled in the vicinity upon the Mottley land, but it also was unproductive. The Younglove Brothers, already named, bought a tract near the Porter farm, and, in connection with others drilled a well several hundred feet in depth. A little gas and a little oil were found, but no value was developed in the well. On the Ham farm, one mile above Porter's, gas was struck, and its force was sufficient to blow the tools out of the wells, according to a tradition that still remains here.

These accounts seem to exhaust the earlier history of the district with respect to petroleum. A new chapter begins with 1887. Drilling was once more resumed in the country and along the lines that had been already tested. The immediate impulse to these new tests came from the wonderful development of gas and oil in the Trenton limestone of Northern Ohio and Central Indiana. The possibility that this great stratum, which is known to underlie Western Kentucky, and, as a rule, within easy striking distance, contained like accumulations of stored power, proved enough to attract once more the oil interests of the country; or, at least, to stimulate local enterprise to make the search for this form of mineral wealth. During the last three years a considerable amount of drilling has gone forward in this general region, and preparations have been made for more, and in the large way, by leasing lands in large blocks. At least one new well has been sunk in Allen county during this time. The traditions of the Porter farm led its present owner, Col. E. L. Mottley, of Bowling Green, in 1887, to locate a new test well within sixty feet of the flowing well of 1866. The work was done by the American Well Drilling Company, of Louisville. At 400 feet a show of oil was found, but the amount was not subsequently increased, though the drilling was continued to 1,300 feet. There was absolutely no value found in the series at this point. The Trenton limestone must have been passed through in the descent.

The Barren County Wells.

Under this section the largest oil field of the Western half of the State, but still a very small oil field, comes into view. A few wells producing gas in small or moderate amount are also to be credited to this county at the present time. In addition to these facts, it must be noted that Barren county is the center of the new interest which is carrying forward, with considerable expenditure of time and money, the search for a new oil field in Western Kentucky.

The early history of the Barren county oil field agrees closely with that of Allen county, already related. There is a circumstantial account current to the effect that soldiers of the Union army of Pennsylvania returned to Glasgow immediately after the war to follow up the "surface indications," which they had previously noted in this vicinity. An oil spring on Boyd's Creek, four and one-half miles southeast of Glasgow, was one of the most significant of these indications, and the first well was drilled in the immediate vicinity of the spring. Oil was obtained at a shallow depth in promising quantity. Some of the wells drilled between 1866, when the work was begun, and 1868, proved to be flowing wells, and one is credited with producing 100 barrels of oil per day for some time.

These wells, and others that were afterwards put down around them, constitute an oil field of small proportions, it is true, but as it has proved, of unusual persistency and of demonstrated value. From 1866 to the present time the field has maintained a fairly steady, though small, production. The oil is black, and its specific gravity is 40 to 42 degrees B. It does not contain an excessive amount of sulphurous compounds, and in fact is not offensive by reason of the presence of such substances, unless the process of distillation is pushed too far. The oil is derived from a stratum that lies about 170 feet below the valley level. The surface rocks at this point are the lowest beds of the Keokuk group. The section found in the beds is reported by the driller as follows:

Conductor	6 to 10 feet.
Gray limestone, cherty	20 feet.
Gray limestone, hard	20 feet.
Shale and blue limestone, alternating and varied	40 feet.
Ohio black shale	35 to 48 feet.
Interval	30 to 40 feet.
Oil sand	5 to 20 feet.

Though the elements of this section were obtained from those who had long been engaged in developing the field, there is no reason to believe that they have employed sharp observation or discrimination in making the record. The most prominent landmark in the section is the Devonian black shale (Ohio shale), which is found as above noted at a depth of about 90 feet below the surface. The oil rock, as already noted, is struck at about 170 feet, showing that an interval of 30 to 40 feet occurs between the shale and the oil sand.

The oil rock is, according to the testimony of the drillers and from the evidence furnished by such samples as could be obtained, a sandstone. No information could be obtained in the field establishing satisfactorily the character of the rock that fills the interval between the black shale and the oil sand. The nature of this interval is an important and interesting question, and the interpretation of the horizon of the oil rock, as will be presently shown, will depend altogether upon the identification of the rock that occupies this interval.

We come, then, to the question: What is the horizon of the oil sand? Or, in other words, to what geological formation does it belong? It is to be regretted that this question can not be answered in positive terms, or at least in such a way as to command the assent of all who are acquainted with the geology of the district. But a section found at and near the South Tunnel of the Louisville and Nashville Railway, in Sumner county, Tennessee, at a point intermediate between Gallatin, Tennessee, and Franklin, Kentucky, about forty miles distant from the oil field under consideration, furnishes us a possible, and, on the whole, a probable reference of the oil rock. This section is as follows :

9.	Gray and blue limestone, fossiliferous	50 feet.
8.	Dark, calcareous shale	30 feet.
7.	Yellow cherty limestone, very hard	2.5 feet.
6.	Dark shale	15 feet.
5.	Black shale, sparingly fossiliferous	35 feet.
4.	Magnesian limestone, fossiliferous	30 feet.
3.	Blue shale, soft, calcareous	10 feet.
2.	White, uneven-bedded limestone	10 feet.
1.	Blue limestone, containing *Orthis sinuata*, and other Hudson river fossils.	

As to the interpretation of the section, it may be said that several of the elements are unmistakable. Numbers 6, 7, 8, 9 belong without question to the Keokuk division of the Subcarboniferous. Number 5 is unequivocally the Ohio, or Devonian black shale. It contains the fossils characteristic of the formation throughout its entire extent, viz; *Sporangites* and *Sporocarpon*. Number 4 is a magnesian limestone containing numerous fossils, and among them *Halysites catenulata*, and a large-celled favosite (*Favosites favosa*). This is unquestionably the Niagara limestone. Number 3 is a blue shale, ten feet in thickness, in which no fossils were found, but its stratigraphy would indicate that it belongs to the Niagara group and represents the widespread Niagara shale. Number 2 is a limestone that, in its bedding and composition, is the exact counterpart of the Clinton limestone of Ohio and Indiana, and, moreover, it contains one or more fossils that are counted characteristic of this formation.

The lowermost stratum, or number 1, is unmistakably Hudson river in age, and can be followed downward in descending courses for several hundred feet along the track.

The oil rock of Barren county lies at just about the same distance below the black shale as that at which the stratum here identified as the Clinton limestone is found. In the latter formation, interpolated beds of sandstone frequently occur, as we know from the well sections of the formation in Ohio, and these sandstones are petroliferous in that State. The reference of the Glasgow oil, therefore, to the horizon here named, viz.: the Clinton, seems on these accounts to be reasonable and probable. At any rate the oil rock belongs 40 to 50 feet below the Ohio shale. No section has been found in Kentucky, so far as is known, in which an interval of this amount would more than exhaust the Upper Silurian system.

The Clinton series in Ohio has recently become, as is well known, an important oil rock and gas rock. In particular, it is beyond question the source of the gas of the Lancaster, Thurston and Newark fields of this State. It is also productive of both gas and oil in considerable quantity in Wood and Sandusky counties, in the northern part of this State.

Leaving, without further discussion, the question of the geological age and name of the oil rock of the Glasgow field, we come to its productiveness. What is its record as a source of oil? The answer to this question will be found in the history of the field. A dozen or more wells have been drilled in a cluster around the original Boyd's creek oil spring, as already related. One of the number, drilled in 1872, is credited with the following production: For two years it is said to have produced as a flowing well 18 barrels per day; for the next two years, 10 barrels per day, and for the next two, 5 barrels per day. At the end of this period pumping was resorted to, and from 1878 to 1884 it is said to have produced about 10 barrels per day. In 1888 it was credited with a production of 3 barrels per day, and this rate is said to be maintained at the present time. On this basis its total production would foot up as follows:

1872 to 1874	13,000 barrels.
1874 to 1876	7,300 barrels.
1876 to 1878	3,600 barrels.
1878 to 1884	14,600 barrels.
1884 to 1888	4,400 barrels.
Total	43,000 barrels.

These figures, as is apparent, are to be taken as representing the facts in a general way only. They probably exaggerate, to some extent, the yield of the well, but they certainly serve to establish the persistency of the supply. The Standard Oil Company entered the field and worked these wells for a number of years, but latterly this interest has been withdrawn, and Col. J. C. Adams, of Glasgow, now controls the product of the entire series. In 1883 he was pumping seven wells, the combined production of which was reported as 25 to 28 barrels per day.

The oil is treated on the premises in a crude way, about 55 per cent. of distillate being obtained from it. This distillate can be burned in the condition in which it comes from the stills, and a small quantity of it is so used in the immediate neighborhood; but it is mainly shipped to Louisville for further treatment, including bleaching and deodorizing. It is hauled from the wells to the railroad in tanks fitted to wagons. The distillation of the oil was formerly pushed to the point of cracking, 70 per cent. of distillate being recovered from the crude oil, but the quality of the distillate suffered considerably by this treatment. Besides this, the quality and amount of the tar and lubricating oil were sacrificed thereby, and these together are worth as much as the refined oil would be.

Recent History.

A new chapter in this history begins with 1887. As already described, the effect of the recent discovery of oil and gas in Ohio and Indiana then for the first time made itself felt in this district. Two or three companies were organized for exploration in the county, and several other companies have been since formed for the purpose, and more than forty wells have been drilled within a semicircle of ten miles radius, with Glasgow for a center, and many lying to the south and west of the town.

The Eureka Oil and Gas Company, under the direction of R. W. Carroll & Sons, took the lead in the new development. This company and the Kentucky Southern Oil and Gas Company, which is understood to represent the same interests, are reported as having drilled more than twenty wells within the limits named, some of them to a considerable depth. The same company has also erected a refinery four miles west of Glasgow, which has been in operation since early in 1890. The capacity of the refinery is said to be 600 barrels per week, but the amount of oil that has been refined here is not known.

The new drilling was, however, begun by a Glasgow company. It put down a well to the depth of 1,200 feet in 1887, unlocking at that depth a strong flow of highly sulphuretted water, generally known as "Blue Lick" water.

Two or more of the wells drilled by the Eureka Company produced dry gas, and one of them from a depth of 850 feet below the surface. These wells are about five miles south-west of the town, on the line of the Scottville pike. Well number 2 is located on the Drane farm. Gas was first struck in it at 835 feet, and the supply is said to have steadily increased for the 30 feet directly underlying. The well was finished at 900 feet. The casing was set at 365 feet, and considerable trouble was experienced from water at or near that depth. A fragmentary record of the section is reported as follows:

Blue limestone	90 feet.
Blue shale	45 feet.

Well number 3, on the Furlong farm, 1,200 feet west of number 1, found a highly sulphuretted and offensive gas at 310 feet, and at 355 feet, a green oil with a gravity of 44½ degrees is reported. Both gas and oil were in small volume. Salt water is also reported to have been found at 278 feet.

Well number 4, 2,400 feet north-east of well number 2, is reported to have found amber oil at 95 feet and a black oil a little below it in the Ohio shale. The well was afterwards drilled much deeper. The section found was reported as follows, while the well was being drilled:

Blue limestone and shale	120 feet.
Black shale	45 feet.
Slate and shells	165 feet.
Limestone, sparingly fossiliferous	330 feet.
Green shales and gray rock, at	1,370 feet.

The production of the Drane well was measured in July, 1888, by means of the anemometer, and a daily production of 87,500 feet was found. The measure was not exact, and the total production would perhaps be found to be not less than a hundred thousand feet per day. The gas appeared to be in all respects of an excellent character.

From the first the gas has been utilized in the drilling of the later wells, and has also been conveyed to the refinery of the company. Much larger wells than the one here named are reported to have been struck since this date, but no authentic accounts relating to them are at hand.

The drilling in the field has, however, all along been directed to oil and not to gas. Of the score or more of wells belonging to the interest named above, all are reported as producing oil in small quantity, and one is reported to be producing three barrels per day. Probably some of the others might be made to duplicate this record. It is said that this oil is found in the Boyd's creek field in all cases, and at a depth of 180 to 350 feet below the surface, the depth varying according to the location of the wells.

The Mills & Haven Oil and Gas Company are reported to have drilled thirteen wells, twelve of which produce oil. One of them is said to be a flowing well, and two of the remainder are being pumped at the present time. Their joint production is reported at 20 barrels per day. These wells are located about four miles west of Glasgow. The remaining wells of the company are shut in. It is probable that their production is small. C. C. Conroy, Esq., has drilled several wells in the neighborhood of the Kentucky Southern wells.

The following record of a well recently drilled on the farm of John Tolle, Esq., 3 miles south-east of Glasgow Junction, has been kindly furnished by Paul J. Mahoney, Esq., of Allegheny City, Pennsylvania. It is as follows:

	Feet.	Feet.
1. Surface deposits	...	22
2. Gray limestone, hard	15	37
3. Limestone, soft, lighter colored	22	59
4. Limestone, sandy	61	120
5. Black shale (sulphur water)	10	130
6. Limestone, sandy	25	155
7. Black slate, with pebbles, a little gas	10	165
8. Gray limestone, part of it hard and silicious, part easy drilling	235	400
9. Black shale (Ohio shale), soft	57	457
10. Sand, white, pebbly	5	462
11. Sand, light gray, carried gas	20	482
12. Limestone, hard and soft bands alternating, entirely destitute of gas and oil; salt water at 700 feet	1,029	1,511

The last great limestone sheet grew harder the deeper it was followed by the drill. The sulphur water struck at 120–130 feet was unusually rank and offensive. Gas was found at two horizons, as noted in the record, viz: at 155 to 165 feet in No. 7, and again in No. 11. The latter carried the odor of petroleum. It is seen to be derived from the regular Glasgow horizon, or near it. The gas shows a pressure of 75 pounds when shut in five minutes. It is thought that the pressure would reach 150 pounds if the well were thoroughly closed. The black shale produced a little salt water, and another vein was struck at about 700 feet. The latter was very strong.

The main interest in the record, as will be seen, centers in the so-called Glasgow sand, which is here reported at 456 feet. The same stratum is found at Oil City and in its vicinity at 185 feet; at Jordan's wells, south and west, at 330 feet.

In addition to these actual tests, a large amount of work has been done by experienced operators from the older fields during the last year, in the way of leasing lands and organizing companies for operation in the county. In fact, the search has been attended with more or less speculative excitement, without which it is hardly to be expected that a new oil field can be developed at all. All the facts of the field have been closely watched by shrewd and experienced operators, especially during the last summer.

What is the outcome, or rather, what is the promise of all this work and expenditure? It may be said in reply that a genuine oil horizon has been proved to exist here about 40 to 60 feet below the bottom of the Devonian black shale. It has not proved, however, in any sense a prolific rock up to the present time. It is found, in fact, at too shallow a depth to warrant the expectation that it will hereafter be so found, but it certainly displays good staying qualities. So far as the facts now appear, an oil field is likely to be developed here, the individual wells of which may make up by their persistency and by the small expense by which they can be drilled and operated for the small production to be expected of them. Two to ten barrels per day seem to mark the common limit of production, but the wells can be planted close enough together to allow a half dozen or more of them to be pumped by a single engine.

The cost of drilling and equipping a well ought not to exceed $500 to $600.

As to deeper sources of oil, it is enough to say that none have as yet been developed. Gas in the quantities already reported and oil in small amount has been found at several different levels as the work has gone forward here, but nothing like an oil or gas horizon has been made apparent. It is quite possible that carefully kept records of the work which has been done in which the showings of gas or oil have been found would disclose some productive band. It is not to be supposed that wells yielding one or two million cubic feet of gas per day, and showing good vitality (such wells are reported), could be found without at some point communicating with a body of oil. In other words, every gas horizon we expect to find, at no great remove, an oil rock.

If any deeper source of gas and oil can be shown to exist here in the shape of some persistent porous bed, it will greatly change the promise of the field. The well records, as at present given by the drillers, show thus far sporadic accumulation only, and such can never afford a proper basis for safe and large work.

THE WARREN COUNTY WELLS.

No oil field or gas field of any promise can be reported for Warren county, but the records of a half dozen deep wells remain to us as proofs of the interest in exploration directed to the discovery of these substances, which has recently overspread so much of this portion of the State.

The rocks of Warren county, like those of Barren and Allen counties, already described, belong to the Subcarboniferous system, but they are mainly included in its highest divisions, viz: the St. Louis and the Chester. In no portion of the State are the characteristics of the St. Louis division, including its fossils, shown to a better advantage than in Warren county. An excellent section of one hundred to one hundred and twenty-five is found within the corporate limits of Bowling Green, beginning with low water in the Big Barren river, and extending to the summit of the reservoir and the College Hills. The Oolite formation, so characteristic of the uppermost beds of the St.

Louis, is found here in good exposures; but in the great Whitestone quarries, five miles south-west of town, the same stratum is found in unsurpassed condition. The coarse red sandstone of the Chester division occurs in surface waste at these points, overlying the limestone. The section of the Whitestone quarries is as follows:

4. Chester sandstone, waste.	
3. Oolite, irregular in bedding	10 feet.
2. Oolite, massive, weathering white, saturated with petroleum	22 feet.
1. Blue limestone, fossiliferous, making road metal	10 feet.

The main stratum of the quarry, marked 2 in the section, is a remarkable body of rock. The joints are well marked, and are directed approximately to the cardinal points. They are never less than 20 feet apart, and sometimes the interval rises as high as 60 feet. The entire stratum, 22 feet thick, is one compact mass, so that blocks of any dimension that can be required can be obtained here; and yet, strange to say, the lines of false bedding that occur here attest unmistakably that the limestone mud was thrown down upon an uneven floor in oblique deposition. This entire mass is heavily charged with petroleum. The quarries reek with the characteristic odor of limestone oil. While about them, one can scarcely resist the impression that a Trenton limestone oil well has been opened near by. From the presence of the petroleum the limestone has a light brown tint when quarried, but on exposure to the air the petroleum evaporates, and the rock acquires a whiteness almost equal to that of marble.

With a stratum like this as a permanent element in the geological scale of the county, it is no wonder that surface indications of oil are common here. In the deeper strata of the county, also, the discovery of gas and oil in small quantity in wells drilled to a shallow depth for water is not unusual, and can be easily explained.

It was a case of this last sort that led to the recent extensive testing of such localities in the county by the drill. The work was begun in this wise: In 1885, Capt. C. G. Smallhouse, of Bowling Green, put down a well in the interest of the artificial ice company of the town to secure water adapted to this use. The well was drilled to a depth of 250 feet, at which point a small quantity of oil and gas were found. It was just at this time that the new oil rock of Ohio was coming to be generally known, and the possibility of a horizon of such accumulations in rocks that had never been credited heretofore with them was everywhere recognized.

In January, 1886, a number of the leading citizens of Bowling Green, being made acquainted with the geological considerations bearing upon the subject, mainly through the agency of Col. M. H. Crump, Professor of Natural Science in Ogden College, secured a charter for a company under the name of the Bowling Green Petroleum and Fuel Company; and later, in the same year, undertook active operations in the way of drilling wells.

The trial well was located on the west side of the town. The contractor was R. W. Carroll, of the American Well Drilling Company of Louisville. The price for drilling was $2,000 for 1,000 feet, and $500 of the stock of the company. The casing of the well was furnished by the company. It was set at 160 feet to shut out a strong vein of sulphur water, which is usually found in the lower measures of the St. Louis limestone.

At 363 feet oil was found in small quantity, a barrel or two being produced in a day. The gravity of the oil was 35 degrees B. Gas in like small quantity was yielded by the rock at this point. Whether the productive horizon belongs to the St. Louis or the Keokuk can not be determined positively, but it is probably included in the latter series. The boundary between the two divisions is obscure, at least under ground. The great shale series of the Keokuk was represented in the well by 250 feet in a nearly continuous series. An admirable set of the drillings of the well was secured in the interest of the company by Colonel Crump, the use of which has been freely offered to the officers of the State Geological Survey.

The further record is based largely on an examination of these samples. For the first 300 feet hard drilling was encountered, the cherty balls that characterize the base of the St. Louis system accounting for this fact. The upper surface of the black slate (Devonian shale) is found with tolerable distinctness at 660 feet. The shale formation appears to extend to 770 feet. The microscopic fossils of the shale were looked for, but were not found in the drillings. A silicious limestone, called by the driller "sharp sand," comes in below the black shale, but this portion of the record is not as distinct as could be desired. The next lower unequivocal horizon is the Hudson river system, which was struck at 990 feet, or thereabouts, as is proved by the presence of the characteristic fossils of the formation in the drillings.

The well was sunk to a depth of 1,782 feet. Near the bottom of the column dark shale was struck. There is little doubt that the Trenton limestone was passed through in the descent, but there is nothing in this part of the country to especially mark this stratum. In open sections it is to be distinguished only by the appearance or disappearance of a few fossils, no constant lithological distinction being found on which a separation from the limestone beds above it can be effected. The well was dry through the lowermost 1,500 feet of the section, no oil, gas or water being found except in insignificant amount.

Well number 2 of the company was drilled on Drake's creek, near the mill site of Sweney & Potter, five miles east of Bowling Green. The special location was determined by the fact that water for drilling was available here, the supply at the time being short throughout the immediate neighborhood; but a slight arch that appears in the surface rocks at this point had its influence in the location of a well in this vicinity.

The drilling was begun in July, 1887. An unexpected condition of things was developed at the start in the unusual thickness of the valley deposits at this point. Eighty-two feet of drive pipe were required to reach the bedded rock. A stratum of limestone, 100 feet in thickness, was the first element reported below the drive pipe. It probably represents the lower beds of the St. Louis limestone, in whole or in part. A small vein of sulphur water was found at this level. Under the limestone a stratum of shale was reached, and at a depth of 248 feet gas was struck in notable quantity. The flow was approximately measured, and its volume was found to be not less than a hundred thousand feet per day. The well remained open from October, 1887, to June, 1888, when it was torpedoed with 75 pounds of No. 1 Ætna blasting powder. The effect of the explosion was, however, unfavorable. It seemed to clog the well and to shut off in large part the supply of gas that had been previously escaping. In 1888 the volume of gas was too small to admit of measurement unless through a very small pipe. The closed pressure reached 35 pounds in eight minutes. The gas rock is reported as a dark blue shale, with a considerable quantity of Anhydrite distributed through it. It was thought to be about ten feet in thickness.

Well number 3 was located 500 feet from number 2, directly upon the anticlinal already named that appears at this point in the roadway. No gas was found in this well. The Devonian black shale was struck at 440 feet depth, and the well was finished at 705 feet without any noteworthy facts being brought to light.

Well number 4, located on the Hess farm, intermediate between Bowling Green and the Drake's Creek wells, was begun in January, 1888, and was drilled to a depth of 500 feet. A little gas was found at 275 feet in the Keokuk group. The Devonian shale was reached before the well was completed.

One more trial of the Drake's Creek district was made, and well number 5 was located about a thousand feet south of well number 2, which had proved in reality the only one of the group that seemed to justify further exploration. In this well the black slate was struck at from 450 to 500 feet, as in the other wells, and the drilling was continued to a depth of 1,200 feet, but without any valuable result.

The resolution of the company was equal, however, to one more test, and well number 6 was located in the same neighborhood as numbers 3 and 4. This well yielded from the Keokuk horizon a feeble flow of gas, perhaps three-quarters as much as that originally produced by well number 2. The well was torpedoed, but not only without advantage to it, but with positive loss. As a result of the explosion, water appeared, while the flow of gas was in no degree improved by it.

The explorations of the company ceased with the drilling of this well. A main object of the search had been to secure a supply of natural gas for the use of the thriving and beautiful town which they represented, but the tests had given no encouragement to the belief that such a supply was attainable here.

In addition to the tests of the Bowling Green company, it is to be noted that still another well was drilled, one mile northwest of the town, by Colonel Atwood Hopson, in 1888. Oil was found in this well at the same level which had yielded gas and oil in several of the wells already described, viz.: at about 250 to 300 feet below the surface. Gas in quantity large enough, as was thought, to supply one or two dwellings, was also reported from the well, but neither oil nor gas were in large enough amount to justify utilization.

The only important fact developed by the expensive explorations at Bowling Green and in its vicinity is that the latter served to establish a weak horizon of petroliferous accumulation in the upper portion of the Keokuk group, 150 to 200 feet above the upper surface of the Devonian black shale. While no economic value has been found thus far in this oil and gas horizon, it still deserves to be specially noted and to be placed distinctly on record. It constantly happens that some feeble source of gas and oil in one district becomes a remunerative, or even a prolific, source of these substances in another. It is accordingly an important part of all geological explorations in this connection to mark such horizons wherever they are discovered, even though they possess no economic importance whatever in the field in which they are first proved to exist.

In the counties previously named this horizon has not been tested. The wells of Burksville, Scottville and Glasgow begin below its level. But in a succeeding section a notable quantity of gas is to be reported that is possibly to be referred to this particular source.

THE HOPKINSVILLE WELL.

A single deep well has been drilled at Hopkinsville, Christian county, as a result of the newly-awakened interest in gas and oil throughout the country. A company was organized, and a test well was begun early in 1888. It was sunk to a depth of 1,500 feet. The well was located in the limestone quarry of S. H. McCarley, a mile distant from the center of the town. The contract for drilling was taken by the Forest City Petroleum, Gas and Drilling Company at a rate of $1,800 for a thousand feet, with the privilege being left to the company of going deeper at a rate of $1.40 per foot. The drilling was uneventful in every particular. The horizon of the well is near the summit of the St. Louis limestone. The record was not kept in such a shape as to furnish much minute geological information. Sulphur water was struck at a depth of 95 feet, and was cased out at 105 feet, below which no further trouble was experienced. The place of the black shale was diligently sought for in the record, but the only testimony available seems to place it at 1,275 to 1,340 feet in the well. These figures will show a surprising, but still not altogether anomalous, thickening of the Subcarboniferous series between Bowling Green and Hopkinsville, the interval not exceeding 60 miles. At 1,375 feet blue shale was reported in the well, and at 1,440 and 1,505 feet brown shale was reported. At 1,600 feet a small vein of gas, accompanied by a little oil, was found. The drilling was suspended at this depth. If the identification of the horizons named above is a true one, the lowermost 200 feet of the well are in the Hudson river formation.

This concludes the account of all the drilling that has been carried on in the southern central counties of Kentucky during recent or earlier years, of which trustworthy records have been obtained for this report. All of the wells described in the preceding section, except those of Burksville, were begun in strata of the Subcarboniferous age, but in different portions of this extensive series. Two approximately steady horizons of gas and oil have been brought to light—one 50 feet below the bottom of the Devonian black shale, and presumably in the Clinton horizon, and the other 150 feet above the upper surface of the same formation. In addition, there has been shown the presence of either sporadic accumulations of petroleum at various levels in the series, or else oil rocks more or less persistent, the place of which has not yet been accurately determined.

In the further drilling that is certain to be undertaken here in the near future, the attention of companies and contractors is especially directed to securing and making public authentic records of their work. Only in this way can horizons of gas and oil be discovered, and only in this way can geological knowledge be made to apply with profit to the driller's work. As an example of what is needed in this line, the record of a deep well in the Glasgow field may be specially mentioned and commended. The samples of drilling were saved at frequent and regular intervals with great care by C. C. Conroy, Esq., the owner of the well. A summary of the record, as thus established, shows a monotonous series of limestones and calcareous shales for most of the distance traversed, it is true, but comparison with other similar records would soon bring order out of the present obscurity.

By the aid of a few more records of this sort, collected in different portions of the territory which is now being tested, accurate information could be secured which could not fail to aid and direct all subsequent work in this line. The difficulty in obtaining such information as is needed results from several causes, one of which is that in the search for stored wealth the common interest is not generally regarded. Another, and a more serious obstacle to obtaining satisfactory records, is the failure of the driller to appreciate the importance of the continuous account of his work and the support of the same by accurately-kept samples of the drillings. He often labors under the erroneous notion that what does not arrest his attention or interest him can not be of value to the geologist, and in this way very often the critical portion of the column is passed without any note of its character. It is from such defects of the records in the Glasgow field, for example, that we are unable, after 40 wells have been drilled, to say whether there is a steady and important petroleum horizon in the Hudson river group of this part of the State or not.

In summing up the facts presented in the preceding pages, it may be said that the Subcarboniferous series of Southern Central Kentucky, while covering minor accumulations of oil and gas at several different levels in the strata, has not yet been proved to be at any point either prolific or even fairly remunerative oil territory; but it must be added that there are still large unexhausted possibilities in this field, and the results of tests now in progress ought soon to show what its real nature and promise in this respect are.

Passing northwards from the district already reported upon, we find that deep wells have recently been drilled in a number of counties, and particularly in Franklin county, at Frankfort, in Oldham county, at Lagrange, and in Jefferson county, in the vicinity of Louisville. All of these have been sunk to the lower rocks of the geological scale of the State. The Frankfort well, indeed, was begun in the Bird's-eye limestone, and must have nearly exhausted the normal section of the rocks of the Paleozoic column in its descent. In all the cases in which this lower series has been reached, so far as known, the rocks traversed by the drill have been in the main magnesian limestones, more or less silicious. Thin beds of sharp sandstone occasionally interrupt the monotony of the series. No interest in the way of gas or oil has in any instance been developed in them. Highly mineralized water, often rank with sulphurous compounds, constitute the only production of these deep wells up to the present time. In this fact the only encouragement to further testing of these ancient foundations is to be found. We have lately learned that in the porous strata or beds that contain these deep-lying sulphurous brines, gas and oil are also sometimes found. At present the Trenton limestone is the oldest source of valuable accumulation of these substances, but this fact has been but very recently discovered. There is, therefore, no inherent improbability that still lower horizons may be discovered. If any such shall be brought to light at any time, they will be identical with the water-bearing beds to which reference is here made, and herein lies the interest of these porous beds. None of the tests thus far made, it must, however, be noted, either in Ohio, Indiana, Kentucky, Illinois, Michigan, Minnesota or Missouri, has disclosed any reservoir of oil or gas to which drilling can be directed with any promise of profit. The record of the Frankfort well is so monotonous that it does not seem necessary to publish it in full. The series that it traversed consists of magnesian limestones, more or less silicious, and showing frequent alternations in color. No further discussion of it is necessary at this time.

The Lagrange Wells.

Four deep wells have recently been drilled in the vicinity of Lagrange by a home company, organized for the purpose of testing their territory for oil and gas. While the immediate incentive to undertaking drilling at this time came from the recent experience of Ohio and Indiana, there was another factor united with it in determining this action. More than thirty years ago the Louisville and Nashville Railway Company drilled a well at Lagrange, to obtain, if possible, an artesian water supply suitable for railway use. Intelligent residents of the town declare that the well was drilled to a depth of two thousand feet; but this would have been an extravagant depth for that day, and in the absence of authoritative records, these figures can scarcely be accepted as trustworthy. Gas was found at one or more levels of the descent, and it is said to have more than once made trouble for the drillers by becoming ignited. At the bottom of the well, wherever the drilling stopped, salt water was struck, which was equally unsatisfactory for railway use, both as to quantity and quality. The well was consequently abandoned, after being plugged; but in spite of this treatment gas continued to escape from it in small amount, and could be lighted for some time afterwards. Four years ago this history was recalled, and doubtless in an exaggerated form. The location of the well was sought out, the plug driven down in the pipe, and gas began to escape from it once more in quantity enough to blaze a foot or two above the tubing. The history above given was naturally counted even more satisfactory testimony as to the presence of underlying gas than any series of surface indications could afford. The facts were considered proof positive that Lagrange was in the gas belt, and that this most admirable and excellent of fuels was to be had here for the asking. The company consequently entered upon its work with the highest hopes of success.

Before taking up the history of the several wells, a few statements as to the surface geology of Lagrange will find appropriate place. The location is an interesting one geologically in this respect, viz: that the junction of Lower Silurian and Upper Silurian rocks occurs at this point. The railroad cuts between Pendleton and the Lexington Junction furnish a nearly complete section of the Niagara formation in this part of the State. The only exception is that the part of the series where the Clinton limestone is due is not exposed. The same section as that found in the railroad cuts, but shorter and more compact, though less thoroughly displayed, is found in passing directly southward one-half mile from the center of the village to the valley of Harrod's creek that flows past the town. The stream is bedded in the Hudson river series, while the quarry in the village is characteristically Niagara.

In the railroad section the top of the Hudson river series, carrying a number of its most characteristic fossils, is found in Vance's cut. Just below this fossiliferous series there are found fifteen to twenty feet of unusually even-bedded sandy and calcareous shales, marked by greenish bands. These beds present the appearance of massive and firm rocks, but they are in reality soft and worthless for all economic uses. They correspond very closely in all their features with a series that is found at a similar point in the scale in the South Tunnel on the Louisville and Nashville Railroad, just south of the Kentucky line. The Niagara limestone, as found at Lagrange, consists of an impure magnesian limestone, which contains crinoidal remains in abundance, but comparatively few other fossils. These few are, however, fairly characteristic.

Four wells were drilled at Lagrange, as previously stated, during 1887 and 1888, two of them north and two south of the railroad. The American Drilling Company, of Covington, took the contract for the first well. This well proved an expensive one for the company, about forty-seven hundred dollars being spent upon it. It was drilled entirely dry to a depth of 1,400 feet, at which point a feeble flow of salt and sulphur water was struck, which rose 200 feet in the course of a few days. The drilling was carried about a hundred feet below this point, and several new veins of salt water were struck in this interval. Samples of the drillings were saved during the progress of the well, and from an inspection of them the place of the Trenton is judged to be about 800 feet below the surface. The well produced no gas.

Well number 2 was dry to a depth of 1,200 feet, at which point a weak vein of salt water, similar to that described in the last section, was found, and by which the further descent of the drill was arrested. The well was begun on higher ground than well number 1, and this fact, taken in connection with the statement above given, shows that the salt water horizons are not regular in their occurrence. Traces of oil were found in the lowest series that was reached, but there was not enough of it to possess any economic importance. The cost of this well was about $1,500.

In well number 3 the section as reported by the driller contained a great deal more shale than was reported in the other wells, but there is no reason to believe that any marked difference exists in the sections themselves. The difference in the record depends upon the discrimination and accuracy of determination of the driller, rather than upon any difference that could occur in the series itself within so short limits. The shales are represented in this last record as extending from 300 to 700 feet, with few interbedded solid courses. Insignificant amounts of gas were found in this series at three different points in the descent. The cost of well number 3 was $1,200.

Well number 4 is located one-half mile south of the town, on the outcrop of the Hudson river rocks, in the valley of Harrod's creek, to which attention has already been called. This well yielded more gas than any of the others, the largest amount being derived from a point about 565 feet below the surface, and in the shale series already noted. The drilling was suspended at this point. The volume of gas was measured by the anemometer a few days after it was struck, and the well was found to be producing 5,000 feet in 24 hours.

The Lagrange Company had now expended between eight and nine thousand dollars, and it was evident that no results had been obtained that would justify the outlay or encourage further expenditure. The work of exploration was, therefore, abandoned at this point. The first wells were carried down through the Bird's-eye and into the Chazy beds. The trace of oil previously reported must have been derived from this lower stratum.

THE LOUISVILLE WELLS.

Within the city limits, and in the vicinity of Louisville, several deep wells have been drilled since the new interest in gas and oil has been developed. On the Indiana side of the river, in like manner, several thorough tests have been made of the underlying strata, to the depth of 2,000 feet or more below the surface. Nothing of economic interest has been found in any of these wells. As a matter of course, light veins of gas and small shows of oil have been found in them at various depths, for it is impossible to go amiss of such in explorations of this character in the Mississippi Valley; but so far as a half dozen or more tests, carried on at an expenditure of not less than $20,000, can settle such a question, there are no valuable accumulations of gas or oil in this immediate region. There was, in fact, no antecedent probability that any such accumulations would be found. The Trenton limestone is the only proved horizon that underlies the geological level of Louisville, and this had been found wanting in productive power for a full hundred miles to the northward and northeastward of the city.

In one of these Louisville wells a deep brine was found, which, during the last two years, has been utilized to some extent in the city as a medicinal water. It is said to rise from a depth of 1,900 feet in an artesian flow, and a small volume of inflammable gas escapes with it. The well is known as St. Patrick's well, from the fact that it was struck on St. Patrick's day, 1888. It is situated on Third avenue, between Weissinger and Magnolia streets. Handsome provision has been made for the disposal of the water, and the usual experience as to the power of such water to heal all the ills to which flesh is heir is being rapidly accumulated. An analysis of the water is furnished in the advertisement by which its merits are made known. The analysis was made by Prof. L. D. Kastenbine, of the Louisville Medical College. It is as follows:

GRAINS IN ONE WINE GALLON.

Free carbonic acid	13.58104
Chloride of sodium	760.53824
Chloride of magnesium	40.33624
Sulphate of lime	128.59616
Carbonate of lime	72.79808
Carbonate of magnesia	6.22256
Carbonate of iron	1.79800
Silica	0.61736
Loss	1.39808
Traces of organic matter, specific gravity	1.011

Temperature 57.2° F.

The geological horizon of Louisville is well known. Its surface rocks belong mainly to Devonian time, but the junction of Upper Silurian and Devonian formations is also found at a few points within the city limits. The Devonian limestone that comes to the surface in the valley of the Ohio river is as remarkable and interesting a representative of this geological age as is known in the world. A depth of 2,000 feet below the surface, which was attained by several of the wells drilled here, would carry the drill down to the same ancient stratum that was reported in the preceding section. The salt water of the Third avenue well is probably derived from some phase of the Chazy formation.

THE MEADE COUNTY WELLS.

We reach in our review the group of gas wells situated in the Ohio valley, twenty-five to forty miles below Louisville, that have awakened more interest and excitement, and led to the expenditure of more money, than any other discovery of either gas or oil within the limits of the State. The stratum from which the gas of the Meade county field is derived is the Devonian black shale, known in the geological column of the State as the Ohio shale. The surface rocks of the district in which the gas is found belong to the Subcarboniferous limestone series, and mainly to the St. Louis division. In this respect the present field agrees with the oil fields of Southern Kentucky, previously described, but the source of the oil or gas, as has been noted, is not the same as in the Glasgow field.

The history of the Meade county wells agrees in its general features with the history of the other fields that have been already described. All can be followed through substantially the same stages, among which the following are almost certain to be recognized in every district, viz: (1) Surface indications of oil or gas, mainly of the former, and in the shape of natural oil springs; (2) Tests, more or less thorough, made in 1865 and '66 by drillers of Pennsylvania; (3) A revival of interest and new tests of the region, based upon the discovery of oil and gas in the Trenton limestone of Ohio in 1885 and '86. The Meade county field agrees with the Glasgow field further in this particular, that a production of some importance has been maintained in it from 1886-7 to the time when the excitement broke out. The early history can be briefly told.

The Early History.—Meade county, in the vicinity of Brandenburg, attracted the attention of the oil well driller as soon at least as any other point in the State. This result came about in the manner here described.

Part of the drainage of Meade county is effected by a stream known as Doe Run, which enters the Ohio a few miles above Brandenburg. Tributary to it, and about three miles back from the river, is a little valley known from early times as Oil Hollow. A seep of petroleum, accompanied by a weak outflow of brackish water, constitutes an "oil spring," of which local ac count has always been taken since the country was settled. To the oil expert of early time this location seemed on every account to be full of promise, and the search was accordingly begun here in good earnest and with great expectations. The money spent was reported to be furnished by Philadelphia capitalists. From twenty to thirty wells were drilled in this immediate vicinity during the years 1863 to 1865. The speculative excitement, without which an oil field can scarcely be developed, broke out at this point. For a tract of 72 acres of land, worth at most a few hundred dollars, $12,500 were offered, and the offer was refused. For a farm that has since been sold at its full value for $7,000, $35,000 was offered and refused. In a single one of this score of wells, which was located near the original oil spring, a little oil was found at a depth of 135 to 150 feet. A tank was built and pumping was resorted to, but the tank was never filled.

One of the trial wells was located a mile above Brandenburg, on the farm of Hon. Alonzo Moreman. Here, at a depth of about 527 feet, a so-called crevice was struck, and a strong flow of inflammable gas and salt water resulted. The drilling was abandoned in disgust on this account.

Several other wells in the list here named found gas in considerable quantities in the descent, but no interest was taken in its occurrence. It was, in fact, decidedly unwelcome, because it was thought to take the place of the oil which the driller was so desirous of finding in paying quantity. Probably none of these wells was drilled to a greater depth than one thousand feet. This was about the practicable limit at this time.

The Moreman well, above referred to, continued its mingled flow of gas and brine in a vigorous fashion and without restraint or appreciable diminution, until 1872, when the utilization of the salt water was begun in a crude way. The recent experience of East Liverpool, Ohio, in manufacturing salt from brine found associated with natural gas, the gas being used as the fuel in the manufacture, was invoked and a small furnace was built. The output was about eight barrels of salt *per diem*.

The obvious advantages that this new manufacture possessed led to the drilling of other wells in the neighborhood. Dr. D. C. Pusey drilled a well for gas and salt water nearer to Brandenburg than the Moreman well, but while the gas was in good volume the brine proved too weak for successful utilization. This well was drilled to a depth of 765 feet, at which point a second but weak vein of salt water was struck. The new brine was tainted with sulphurous products, which would probably have rendered it inferior as a source of salt, even if the quantity had been large enough to justify utilization.

At the Moreman Salt Works the manufacture has been carried on continuously since 1872, and of late years by an improved process. A second and third well have recently been drilled near the first to increase the supply of both brine and gas, and the daily output of the works has been increased to about 25 barrels. The brine has a strength of 107° to 107½° B. The temperature at which it is produced was found to be 70 degrees in July. The quality of the salt is of the very best character, and the product has the advantage of the local market to such a degree that it can command from 20 to 30 cents more per barrel on the yard than the salt of the great districts More money has been made in proportion to the investment from these salt works than probably from any other in the country during the last fifteen years, but it must be confessed the scale of manufacture is not large.

The gas from the three wells is used not only in the salt manufacture, but in driving the machinery of a large flouring mill in the vicinity, and during the last year the residence of Mr. Moreman has been supplied with light and fuel from the same source. This is the first example found in the western half of the State in which natural gas has been utilized as a domestic fuel. Through the courtesy of Mr. Moreman an opportunity was afforded the officers of the Geological Survey to measure the volume of the original well in the summer of 1888. The conditions were not such as to allow an absolute measurement, but the approximate measure obtained was 200,000 feet per day.

The Recent History.—This brings us to 1886, the year in which the influence of the wonderful discovery in northern Ohio and central Indiana was beginning to take effect on all the surrounding country. The discovery of a new and most prolific supply of gas from an entirely unexpected source in the geological scale seemed to unsettle all the old foundations in this regard, and every wakeful-minded community began to feel that grand possibilities in the supply of heat and power might be sealed up in the rocks underneath it, awaiting only the enterprise that should send down a key in the shape of the drill to unlock this imprisoned power. In the enthusiasm that attended these remarkable discoveries, it would probably have been counted far more desirable by many that a gas field should be found underlying a town than that a coal field should be so discovered. Furthermore, the inducement to make the test was sufficiently great to command abundant capital for this purpose everywhere. The turn of Louisville and New Albany to engage in this geological exploration came in due order, as has been already shown, and the Trenton limestone was forthwith reached in numerous wells, but without bringing to light any accumulation of the much-coveted fuel. The Meade county gas field, already 25 years old and but 40 miles away, could not remain unnoticed while this eager search was going forward, and companies were presently formed to investigate the supply of the Ohio valley in the Brandenburg district. This work was begun for Louisville by a company organized by Col. J. B. Castleman in 1886, under the style of the Economic Heating Company. Their first well was drilled on a piece of land belonging to J. A. McGehee, on Doe Run, near the original oil spring, to a depth of a thousand feet, but nothing of value was discovered in it. The second well was drilled a thousand feet deep in the same neighborhood, on the H. A. Haynes farm.

Gas was found at a depth of 400 feet, but the contract with the driller allowed him to charge for a thousand feet, at whatever point he should stop, and the company concluded, therefore, to have the work go forward to the full depth required. The gas was accordingly cased out. It was found in moderate amount only.

The interest that was thus being shown by their city neighbors in the Meade county gas field presently led several of the most enterprising business men of Brandenburg to organize companies to further investigate the field in their own interest, whether for utilization at home or in a more distant market. The Union Gas Company was organized by, and remained under the direction of, Hon. O. C. Richardson, of Brandenburg. The First National Gas Company was organized under the presidency of J. W. Lewis, Esq., of Brandenburg, but the capital of both companies was drawn in considerable part from Louisville. The Union Gas Company secured territory mainly on the Indiana side of the river, in Harrison county. The First National Gas Company secured leases on about 3,000 acres of land on the Kentucky side, and in the neighborhood of West Point, a dozen miles above Brandenburg. Gas from the Brandenburg well is used in Brandenburg in the hotel for fuel and light.

The Union Gas Company called to its service, in the organization of its work, an excellent geologist, who was at the same time thoroughly acquainted with all the elements of the geological section involved, in the person of Major W. J. Davis, Secretary of the School Board of Louisville. The entire work of exploration of the valley took on a new character from this date; it became more intelligent, orderly and economical. The true nature of the supply was recognized, and the deep, costly and futile borings that had hitherto been in vogue were at once abandoned. In a careful preliminary study that Major Davis made of the field in the interest of the company, he found a low arch traversing the strata, as they are exposed in the river hills, the centre of the arch lying not far from Tobacco Landing, on the Indiana side. Beneath what appeared to be the center of this weak uplift, he drove the stake for well No. 1 of the Union Company. The well was completed in September,

1887. It proved from the start a source of perfectly dry gas. The volume of the gas was not large when judged by the standard of a great field, but there was no drawback whatever in connection with it. The quality of the gas was of the best. It was obtained from a well, the depth of which was shallow, and the cost of which was small, and, as before remarked, the gas was entirely free from either oil or salt water. The volume of the well was measured by the late Charles A. Ashburner, Geologist of the Philadelphia Company of Pittsburg, immediately after the well was completed, and was reported by him as 805,000 feet per day. Major Davis subsequently measured the well, and found the volume 807,000 feet. Measured for the State Geological Survey in July, 1888, it showed a volume of 803,000 feet. The last measure was taken after the gas had been allowed to burn in the air for nearly one year, during which time not less than 275,000,000 cubic feet had thus been destroyed. The well was named in honor of Major Davis, and it did more than any other single factor to bring the field into general notice. It was kept lighted for many months, and attracted the attention of all who passed by on the river route.

Geological Section of the Gas Field.—No better point can be found for describing in somewhat more detail the geological section that is exhibited in the Brandenburg or Meade county field. As already stated, the surface rock belongs to the middle portion of the Subcarboniferous series, and mainly to the St. Louis group. Bold cliffs of this limestone, 200 feet in height, rise abruptly from the river's edge, first on one side of the valley and then on the other. In the river bottoms, however, an extensive erosion of the bedded rocks has taken place, and probably at a comparatively late geological period, the space from which the rock has disappeared being now occupied by the usual valley deposits of clay, sand and gravel to a depth of 100 to 130 feet. The well now under consideration was, however, begun on the outcropping edge of the St. Louis limestone, and the series was consequently found regular throughout. Alternating limestones and shales, the former predominating, occupied the uppermost 245 feet of the well section, representing unmistakably the Keokuk group, at least in part. At this point the soft shales of the Knobstone group were struck, and they continued without interruption until the Devonian black shale was reached at a depth of 375 feet. The Knobstone shales are thus seen to have had in this well a thickness of 130 feet, but this element is by no means constant, as was afterwards found. The Knobstone shales are known by the driller as the "Mudstone," and the casing is in all cases set as soon as this horizon is reached. The black shale, which is the source of the gas, has been found by repeated tests to have a thickness of 50 to 100 feet. In the well now being described a small flow of gas was found as soon as the black shale was reached by the drill. The amount gradually increased to a depth of 25 feet in the shale, making the total depth of the well 400 feet. The rock pressure of the gas was found to be somewhat more than 100 pounds to the square inch.

From one well the record of all can be learned, so far as the main features of the section are concerned, and with the qualification already introduced as to the valley localities. In the latter the drift beds are uniformly found about 115 feet in thickness, as before noted.

Further Developments of the Union Gas Company.—The Union Gas Company proceeded with its developments, and in October, 1887, drilled Well No. 2 at Boone's Landing, two miles below Well No. 1. This well justified the location of the first by showing distinctly the reality of the relief that was claimed for the former. In No. 2 the Knobstone shale was struck at a depth of 400 feet, or 155 feet lower than in the first well. The black shale was found at 498 feet, and occupied mainly with salt water, only a small volume of gas at any time appearing in its production. The slate was drilled completely through, and its thickness found to be 81 feet. The well was of no value.

Well No. 3 was located on the Webb farm, and 400 yards above Well No. 1. It was finished in May, 1888. The Knobstone shale was struck at 230 feet, and the black shale at 345 feet, showing even more favorable relief than was found in the first well. When completed, it produced but a small volume of gas from the first thirteen feet of the shale, and no increase was derived from going deeper in this stratum. It was then torpedoed at the lowest level at which gas was found with 14 pounds of dynamite, and a noticeable increase of the flow of gas was the result of the explosion. Measured by Major Davis, soon after its completion, the volume was found to be nearly 800,000 feet per day. In July its volume, as measured for the Geological Survey, was found to be nearly 1,000,000 feet per day.

Well No. 4, which was finished in June, 1888, was located on the same farm as No. 3, but upon the top of the river hill, and about 600 yards northeast of the former. It was consequently about 175 feet deeper than the latter, but in absolute elevation the strata that were found agree very closely with those reported in the previous well. The casing was set at 411 feet, and the black shale was struck at 506 feet. Gas was also found here in the uppermost 13 feet of the stratum. In volume it agreed closely with Well No. 3.

While the drilling above described, which had occupied nearly a year, was going forward, under the direction of the Union Gas Company, there was great activity in the organization of other companies, and in the testing of new portions of the territory.

The Kentucky Rock Gas Company.—The company whose work is now to be described holds by far the most prominent place in the development of the Meade county field. It grew out of the work, in large part, that was done by Major Davis in his discovery of the geology and structure peculiar to the Brandenburg field, and it presently absorbed the interest of the Economic Heating Company, which was the first to appear in the field, and whose early tests have been already named. Its work was begun in the latter part of 1887. Tracts aggregating 7,000 acres were secured by Major Davis and his associates within the lines which he had determined to be geologically the most promising, so far as the relief of the field was concerned. The lands of the company occupy the Kentucky bottoms in an almost unbroken body directly opposite to the Tobacco Landing arch. Ample capital was furnished by leading citizens of Louisville, and the work of exploration went forward vigorously and judiciously under the management of Major Davis. The first well of the company was begun

December 5, 1887, and completed January 8, 1888. It was located on the Bickerstaff farm, and is known as Bickerstaff No. 1. Its record is as follows:

Drift beds	115 feet.
Casing set at	310 feet.
Gas rock struck at	386 feet.
Gas found at	392 feet.

The gas appeared in large volume, and was allowed to burn from the open pipe of the well for three months. It was then kept closed for a month, and at the end of this time it was found, upon being opened again, to have been invaded by salt water to such an extent that its pressure was weakened and its volume decreased. In May, 1888, the daily volume was found to be 450,000 feet.

It is not necessary to follow the individual history of the wells drilled by the company, but a brief recital of the leading facts in the development will be in place. A second well was drilled at a later date on the Bickerstaff farm, which proved to be a very large well for Meade county, and a respectable well for any field. Its record is as follows:

Drive pipe	118 feet.
Casing set at	234 feet.
Black shale struck at	342 feet.
Gas in the shale at	426 feet.

The well was shot with 45 pounds of dynamite, and greatly improved thereby. Its rock pressure was 119 pounds; its open pressure, 7 pounds in a two-inch pipe. Its daily volume was two million feet per day.

The McGehee farm, lying directly opposite to the Tobacco Landing arch, became a necessity to the Rock Gas Company, on the theory upon which it was already working, but it was obliged to pay a round rate for the gas rights of the farm, viz: a thousand dollars a year cash rental. The first well on the farm bore out in the main the forecast above noted. The drift was 115 feet thick; the black shale was struck at 398 feet; the well was finished at 410 feet. Gas was found in large volume, a measurement made soon after the completion of the well showing it to be not less than 1,500,000 cubic feet.

On the Fountain farm three wells were drilled by the Rock

Gas Company. Well No. 1 is located a mile back from the river and near the base of the hills. It produced gas in but small amount and salt water in large volume from the beginning. Well No. 2 was located in the bottom lands, near the river, and has the following record:

Drift beds	114 feet.
Casing set at	326 feet.
Black shale struck at	411 feet.
Well finished at	428 feet.
Gas found at top of shale and at	416 feet.

The gas was dry at first, but was soon overtaken by salt water. When first completed, a measurement made by Major Davis showed its production to be 1,539,000 feet per day, but in July the water had invaded it to such an extent that its volume did not exceed one and a quarter million feet per day. In Well No. 3 the gas rock was found to have fallen away from the level required in the field for dry gas. The top of the shale was struck at 446 feet. The flow of gas was feeble from the first, and was not improved by the effect of a torpedo, the salt water taking full possession of the rock thereafter. The brine from this well was found to be one degree stronger than any other salt water tested in the field, registering 108 degrees B. It had a temperature of 64 degrees F. as it escaped from the well. The approximate measurement of the gas showed the daily yield to be thirty-six to forty thousand feet.

Wells were also drilled by the Rock Gas Company on the Ditto, Hendricks, Benham, Shacklett and Shrewsbury farms. Each represents one phase or another of the history already traced. The Shacklett well added a new element in a single particular. Its record is as follows:

Cased at	348 feet.
Gas rock struck at	429 feet.

Salt water was found as soon as the shale was tapped, and after it had been drilled into for 7 feet the water rose in the tubing 420 feet. A little gas was found at 7 to 10 feet in the shale, the entire thickness of the gas rock being found to be 63 feet. The gas had energy enough when first struck to free the tubing from water once in 23 minutes in geyser fashion. The interval was soon extended to several hours, and presently the action ceased altogether. The well was then torpedoed, but the effect was only to increase the water. The gas was snuffed out finally by this treatment.

Most of the wells named above, in association with the one here described, were, like it, overrun with salt water early in their history, and but one of these, viz: the Hendricks well, showed any considerable volume of gas.

The Rock Gas Company had completed, within the first eight months of its active operations, 18 wells, all located within the territory described above, and it was able to count up, on fair measurements, a daily production of 11,000,000 feet from the tubed wells.

Before describing the work of the latter company in piping the gas from the field to Louisville, it will be necessary to give account in few words of the work of a few other companies that were at this time organized, and that began work in the same general field.

The First National Gas Company, already named, had drilled eight wells at the time when the examination of the field for the Geological Survey was begun. Its territory comprised 3,000 acres, extending from Otter creek, in the Ohio Valley, where it joins the Rock Gas Company's lands, to within two miles of West Point. The capital stock of the company is $1,000,000. Of this amount $200,000 of the stock was sold to provide funds for the operating expenses. Work was begun in November, 1887. The well sections agreed in every respect with those already reported from the Brandenburg field, except that the rocks are slowly rising as they are followed up the valley.

The Dooley well was the first to be completed for this company. In it the black shale was found at 400 feet below the surface. The well proved of little or no value as a source of gas.

The next wells to be finished were a group half-way between West Point and Otter creek, and about three miles from Muldraugh Station. They were drilled on the Boyd Withers, the Newton Withers, the Franzell and the Smith farms, and are known by the names of the land-owners. In several of these, and notably in the Boyd Withers, Smith No. 1, and Franzell wells, the gas was dry when the rock was reached, and it was also in good volume. As measured by Major Davis, the Franzell well showed a daily production of 360,000 cubic feet in May, 1888, one month after its completion. The Smith well is described as much the strongest of the group, but it began to throw a large volume of water with the gas within a few days after its completion. While dry the well was measured by Major Davis, and its production found to be 1,140,000 cubic feet per day. It threw a large volume of salt water during the entire summer of 1888.

In this and other wells drilled in the same district by the First National Gas Company, the gas rock was struck at about 300 feet below the surface, and the gas was generally obtained very near the top of the stratum.

Another of the companies engaged in the development of the territory at this time was the Doe Run Company. Its territory, which consisted of two farms, was contiguous to that of the Rock Gas Company, being included within the boundaries of the latter. The company drilled two wells early in 1888, viz: the Fowler and the Ricketts wells. The Fowler well was finished in February. Its record is as follows:

Top of black shale	396 feet.
Small flow of gas at	396 feet.
Gradual increase until shale was penetrated at	403 feet.

The well was then shot with eleven pounds of dynamite, and the flow of both gas and salt water was largely increased. The volume of the gas was measured in April by Major Davis, and was found to be 1,570,000 feet. In May salt water appeared in large quantity, and the volume and the pressure of the gas seemed to fall away rapidly thereafter.

The Ricketts well was located one-half mile west of the well last named. It was cased at 340 feet and found the shale at 425 feet. The gas appeared as soon as the rock was struck, but at eight feet in it a strong flow of salt water was reached. The gas escaping with the water was found, on measurement, to show a daily volume of 400,000 feet.

Two wells were drilled on Otter creek—one by the First National Company, on the Griffee farm, and the second by the Grahamton Mill Company. The first produced a small flow of gas with a large quantity of salt water; the second was a salt water well, pure and simple, from the start. The shale was reported in it to be of a chocolate color instead of being black.

Two wells were also drilled at and near West Point—one by Cox & Montgomery, in which the black shale was found at a depth of 260 feet. Salt water and gas, both in small amount, were struck at a depth of three feet in the shale. The second well was drilled by a West Point company in Round Hollow, but salt water only was obtained from it.

The Laswell well at West Point flows well, and furnishes gas to a number of houses.

Numerous wells have been drilled since the date at which these facts were gathered; part of them by the companies already reported and part of them by companies that have been organized since that time. None of them, so far as known, has added any thing of importance to the records already given.

Summary of the Facts of Production.—The facts of the field are shown with perfect distinctness in the review that has now been made. They can be summarized as follows: The black shale, which has an extensive outcrop at New Albany, opposite Louisville, just above the level of the Ohio river, and which takes cover directly below this point, is found at a depth of 260 feet below the valley surface at West Point; 300 feet at Otter creek; 400 feet at Tobacco Landing, and 500 feet at Brandenburg, and in the interval between West Point and Brandenburg it has become a reservoir of gas and salt water. In outcrop it is everywhere a source of shale gas, but the volume of such gas is always small and its pressure is light. In these wells, however, the daily volume of the gas may rise to millions of feet, and the pressure, though not very great on account of the shallow depth at which the gas is found, is still a true water pressure.

All this is confusing to a high degree. It seems, at first sight, as if such an experience destroyed all possibility of practical or scientific prevision in the search for gas or oil. If there was any thing in regard to natural gas three years ago of which we could feel certain, it would seem to have been the facts as to the gas derived from the black shale. The formation had been followed through at least four States, and in all of them had been found a source of gas, and the gas had been found to possess a few definite characteristics, viz: low pressure, small volume, great persistency, and the absence of salt water. All at once we come upon wells in which the gas derived from the black shale is unmistakably driven by a salt water column, or, in other words, is stored in a porous rock, and the volume of the wells reaches a maximum of two and one-half million feet per day.

But the change is not as thorough as it would seem to be. In reality there has been but one factor in the Meade county field which differs from those found in other occurrences of gas derived from the black shale. It is this, viz: in the accidents of its history the stratum has here become in a measure porous, and, consequently, a reservoir for gas, oil and water. All the other facts noted above as characteristic of this field follow necessarily upon the transformation of the shale from an apparently impervious to a porous rock.

Producing, as it does, reservoir gas, the Meade county field falls under the laws of gas accumulation that were formulated in chapter second. It is a stored product, accumulated in the arches and terraces of the shale, compressed there by the force of a water column which takes its rise in the nearest outcrops of the formation. Its source is undoubtedly the lower beds of the black shale itself, inasmuch as the gas agrees in chemical character with that everywhere yielded by the shale. The cover is either the Knobstone shale or the upper portion of the Black shale itself. The salt water must also be indigenous to the formation. There is no other source from which it can be derived.

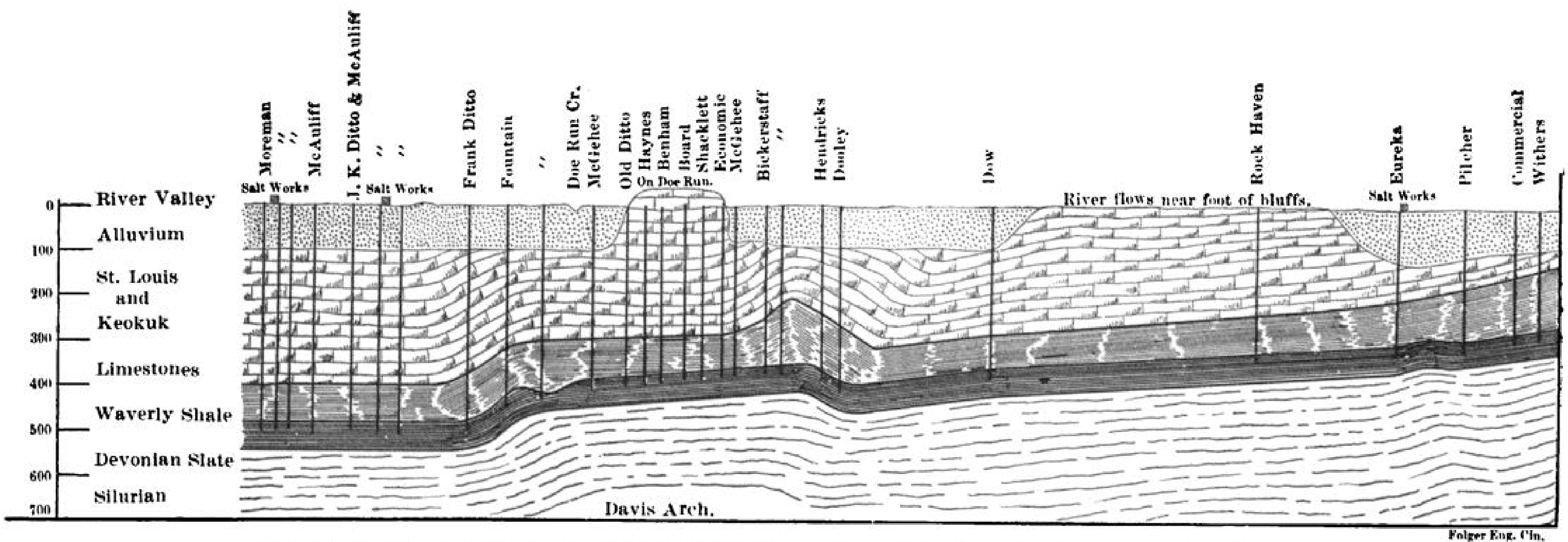
The relief of the rock in its most favorable portions is seen to be very light and wholly inadequate to the separation of the contents of the shale, viz: gas and water, for any great length of time. In all the records given above, the water is seen to have been very near the gas. Almost every well showed its presence within a few weeks at longest after it was drilled, and many found it associated with the gas from the beginning.

A striking peculiarity of the Meade county field, and the only one which comes to light in all this experience, is the maintenance of the combined flow of the gas and water from the same wells for so long periods. Of this joint product of the rock the Moreman well furnishes the best example. For 25 years it produced salt water and gas without any great abatement of the flow of either, and without any manifest change in the proportions of these substances. In almost every other field, when salt water once finds access to the well, it gains rapidly at the expense of the gas, bringing about the complete extinction of the latter after a brief period.

An approach to this condition of things is found in some of the Berea Grit gas wells of central and eastern Ohio. The famous Neff wells of Coshocton county show this peculiarity, but in them the salt water finds entrance in small volume, and the gas can not be depended upon to remove it, but it must continually be kept down by the pump.

The volume of gas produced by the Moreman well in August, 1888, has been given on a preceding page as approximately 200,000 feet per day. It is not at all probable that the original flow has been maintained throughout all these years without diminution; but assuming that it has been, what is the total volume of gas to be credited to this little drill hole at 200,000 cubic feet per day? The calculation shows 1,825,000,000 cubic feet. We are certainly warranted in enlarging this amount to cover the diminution of the well to a total of 2,000,000,000. Such a fact brings out in clear light the peculiarity of the field which is now under consideration, viz: its persistency in spite of the presence of salt water. The Meade county gas production must, therefore, be considered exceptional to a marked degree in the history of gas fields.

The Structure of the Field.—The structure of the central portion of the field is indicated in a general way in the accompanying section, prepared from notes furnished by Mr. McDonald, the engineer of the Rock Gas Company, for the use of the Geological Survey. The records of the wells show the reality of structural relief, however, better than the section on the scale upon which the facts are there represented. It has been demonstrated by the experience of several companies, and particularly by the work of the Rock Gas Company, that at the beginning of the development there were a few arches and terraces of dry gas in the



Section showing strata from Moreman's wells south-east to Potter's Cr. wells — 9 miles viewed at right angles to line of dip. Constructed from records of well borings.

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field, but that they were of small extent. None of them commanded more than a few feet of dry rock with which the salt water was in contact everywhere at the proper levels.

The fact that the gas is discharged with the water in most instances renders it difficult to ascertain to exactly what height hydrostatic pressure alone would lift the water-column in the well. In the Shackleford well a column of 420 feet was reported. This figure would indicate a rock pressure of the gas of about 190 pounds. Such a pressure has nowhere been attained ; but it must be remembered that the field had been open for 25 years when these measurements were taken. The highest rock pressure reported is 120 pounds to the square inch.

Utilization of the Gas.—The activity that has been reported as existing in the Meade county field was by no means aimless exploration ; but, on the other hand, it was directed to a specific and practical end, viz. : the supply of Louisville with natural gas for fuel and power. One of the companies, the organization and work of which have been previously described, viz : the Kentucky Rock Gas Company, had the courage to undertake the serious task of bringing the gas to a market large enough to absorb all that could be made available. This involved a very different character of expenditure from that which had been thus far required in leasing territory and in drilling a few dozen shallow wells. Hundreds of thousands of dollars would now be required where thousands, or, at most, tens of thousands had been needed before.

The company issued a circular in August, 1888, setting forth the work which it had undertaken, and inviting the co operation of the citizens of Louisville. The substance of the circular is introduced here, as it presents the views that were held in regard to the character of the Meade county gas field better than any statements from outside observers could do :

The Kentucky Rock Gas Company has for some months been maturing plans for supplying the city of Louisville with natural gas for heating purposes, both for the use of manufacturers and private consumers. Since the efforts of the Economic Heating Company were discontinued, this company became the pioneer in the gas territory of Meade county in this State, and as such, looking over the whole field there, they secured proprietary rights on seven thousand acres of land, selected as being the most promising for large and continuous yield.

A test of the value of their property has been made by boring a number of wells, all of which have yielded more or less gas, and have given to the company an aggregate daily output of eleven millions cubic feet of gas.

The success of this company in establishing the large value of their property stimulated the formation of a number of other companies which have taken leases upon over thirty thousand acres of land in that vicinity, some of which has been partially developed by the First National, Doe Run and Union Companies, with an aggregate daily production of six and one-half millions cubic feet of gas.

These facts have practically demonstrated that the gas territory of Meade county and vicinity is of far greater value than, a year ago, the most sanguine would have felt justified in believing.

Unquestionably it may be confidently said that the territory may be relied on to furnish to the city of Louisville natural gas in quantity sufficient for present demands, as the present yield, seventeen and one-half millions, is from a small part of it, and much the larger part is yet entirely undeveloped, and is held in reserve for future increased requirement.

There is also good reason for reliance upon permanence of production, for the reason that the well bored twenty-six years ago on the farm of Mr. Moreman is now yielding the same quantity as when it was first put down, and the wells bored during and since last fall show no diminution in yield since completion.

In this respect the territory compares favorably with the Pennsylvania, Ohio and Indiana districts, the first-named having enjoyed uninterrupted supply for five years past, giving to Pittsburg a new lease of supremacy for her manufacturing interests.

The commercial value to our city of an adequate supply of natural gas can not be overestimated. It is closely allied with the interest of owners of real estate, of merchants, manufacturers, and, indeed, of every citizen; it will do more to promote rapid increase of our population, to augment the number and importance of manufactures, to add to the wealth of our city and the comfort of our citizens than any other available agency.

It is, therefore, an event in which every citizen has a direct interest.

The Kentucky Rock Gas Company, fully convinced of these facts and of the importance of co-operative action for the attainment of the best results for their own interests and the public good, have offered favorable contracts to producing companies for their gas, and have concluded a contract with the First National Gas Company for their product.

Their policy will be to promote production as may be necessary to supply increased demand, and thus avail the entire product of the territory for the demands of our city.

Thus fortified with a large present supply and abundant good territory as a reliance for increased demand, the company have obtained from the city of Louisville the right to lay their mains and pipes through the streets and alleys of the city, which, in recognition of its great importance to the city, was promptly granted on application.

They have determined to lay a pipe line to the city, and to distribute the gas to consumers. To do this will require a large outlay of money, which they propose to raise at home, and in such manner as to share benefits with the purchasers of the company's bonds, to be issued to the amount of $500,000, as authorized by the charter of the company. This amount will enable the company to lay its main pipe to the city and through a large area within it, with ability to make further extensions as wanted, from reserved assets and current earnings.

The bonds will be made payable in twenty years from October 1, 1888, with the option to the company to pay them at any time after five (5) years, with attached coupons for payment of semi-annual interest, on April 1st and October 1st of each year, at the rate of six per cent. per annum.

They will be issued in denominatious of $1,000, $500 and $100, the smaller amounts being intended to give an opportunity to citizens of small means to unite in a popular movement for the public good. The price of the bonds will be par; they will be placed with the Fidelity Trust and Safety Vault Company as trustee, to be paid for by subscribers therefor as follows, viz.: 35 per cent. on September 15th, 35 per cent on November 1, 1888, and 30 per cent. on January 5, 1889, the purchaser having the benefit of interest on the bonds from October 1st, and also to receive of the stock of the Kentucky Rock Gas Company fifty per cent. of the amount of bonds subscribed and paid for, that is to say, that for each $1,000 bond purchased $500 of the stock of the company will be delivered with the bond, and in like proportions for the smaller denominations.

Under the conditions stated, it is not an extravagant estimate to say that the dividends on the stock will be ten per cent. per annum, which, being realized, will, in most cases, be nearly or quite sufficient to pay for cost of gas or other fuel consumed by a family of average size.

With this presentation of the plans and purposes of the company, thus fully made, the Kentucky Rock Gas Company ask a prompt subscription by our business men and citizens for the bonds to the full amount of $500,000.

If this is done, the company will proceed at once to lay their mains to and through the city, and make connections with the property of consumers subscribing therefor, with the expectation of furnishing gas to them before the close of this year.

The action foreshadowed in the circular of the company was soon entered upon. There was raised by the company $400,000 in the way indicated above, and the construction of a pipe line was forthwith begun. An eight inch wrought iron pipe, of the most approved quality, was laid from the field to the city, a distance of 32 miles, and a distributing service in the city was carried forward at the same time.

The important fact that the gas of this field, with a maximum initial pressure of no more than 120 pounds to the square inch, would be unable to transport itself through the line in quantity large enough to meet the demand, practically and commercially, was recognized by the company from the first, and a pumping station became an essential part of its plans.

Pumps had been introduced at many places during the last few years to reinforce the declining pressure of the various gas fields. In a few cases it would appear that satisfactory results have been attained from such use. The company sought to duplicate this successful experience, and established at West Point, intermediate between Louisville and the gas field, two Clayton compressors. (No. 9.) During the closing months of 1888, while this work was going forward, the Geological Survey was urged to furnish a preliminary report of the observations made in its interests in the Meade county field. Such a preliminary report was prepared and published in part in the newspapers of the State. (Courier-Journal, December 12, 1888.) In it as favorable a view as the facts would allow was taken of the field. Special attention was called to the persistent and peculiar character of the gas as shown in the Moreman well, and the geological sagacity and scientific character of the explorations conducted by the Rock Gas Company was fully vouched for. The concluding paragraphs of the report were occupied with an answer to the question, how long will the gas field hold out? These paragraphs are produced here:

"No one duly acquainted with the history of gas and oil production in this country and elsewhere can, for a moment, doubt that in all their usual occurrences they are forms of stored power. There are no forces in operation that will ever refill the reservoirs which the driller exhausts. Least of all, has nature the power to meet, with her slow and patient method of working, the rapid depletions which our modern engineering skill can effect? The renewals of nature are adequate to the maintenance for long periods of the weak outflows of gas and oil which we call 'surface indications,' but beyond this they can not go.

"The bituminous matter, including gas and oil, of the black shale of Central Kentucky, and also the salt water that is found associated with the gas, are, in my opinion, undoubtedly stored products. The amount of them now existing in the shale is practically all that there ever will be. If brought to the surface on a large scale the salt water will gradually lose its strength, being replaced by fresh water that will follow it from the outcrops of the formation, and, in like manner, the volume and pressure of the gas will presently decline, as wells are multiplied.

"Is there enough gas in this great reservoir to justify the large expenditure that a pipe line from the gas field to Louisville requires? It is obvious, I reply, that a few billion feet of gas brought to the Louisville market will suffice to return the capital invested in the entire plant, and also to duly reward the enterprising company that is solving the problem of making demand and supply meet, so far as this much-coveted fuel is concerned. The gentlemen who are engaged in the work have looked intelligently at all the available facts, and they have satisfied themselves that they occupy safe ground. This gas field, as already shown, stands by itself in several important particulars, and must make its own history. Let us hope that it will meet all reasonable expectations on the part of those who are developing it.

"In view of the ever-expanding enterprise of American towns and American manufactures, and especially in view of American extravagance and wastefulness, it does not appear probable that natural gas will continue to supply for many decades, I will not say years, the favored districts that now enjoy it. But even if it proves transient, it still has a most important and beneficent work to do. It is bringing in an industrial and economic revolution of no small proportions, viz: the replacement of solid by gaseous fuel. It is educating people by an object lesson as to what constitutes a perfect fuel. The communities that have once enjoyed the luxury and economy of natural gas will be slow to return to the barbarism of raw coal, and heat and power will at no distant day be distributed in all our towns from central stations, as light is now supplied."

Just about this time a sharp speculative excitement broke out in Louisville in regard to gas lands, proved and prospective, and mainly the latter. The speculator added to the known gas territory a considerable part of Meade county. Fifteen or twenty new companies, and probably many more, were organized forthwith, some of them claiming the gas rights of eight or ten thousand acres of land. The bonds of these companies were eagerly competed for in the markets of the city, and the daily transactions reached large figures. It is asserted on apparently good authority that during the height of the excitement the bonds of companies were bought and sold that had no claims on even an acre of land, and that had nothing to trade on in fact except a name more or less suggestive and sonorous. The fever ran its course in a few days, and died as suddenly as it rose. The movement was irrational to the last degree.

The subsequent history of the field has brought more or less disappointment to the companies and individuals that invested their money in it, but gas continues to flow through the pipe line that was laid to Louisville by the Kentucky Rock Gas Company. The pressure of the gas in the field fell rapidly after the widespread drilling already described was entered upon, coming down as low as 60 pounds, and even 40 pounds, to the square inch. The salt water, which was always aggressive, overran many of the wells that were left neglected; but where it was taken care of properly by pumps, the gas has shown the same remarkable tenacity that the original well displayed. A fair supply was brought into Louisville for the winter of 1890-1, most of which was turned to account as fuel for domestic use. The prospect is said to be good for a continuance of the same moderate supply for the next winter, and in fact for several years to come. The pressure of the field is now reported at 60 pounds to the square inch.

Two companies are engaged in the manufacture of salt in the Meade county field from the brine that accompanies the gas, the latter being used for fuel. The supply of brine is said to be failing, both in quality and quantity. That the brine should lose its strength when drawn upon continuously is a result that would naturally be expected. The depth at which it is found is too shallow to allow of any great movement except by dilution from the surface waters that enter the gas rock to the eastward.

Further Explorations in the Ohio Valley.

It was impossible that an interest as great as that aroused by the new expenditure and development in the Meade county field should be arrested by an abrupt and definite boundary. Numerous other towns in the Ohio Valley below Brandenburg were invited and encouraged, in part by the blazing well seen on the river bank in the last-named neighborhood, to test their own fortune in this regard. During 1888 and 1889 wells were begun in Stephensport, Lewisport, Cloverport, Hawesville, Henderson, Smithland, Paducah, and probably at various other towns beside. Back from the river, also, exploration was carried on at several points to be hereafter named. The Indiana side of the valley was also tested at various points. At Evansville, in particular, a deep and costly well was drilled. At Tell City, also, a deep well was drilled.

Of the wells at Stephensport and Lewisport no minute records have been obtained. They were begun in the Chester limestone, and were carried to the Waverly, which is reached at a depth of 1,400 to 1,500 feet. Several veins of salt water were struck in the descent. Beyond this there was nothing noteworthy.

THE CLOVERPORT WELLS.

Cloverport has been the scene of a larger interest and more development than any other point in the valley except Brandenburg. The drilling has been mainly carried on by home companies, of which there are at least four in the field with capital stocks ranging to a million dollars, and from two to three thousand acres of land each. The first well was completed in June, 1889. Since that date eleven other wells have been drilled to the same horizon as the first. The surface rocks of Cloverport belong to the Chester formation. No better display of this great series is to be found in Western Kentucky than in Breckinridge county. The Chester sandstones give bold features to the immediate vicinity of Cloverport. The interstratified limestones, with their characteristic fossils, are also shown here in great distinctness.

The first well was begun in the valley of Clover creek, within or near the southern limits of the corporation. It was driven through a series of St. Louis and Keokuk limestones to a depth of 896 feet, at which point a considerable vein of gas was reached. The well was estimated by competent observers to be at least equal to the average wells of Meade county. A somewhat minute record of this well is available, but the very frequent changes from limestone to shale, and back again, that occur in it have no such significance or persistency as to require an extended statement here. The drift clays of the valley occupied the first 46 feet of the descent. Of the first 300 feet of the rock series, almost exactly 33 per cent. are shale. Of the next 550 feet the drillers' record shows little but limestone, changing from soft to hard and from blue to grey, white or brown. A single stratum of sandstone 20 feet in thickness begins at 540 feet. Many of the limestone beds were rank with the petroleum which they carry. The gas is reported as having been found in two feet of dark grey porous limestone, overlaid by 100 feet or more of brown limestone, according to the record. There is nothing in the account which is furnished of this well to explain in any way the occurrence of the gas which it produces; but this fact need not surprise us. The driller's interpretation and classification of the series that he penetrates is often quite different from that which the geologist would make if he had equal opportunities for observation. At 400 feet salt water was found; at 600 feet brine of 10 degrees B. in strength, and very pure. The gas carries the usual odor of limestone oil.

The fact that the first well struck gas made it certain that many other wells would be drilled in the neighborhood. Eight or ten wells followed at short intervals. Up to the present date twelve have been drilled in all, within a radius of one and a half miles from Cloverport, eight of which produce more or less gas, and the rest of them salt water. Two other wells are now being sunk, more with the hope of reaching a free flow of salt water than to obtain gas, inasmuch as a plan to utilize the former is now taking shape.

The best of the wells producing gas is located on the river bank, near the flouring mill. Its daily yield is reported as two and one-half million feet. Two of the remaining wells furnish an ample supply of domestic fuel to the town, which has been piped for this purpose. Cloverport thus becomes the first town in Kentucky to secure the inexpressible convenience of natural gas for fuel in quantities largely in excess of the demand. The gas answers an excellent purpose as an illuminant, and is used for this purpose also. The wells are troubled to some extent with water, which it is found necessary to keep down by constant care. If the various interests that now occupy the field can be so harmonized and combined that no new wells shall be drilled until the demand for gas approximates much more closely the supply, it will be greatly to the interest of the community. Every new well drilled necessitates new dangers to the field and new drafts upon it. More or less gas must be wasted by every new opening to the gas rock, and the danger that the upper waters will find their way to the gas reservoir are inevitably augmented by the multiplication of wells. By the constant application of sound judgment and wise economy the town may continue to enjoy its great advantage for several years. But the presence of salt water throughout the series penetrated by the drill, as well as in portions of the gas rock itself in close proximity to the producing wells, makes it certain that an aggressive and never-sleeping enemy is in the field, whose final victory may be postponed but can not be averted.

Cloverport is near the eastern edge of the great coal basin of Western Kentucky and Indiana. The structure of this basin would forbid us to expect accumulations of gas or oil within it, unless it should be found traversed by minor uplifts or arches of the right character to furnish such relief as these substances demand for their reservoirs. In the normal condition of the coal basin we should have a right to expect salt water, and that only in the porous rocks that help to compose it.

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*Since the above was written, a more detailed examination has been made of the region about Cloverport, and a new well has been drilled at the brick-plant, on the eastern edge of town. The rocks, coming from the east, are dipping to the west with a moderate dip until a point a short distance east of Cloverport is reached. At Cloverport there are a series of small arches or anticlines in the rocks, followed by a sudden increase in the dip to the west. This increased dip rapidly carries the Chester rocks under and brings the coal measures up. The well at the brick plant is on the summit of one of these arches, as are two or three of the best flowing wells inside the town limits. The sudden change in the dip of the rocks practically puts Cloverport on the summit of an anticline, and makes the prospect for a longer life for the wells more favorable.

The new well at the brick-plant was sunk through about the same series of formations as the others in the town, striking a good volume of gas at 872 feet in the same porous Keokuk limestone. The pressure, measured by steam-gauge, ran up to 175 pounds. It is being burned under the boilers and in the kilns of the brick-plant, furnishing all the fuel necessary at present to run the plant. The working pressure is probably about 120 pounds.

For a more detailed report on this section and a new gas field in Breckinridge county, the reader is referred to a report on the geology of Breckinridge county now in course of preparation. J. B. H.

A deep well has recently been drilled at Hawesville, but it produced only salt water. It was about 1,500 feet deep, and was carried into the Keokuk group. At Tell City also, on the Indiana side, a deep well was drilled, with a like barren record.

Owensboro.—At Owensboro a well was drilled in 1882, for the water supply of Field's distillery, to a depth of one thousand feet. The record was not kept in such shape as to furnish any valuable information as to the series penetrated. Several small coal seams and impure limestones are said to have been cut in the descent. At 765 feet a white sandstone was struck, which filled the four-inch pipe with a weak brine; at 900 feet a coal-black slate is reported, 70 feet in thickness. The water was growing less and less fit for the contemplated use as the drill descended, and consequently there was no motive to continue the work beyond the point already reached. Every thing pertaining to the surface geology of Owensboro would lead us to expect there the normal structure of the coal basin, and such explorations as have been made lead to the same conclusion. Drilling was accordingly discouraged in the region by the representative of the Geological Survey. The energy of Owensboro that was available in the search for gas and oil, which every thriving town was bound to make, was not wasted on new trials of a series that had already been weighed in the balance and found wanting, but was directed to a field that contains at least some geological possibilities in this line. The tests referred to will be described on a succeeding page.

Henderson.—This thriving town, when reached by the new interest in gas and oil, had the advantage of several fairly thorough tests of the underlying rocks that had been made at an early day for coal and salt water. Henderson is situated near the center of the Western coal field of Kentucky, on an east and west line. The presence of coal underlying the town was long ago established, but between 1850 and 1860 two deep wells were drilled here, the records of which are preserved in Owen's Geological Reports. The wells are known as the Burbank and Holloway wells.

The Burbank well was located in one of the ravines above the town that led from the sandy plains to the river. Salt water was struck in it at various depths, and the final result was a vigorous artesian flow of brine, which has been maintained apparently without diminution of volume to the present time. The brine is clear and sparkling, but it contains a small percentage of iron, which is deposited in the usual form of hydrated peroxide when it reaches the air. The temperature of the water is about 60 degrees F. The water has long been turned to some small account for hygienic purposes, being used both for drinking and for bathing. The structures required for the latter use have been provided and maintained for many years. It is said by those who have followed the history of the well from the first that a tar-like scum was found upon the water in its early days, indicating a weak source of oil somewhere in its descent.

The presence and the outflow of the salt water are, however, the chief features of the well, and they fully confirm the geological inferences as to the structure of the coal basin, to which reference has already been made. Of the various contents of the porous rocks which belong in this general section, only the salt water can be expected here. The coal basin is what its name implies, a trough from which gas and oil are excluded.

The coal measures have been demonstrated by the drill, in the borings alluded to above, to continue to a depth of about 900 feet below the surface, a six and a half feet coal seam being reported below 860 feet. Nine seams are shown in the Holloway well, ranging from one foot to six and a half feet in thickness. This well was carried to a depth of 1,024 feet. The main Newburgh coal seam is found in Henderson at 190 feet below the surface. The nearest remnant of the great showing of the coal measure rocks that originally occupied all this region to a height of several hundred feet above the river, but which have been removed in the progress of the vast erosion which the whole valley has suffered, is found four or five miles above Henderson, near the mouth of the Green river. Here the normal ravines and gorges into which the swift-flowing streams always carve the uplands and slopes from which they flow occur. The usual circumstantial accounts of lead and silver mines worked by the aborigines found a local habitation here, and here also some traditions of gas and oil have long existed. There is nothing, however, apparent in the surface rocks to warrant the belief in any considerable uplift at this point, and the drill should be expected to make the same sort of record that the other wells of the vicinity have shown.

Some of the traditions of the oil excitement of 1865 still survive in the neighborhood. A well was drilled at that time about sixteen miles south of Henderson, and just beyond the county line, in Webster county. At a depth of 430 feet a flow of gas was struck, which increased to 536 feet, and which became so troublesome as to arrest the drilling at that point. The gas was ignited, and it maintained its flame for several weeks, exciting great curiosity and some uneasiness in the neighborhood. It was finally extinguished. The well was plugged to some small depth in the rock and the conductor hole was filled with earth.

A Henderson company, recently formed for exploration in this line, concluded to make its first trial in this locality. The land was accordingly leased for this purpose, and the first thing done was the opening out of the old well, from which a small volume of gas still flowed after its long-continued repression. A new well was then located within 120 feet of the old one, and drilling was at once begun. The record obtained was as follows:

Drift	30	feet.
Sand rock	8	feet.
Blue shale, soft	121	feet.
Hard rock	1	foot.
Coal	7½	feet.

This seam, found at 161 feet below the surface, was thought to be the same seam reported in the Burbank well at Henderson, at a depth of 861 feet. If this interpretation is a true one, there is a manifest and marked uplift of the series at this point. Gas was struck at 177 feet, 195 feet and 347 feet. The final pressure of these aggregate veins was *estimated* at 120 to 150 pounds. At 430 feet water was reached, and the drilling was arrested at this point. A second well was forthwith located one-half or three-fourths of a mile nearer Henderson, the object of the drilling being to secure a supply of gas for the city. The results of the further explorations have not been obtained, but it is fair to conclude, from the lack of published information, that nothing of value has been obtained thus far.

The costly drilling done within the last three years at Evansville, Indiana, may be briefly recorded here, as it has nearly the same significance for Henderson that it has for the opposite side of the river. A company, consisting of eight or ten members, was organized at Evansville in 1887 for the purpose of securing natural gas for the city, if it could be found by drilling. The company leased forty-five acres of land two or three miles to the north of Evansville, and began work at once. In April, 1889, the first well had been carried down to a depth of 1,829 feet. The contractor, after working more than a year upon the well, threw up the contract, and an expert driller was put in his place by the company on day wages. When he had been in charge of the work for 16 months he had deepened the well by about 250 feet. There had been expended on it up to April, 1889, $19,000, or an average of more than $10 a foot. The company was at this time seeking for public aid to continue the work to a depth of 3,000 feet. The city council it was expected would appropriate money from the public funds for the purpose of completing the so-called test.

A record of the well is of comparatively small value, because of the confusion and uncertainty that attach to nearly all portions of it. Even the great land-marks, as, for example, the base of the coal measures, is not agreed on by those who have followed the work most closely. This horizon is probably found between 800 and 900 feet below the surface. It is agreed by all that under the coal measures a great body of sandstone is found. Distinct seams of pebble rock occur at several different levels. Among the horizons, determined by samples kept by the company, are the following, viz: sandstone at 932, at 1142, at 1235, at 1310, at 1598 feet.

Salt water was found at several levels in the rock, but the strongest flow was obtained from about 1,400 feet. A little below 1,800 feet, a bowlder, so-called, was reported, and dynamite was to be applied to it to allow the drill to pass. The great trouble and expense connected with the well resulted from the continual caving-in of some of the material passed through. A short-grained shale, carrying balls or bowlders of limestone, is counted the most dangerous element.

It would be a waste of time, because of the unreliable character of the record, to attempt to correlate the series reported here with the known geological section of the field. The Chester group is apparently strongly represented in the sandstones that make so conspicuous a part of the middle section of the well. Not a particle of promise has been found of an oil or gas field at any point in the descent, and there was none at the outset, as has been already shown. The center of a coal basin, while retaining in its structure the normal swamp upon which it was originally based, is, of all places, the most unlikely to prove a source of gas and oil. In fact, large accumulations in such geological situations are clearly impossible.

Smithland.—At Smithland, in Livingston county, a deep well was drilled in 1888. It was begun in the upper portion of the Subcarboniferous series, and was continued to a depth of 1,200 feet or more without valuable result, so far as has been learned. The region is very interesting, geologically, on account of its being traversed by one or more distinct fissure veins, the one nearest to the town carrying fluor-spar, galenite and blende, the latter, however, in small proportions. Large amounts of money have been expended here in explorations and in mining, but no adequate returns have so far been secured. Much remains to be learned of the geological structure of the district, in addition to Mr. Norwood's interesting report, to which reference has been already made. Whatever mineral value may be developed in the fissure veins above named, it does not now appear that the district is likely to prove productive of the bituminous substances to which this particular examination has been directed. The same line of remarks applies to Paducah, where another deep well has been drilled within the last few years.

THE ROUGH CREEK ANTICLINE.

There remains to be briefly described the drilling that has been done on the line of the Rough Creek Anticline, which has already been characterized as the most important structural feature in the geology of the western half of the State. Its location and general direction will be borne in mind. These facts are indicated on the map of Kentucky that accompanies this report.

The McLean County Wells.

The first of the districts to be described lies a few miles to the north and west of Calhoun county. The history is similar to several of the histories already traced. It goes back for its beginning to 1865, the golden age of drilling in Western Kentucky, and, as usual, a tar spring is at the bottom of the exploration. Such a spring is found on what is known as the Mayo farm, on Longfall creek, about two miles north-west of Calhoun. The spring has been famous in the region from the earliest occupation of the country. A fairly generous flow of water boils out from the fractured sandstone stratum that makes the wall of the creek at this point, and with the water small globules of heavy oil, known as tar from the fact that it is black and viscid, are produced. The spring has been valued from the first for both water and tar, the two products being easily separated. A gum was sunk long ago around the spring, within which the oil accumulated for a few days at a time, while the water flowed away. The coating of tar was frequently removed from the gum and the surrounding area by the people of the neighborhood, by whom it was highly valued as a lubricant, and especially as an application for bruises and wounds of man and beast. A bottle of the tar was counted almost a necessity to the farmers of the region, and indeed its virtues became known outside of the immediate neighborhood.

This fact was enough to attract the driller in his search for oil, and shortly after the war, Mr. A. J. Ayer, of St. Louis, put down a well within ten feet of the spring already described. At a depth of 30 feet in the sandstone he found the oil in larger quantity than was yielded by the spring, but distributed, as in the spring, through a large quantity of water. Mr. Ayer began pumping the well, but the accounts vary as to the daily yield of the oil. Some place the amount as high as four barrels per day; none place it lower than two barrels. The price of rock oil was high at this time, a barrel readily commanding twenty, or even twenty-five, dollars. It was used mainly as lubricating oil. When the price of such oil was reduced the production was suspended, but the original spring maintained its flow, and indeed does so to the present day. A second well was drilled at sixty feet distance from the well above described in 1865. It found oil in the thirty-foot sandstone not far below the surface, which is the source of the oil in Well No. 1, but the drilling was continued to a depth of 200 feet. Here a hard blue rock was struck, in which the progress of the tools was so slow that the attempt to penetrate it was soon abandoned. The two wells have maintained a small production of oil to the present time. The amount does not exceed six to eight barrels a year, but the oil would be missed from the region around about if the production should entirely fail. It is now sold at about six dollars per barrel.

Nine other wells were drilled in the last-named year, viz: 1865, in the neighborhood of Calhoun. None of them reached a depth of more than 400 feet, and none of them reached a production in which either value or promise could be discerned. The stratification is much disturbed in the neighborhood of the spring. The beds pitch at varying angles, ranging from 20 to 50 degrees, in a direction a little east of south. On the E. J. Ashton farm, in the Upper Calhoun precinct, about two miles from the tar spring, the Subcarboniferous limestone rises, in territory where the coal measures are due. The limestone beds exposed here are not less than 25 feet in thickness, and they rise to a height of 50 feet above the valley. The limestone is burned here for neighborhood use. It is highly fossiliferous, but the number of species found was small. Above the limestone a massive cliff of sandstone occurs, the lowermost 10 or 15 feet of which are distinctly, though not coarsely, conglomeritic, the upper beds of the stratum being fine-grained and flinty. The rocks that are shown at this point dip in a direction 10 degrees west of south at a rate of 20 to 30 degrees. On the Gibson farm also, one mile west of Glenville, exploration was attempted in 1865. The owner of the farm had previously deepened a spring at the foot of a small hill near his residence for the purpose of obtaining a better supply of water, but the water proved to be petroliferous to such an extent that it could not be used for drinking purposes but a little later, viz: in 1865, Hon. R. S.

Triplett, of Owensboro, had a shaft dug at this point to a depth of 12 feet. The shaft was carried down through a sandstone stratum, which yielded both oil and water, but no considerable accumulation of oil was found, and the work was, therefore, abandoned.

At Lewis Station (Utica), a few miles to the eastward, a coal seam is worked, the dip of which is 1 in 12, to the northeast. The coal is considered to be Seam No. 9. This station, as well as the points above described in the Longfall valley, is directly on the line of the Rough Creek Anticline.

It is evident, from the facts that have been recited, that at least a small amount of heavy oil is found accumulated in some of the coal measure sandstones along the line of the anticline. While the tests of 1865 can not be considered final, especially on account of the shallow depths to which the wells were sunk, there is nothing in them that holds out any special encouragement to further drilling. They do not, however, serve to condemn the territory in this regard. On geological grounds, the Ashton farm would seem to offer greater promise than any other point that was found in the neighborhood of Calhoun. The due relief of the strata is assured here by the occurrence of the Subcarboniferous limestone as a surface rock.

The Sebree Wells.

At Sebree, in Webster county, on the line of the Henderson branch of the Louisville & Nashville Railroad, there is a notable display of the disturbed condition of the rock that belongs to the anticline already named. The Subcarboniferous limestones are brought to the surface here in a much disturbed condition. The beds have been broken in the process of uplifting into small fragments, and have been reunited by a deposition of calc-spar, the seams of the latter being an inch or less in thickness. From the base of the outcrop a strong sulphur spring rises. North of the limestone outcrop, and not more than forty rods distant from it, a four-foot coal seam is found at a depth of 40 or 50 feet below the surface. South of the town a massive and coarse sandstone occurs, rising from 50 to 75 feet above the railroad. A slight arch occupies the middle portion of the exposed stratum. The sandstone is undoubtedly of Coal Measure age, and may be on the horizon of the Anvil rock. The facts above set forth can be most easily explained by counting the date of the Rough Creek Anticlinal in this region as antecedent to the deposition of the Coal Measures. The outcrop of Subcarboniferous limestone, according to this view, was thrust up in a mountain-like mass from beneath the sea, in which and around which Coal Measure rocks were growing. These rocks now appear to abut unconformably against this ancient line of upheaval. That the proposed explanation is not to be applied to the whole history of the anticline is evident from facts previously stated, showing that the Coal Measure rocks are involved in it in many parts of its extent. According to this view, therefore, its history would cover more than a single geological period. Uplifts took place along this line of weakness in the crust before the Coal Measures were completed, and possibly before they were begun; but similar movements continued long afterwards, involving the later formed strata of this age. It is acknowledged that this explanation is supported by a scanty supply of facts, but if the coa mining that has been begun here is carried on vigorously, the underground work will be likely to show within a short time whether there is any foundation for such a supposition as has been offered here. In any case, uplifts along such extended lines of fracture, at widely separated intervals in time, are geological phenomena of comparatively frequent occurrence in disturbed regions.

A well was recently drilled in Sebree, in the Subcarboniferous ridge above referred to, to a depth of 90 feet, the object of the drilling being to obtain a supply of water to be used for the steam production of the adjacent mill. In this well a small quantity of black and heavy oil, almost tar-like in consistency, is found. The quantity is insignificant, but the product has thus far been constant, the oil appearing with the water whenever the well is pumped. Its occurrence is of interest as connected with the uplift above described.

To several of the river towns that were anxious to drill wells in search of gas or oil, and whose location seemed on the whole so discouraging as to any considerable amounts of these substances being found in their own underlying rock series, the suggestion was made that tests which would have some possibility of successful outcome might be made along the line of the Rough Creek Anticline at its nearest accessible points One or more companies were formed for this purpose at Owensboro, and some tests were planned of the rocks at Sebree, but the outcome of the tests, if such were made, has not been learned. It is safe, however, to suppose that they were unsuccessful, for if the drilling had been successful the facts would doubtless have attained general circulation.

Other points along the anticline that would well deserve the driller's tests, if such were to be made anywhere in the western Coal Measures of Kentucky, are on the extremities of the uplift in Grayson and in Union counties, respectively. In Grayson county the Lower Coal Measures are involved in the anticline. At Leitchfield the uplift takes the form of a low arch, which seems to meet every geological demand in the way of proper structure for gas and oil accumulation. One or more companies have been formed, it is understood, to test this region in a practical way. To the results of drilling here, great geological interest would attach.

Chalybeate Hills.—In Union county, again, on the western extremity of the anticline in Kentucky, the disturbance is of a kind that suggests possible favorable structure for these bituminous accumulations. In the Chalybeate Hills, three miles southeast of Morganfield, and in the Bald Hill, six miles west of the same town, marked uplifts of the strata occur. Directly south of the Chalybeate Spring, in the former location, the strata are found dipping at an angle of forty degrees to the southward. In the adjoining coal field the seams of coal are found pitching at the same or at least at a high angle. The spring itself breaks out from a Coal Measure sandstone that occupies nearly a vertical position. The sandstone is massive, and, in places, conglomeritic, and carries imprinted upon it the impressions of characteristic Coal Measure trees as *Lepidodendra*..

In the Deer Lick Hollow, one-half mile west of the Spring, a heavy limestone, apparently of Subcarboniferous age, comes to the surface. Its place in the normal arrangement of the rocks would be 800 to 1,000 feet below the surface Salt water escapes from it in some weak springs, as the name of the hollow implies.

The best location for a test well would seem to be to the north of this great disturbance, and a half mile or more distant from the line of uplift.

The Sulphur Springs, six miles east of Morganfield, mark another outcrop of the Subcarboniferous limestones, and they occur here in much greater force than in the Deer Lick Hollow. A number of strong springs, three of them carrying notable quantities of sulphur water, occur on the place, emerging from a somewhat lower level than the outcrop. The limestone has been burned on the premises to a considerable extent in past years. The waters of the springs were formerly held in high repute, and a summer hotel, large enough to accommodate several hundred guests, found full occupation before the war.

THE HIGHLAND LICK WELL.

The Highland Lick Salt Works of Webster county, fifteen miles east and a little south of Morganfield, and just beyond the Union county line, may be properly named in this connection. They form a conspicuous outcrop on the line of broken and tilted rock which is now under consideration. Brine has escaped from this outcrop in springs of small volume from early times. The Indians made salt here for a period long anterior to the occupation of the country by the whites. Fragments of their clay kettles and of other utensils employed in the manufacture are still found here. Furthermore, it is stated by old residents, whose testimony is counted entirely trustworthy by those who knew them personally, that ashes and charcoal were found in one well at a depth of 35 feet below the surface. This would imply a distant and even prehistoric date for the beginning of the utilization of the spring. In 1796 Colonel Robinson, a Revolutionary soldier, made this Salt Lick the center of a survey, and had 15 or 20 wells dug in the immediate vicinity, the water of which was raised by a well-sweep, and used in a salt-block of small size. Up to the date of the discovery of Kanawha salt, the manufacture was maintained at Highland Lick. Col. Robinson employed forty hands, each of whom took up land by occupation, deeding it back to him, and the new subdivision and distribution of the land has been but recently effected.

In 1865 a company was formed, of which Dr. R. H. C. Rhea, of Morganfield, was a leading stockholder, for the purpose of testing this district for oil. A well was begun near the brine spring, and carried down to a depth of about 525 feet. A little gas was found in descending, and a dark and heavy oil was struck in small quantity at the depth above named. Water was also struck in connection with the oil. The force of the gas was strong enough to clear the pipe of both water and oil by intermittent flow. The well was finally tubed with a two-inch pipe, and a pump was applied, but the production was never any thing more than inconsiderable, and the work was, consequently, soon abandoned.

The nearest recent test that has been made along the line above described for this region is at Shawneetown, Illinois. A well 1,500 feet deep was drilled there in 1888. Shawneetown, it may be remarked, is on or near the direct line of the Rough creek anticline. At a depth of 500 feet a small vein of gas was struck. At 1,500 feet salt water was set free in such a quantity that the drilling was brought to an abrupt conclusion.

This statement of facts concludes the account that was undertaken of the search for oil and gas in the Subcarboniferous and Coal Measure rocks of Western Kentucky, and of the results of such search as far as they have been obtained. Wells have been drilled at a few other points, possibly, in addition to those named in this review, but all the production that has become in any way important has probably found place in these pages. The aggregate, it must be confessed, is very small. The Meade county gas field was by far the most important of these productive districts, and if the gas had been left to the people of Meade county, it could have been made to render a long and invaluable service to them, but it proved itself altogether wanting in adaptation to exploitation on the large scale that was attempted, and it has brought prospective loss on the company that undertook the work.

The Cloverport gas field has not yet demonstrated its character, but a long lease of life is scarcely to be expected from it.

Of the oil production, Glasgow and its vicinity monopolize the present interest; but thus far there has been but little production brought to the surface by the somewhat extensive and costly exploration that has been and is still going forward there. In a word, the valuable oil and gas fields of the western half of Kentucky, if such there are, remain to be discovered; and the results of the large expenditures begun in 1865, renewed in 1885, and maintained up to the present date, are not assuring as to the successful outcome of the search, however energetic and persevering it may be.

TAR SPRINGS AND BITUMINOUS SANDSTONE.

The last section of the natural accumulations of the bituminous series in Western Kentucky remains to be briefly described under the head given above. The two phases, tar springs and bituminous sandstone or asphalt rock, as it is often called, are named together because they belong together. The so-called asphalt rock is one of the stages of a tar spring, and frequently the last stage; and the tar, in like manner, is an oxidized product of petroleum. A tar spring is in fact an oil spring, the flow of which is so slow that the oil undergoes oxidation before it escapes from the rock, the change being accompanied by a partial loss of liquidity and a blackening of the entire product. In like manner, when the viscous product called tar is further acted upon by the atmosphere it loses at last its liquid character altogether, and remains in hardened masses around the sources from which it escaped. The last phase is called asphalt; but this form of the accumulation is found in comparatively small amount. What passes generally for asphalt rock is a sandstone more or less charged with the hardening tar. So far as observed, it is in all instances found in outcropping strata; or, in other words, in beds lying above the drainage level and cut by natural sections. In no instances, so far as known, has it been found in any boring carried below the level of the valleys.

The facts as to the occurrences of these substances can, however, be best presented in the description of some of the actual examples.

TAR SPRINGS OF BRECKINRIDGE COUNTY.

The tar springs of Western Kentucky can scarcely have failed to attract the attention of any of the races of men that have ever occupied this territory. We know that the Indians who were displaced by the present occupants of the region were well acquainted with them; and, further, that they set a high value on this bituminous production. By exclusion of the air from abrasions and wounds, and possibly by some more definite curative action, the tar came to be recognized by them as a valuable application for bodily injuries. In one case in Western New York, when giving up their title to lands previously occupied and claimed by them, they made reservation of a spring from which they annually gathered small quantities of heavy oil, which was on the way to the same state which the tar of the Kentucky springs has already reached. The early white settlers of Kentucky followed the traditions and practices of their predecessors in this regard. The water of these oil springs is often sulphurous, and such springs as showed this quality soon acquired reputation as medicinal spring waters in addition to the value credited to them for their petroliferous contents. A good representative of the class can be found in the famous Tar Springs of Breckinridge county. They are situated about four miles south of Cloverport, on a small tributary of the stream known as Tar Creek. The Chester division of the Subcarboniferous system is finely displayed in this immediate region, consisting of interstratified sandstones and limestones, with occasional beds of shale. One of the sandstones in particular is massive, occasionally attaining a thickness of 75 or 80 feet. This is the third massive sandstone in the Chester above the top of the St. Louis limestone. In Breckinridge county it is a moderately coarse and fairly pure rock, portions of it being white enough for the common sorts of glass manufacture; but a few ferruginous stains shut it out from the highest grade. The rock is also quarried on a large scale for a building stone. In years past the stone had a good reputation for this use.

The springs are found at the base and in the recess of an overhanging cliff of sandstone, 80 feet in perpendicular height, and 200 feet across the recess or amphitheatre. A sheet of limestone abounding in crinoidal remains and other fossils, and showing evidence of shallow water at the time of its deposit by the ripple marks that cover some of its beds, lies directly below the sandstone. This limestone may be the source of the petroleum from which the tar is derived. Its uppermost beds are blackened with the weathered oil, but the lower portion of the sandstone is still more heavily charged. Upon the upper surface of the ledge there are also found masses of asphalt which seems to show that the petroleum has at some previous time found its way through the whole sheet of sandstone to its present surface. The springs, which are feeble in volume, issue from the line of junction of the sandstone and limestone. The waters are moderately charged with sulphuretted compounds, containing globules of oil, which are generally arrested at the margin of the outflow of the spring, and here they undergo a further thickening and darkening. This constitutes the tar, and the accumulation has become large enough in many instances to make it possible to dip a few quarts from the spring every week or two.

The same geological level, viz.: the junction of the great sandstone with its underlying limestone, carries like contents at numerous points in the vicinity. A good example is seen in what is known as Smart's Spring, on the west side of the creek. Another is found in the Ohio Valley, two miles below Cloverport; and a third section of the tar rock appears two miles south of Cloverport, at a railroad cutting, on a line that leads back from the river to the cannel coal mines. Not all the springs that issue from this horizon are, however, petroliferous or sulphurous. Within 20 or 30 rods of the tar springs, now being described, a fair volume of excellent potable water flows out from the base of the sandstone in a perennial spring. It has been the main reliance for all the ordinary uses of the people that visit the springs.

The Breckinridge county tar springs were widely known and highly esteemed through the Mississippi Valley before the war. Excellent accommodations were provided in the way of hotels and cottages. Visitors from the Gulf States, in particular, found their way hither in large numbers every summer. The scenery is remarkably picturesque and beautiful, and the waters enjoyed a high reputation for their curative qualities. Judging from the current accounts, it seems probable that they did their best service as an external application in skin diseases; but they are also credited with all the virtues that are generally looked for in waters called mineral waters. The buildings have been mainly destroyed by fire, and the springs have been entirely neglected, as far as care of them is concerned, for more than a score of years, but still they are visited by a good many people from the surrounding country. Various schemes for restoring them to their old place of prominence and service have been devised. Great advantages over the old conditions would now be found in the railway connection which has been established through the valley. Whether the mineral waters could be developed in large enough amount to justify a provision for the accommodation of the public, remains to be seen.

One of the main horizons of the tar springs of this portion of Kentucky has now been described in the case of a conspicuous example. The facts are seen to be as follows: The Subcarboniferous limestones, both of the St. Louis and of the Chester Group, are found to be charged with petroleum, which, by a system of slow exchanges, in which water takes a part, has risen to the upper beds of the stratum, and when the conditions have been favorable, has passed out of the limestone, in large part, into the overlying sandstone. Escaping from this sandstone, it has given rise to the tar and asphalt rock, the gradations between the two being dependent on the conditions for oxidation that the rock has provided. This horizon may be known as the Chester * Asphalt rock.

TAR SPRINGS OF GRAYSON COUNTY.

Other excellent examples of the same horizon are found in the valley of the Big Clifty creek and its tributaries in Grayson county. A section previously reported may be repeated here for the purpose of presenting more convenient reference to the question involved.

At the Pearl Ford of Big Clifty, three miles north of Gray-

* Since the above was written, a quarry of Asphalt rock has been opened at Garfield, Breckinridge county, in the Second Chester Sandstone, and Asphalt rock is being shipped to Buffalo, N. Y., to be used on the streets of that city.

son Springs Station, a section of the series shows the following elements, in descending order:

1. Sandstone, surface rock, thin bedded . . . . 30 feet.
2. Limestone, shaly at top, bluish in color, carrying Archimedes, Pentremites, and numerous other fossils, and also Oolitic in structure (Kaskaskia limestone) . . . . 36 feet.
3. Sandstone, massive and uneven bedded . . . . 65 feet.
4. Limestone, petroliferous, showing in bed of creek . . . . 15 feet.

On the Whitfield farm, a mile or two below this point, the Big Clifty sandstone is found to be an asphalt rock under the following conditions: At the base of the limestone (the Archimedes limestone, above described as number 2 of the section), five feet of a fine-grained blue clay, called kaolin, occur. This makes a water horizon, a constant outflow in seeps and springs occurring here from the descent of the waters at this point. The same sheet of clay prevents the ascent of oil into the sandstone to any higher level; and accordingly we find the uppermost beds of the sandstone variously, and sometimes quite heavily, charged with tar in its several stages of hardness. The accumulations are spotted in character, being manifestly affected by the physical conditions of the rock. Change in the grain, or any unusual hardening in the sandstone, is shown at once in a reduced percentage of bituminous matter.

Another series of tar springs and exposures of asphalt rock is found nine miles south of Grayson Springs, within a few miles of the southern boundary of the county. This accumulation belongs to a different geological horizon from that already described. It is found in a sandstone, as in the examples already given, but the sandstone in this case is the Conglomerate sandstone of the Coal Measures. It is uneven-bedded, fairly massive, and carries a few quartz pebbles of small size. Pebbles of sandstone and shale are also found in a ledge near the bottom of the sandstone. It directly overlies a limestone of Chester age. The section shown on the Barker farm is as follows:

Conglomerate sandstone, 10 to 15 feet in outcrop; uneven bedded, moderately coarse; carries notable quantities of oil and tar.

Conglomerate shale and shale sandstone, 6 feet; charged with oil and tar.

Subcarboniferous limestone, 2 feet, with large accumulations of tar.

Subcarboniferous limestone, solid, fossiliferous; crinoidal at bed of run; also carrying oil.

The oil is unmistakably derived from the limestone in the cases previously noted, and has risen in the sandstone until obstructed by some physical change in the rock.

The four horizons that have now been described as asphalt-bearing, viz: the three Chester sandstones and the Conglomerate sandstone, are doubtless reinforced to some extent by other sandstones in the series, carrying the same contents; but these two formations unquestionably constitute the main horizons of tar and asphalt rock in Western Kentucky. The exposures of these horizons are large, and they extend into Indiana as well. The regions in which they are to be found are well indicated by a geological map of the districts. Taking a belt five miles in breadth on each side of the boundary of the Coal Measures, the territory most productive of these substances will be found included within it. The only exceptions noted are in the cases of uplifts that have taken place within the Coal Measures, by which the Subcarboniferous limestone and the associated sandstones have been brought up to the surface outside of their normal boundaries.

Percentage of Bituminous Matter.

The bituminous sandstone, in its most pronounced phases, has no other bond but the bituminous matter. When the tar is dissolved or burned out of the mass, nothing but unconsolidated sand remains. This is in the main white, like the portions of the rock that have not been overrun with these foreign products. As to the amount of tar held in the rock, it is impossible to make any general statement. The richest portions of the rock, selected from the Barker farm last named, were examined with this reference by Dr. Peter, Chemist of the Survey, with the following result:

Best sample, lost by burning . . . . 9.4 per cent.
Second sample, lost by burning . . . . 8.0 per cent.

Another sample of asphalt rock from Hardin county gave the following result when submitted by Dr. Peter to the same treatment:

Loss by burning . . . . 8.75 per cent.

Larger proportions than these have obtained currency, but probably none of the more careful determinations would show a maximum of more than 10 per cent.

Dr. Peter further reports that the tar is readily soluble in benzine and ether; and when these last named substances are driven off, after having dissolved the tar, the residue is heavy oil. From a maximum percentage, as indicated above, the proportion of bituminous matter falls away, sometimes abruptly and sometimes by slow degrees, until a mere stain only can be recognized in the rock. A total amount of two to four per cent. gives a characteristic bluish cast to the rock.

Summing up the facts to which attention has now been called, it can be said that in the outcrop of four great sandstones, viz: the Garfield, Big Clifty and Tar Springs Chester sandstones and the Conglomerate sandstone of the Coal Measures, as they are found in Western Kentucky, numerous occurrences of oil, derived in all cases from the limestones of the Subcarboniferous series that directly underlie the sandstones, are met with. And further, these oils pass, by natural processes of oxidation, into a viscous form called tar, and a solid or a semi-solid, properly called asphalt. These oxidized products are retained in large amount in the outer or most exposed portion of the porous sandstones that are found in contact with the oil-bearing rock. They are in their very nature marginal and superficial. The conditions under which they can be formed have been already distinctly indicated. The rock must be exposed to the action of the atmosphere. All the deposits so far known are, without exception, derived from planes above the drainage levels of the districts in which they occur.

Utilization of the Bituminous Rock.

What has been thus far written upon the occurrence of tar springs and bituminous rock in Western Kentucky has been directed exclusively to the scientific relations of the facts; but at the present time there is another side to the question, viz: an economic side, and this commands considerable attention in the regions where these rocks appear. The bituminous rock is being introduced into the cities of the country on a considerable scale as a paving material, and the territory in which it occurs is being rapidly covered by options, or being bought in large blocks in fee-simple. Speculative excitement is already manifested in acquiring the ownership of what is counted promising territory, and prices six or eight times the actual agricultural value of the land are being offered for tracts containing good phases of the asphaltic sandstone.

The use of asphaltic rock for such purposes is comparatively new in this country. As an architectural bond, asphalt, as has already been shown, goes back to the very dawn of recorded history, but in road-making our experience is mainly limited to the last three decades.

Bituminous *limestone* was the first to be turned to account for these uses. The limestones thus far most widely used are found in France and Germany. A little is also obtained from Sicily. The most famous French localities are Seyssel and Val de Travers. The vicinity of Limmer furnishes the main supply for German cities. The material taken from the quarries of these districts has been used in the construction of about fifty miles, in the aggregate, of street pavements in Paris, London, Brussels, Berlin, and one or two other European cities. These pavements are laid in some of the most conspicuous streets of the respective cities in which they have been used, as, for instance, in Cheapside in London, and they have come to be very widely known on this account. In addition to streets, about a thousand miles of sidewalks, made from the same materials, have been laid in European cities within the last few years.

The limestones employed for this purpose are shown by published analyses, largely taken from *Die Zeitschrift für Transportwesen und Strassenbau, Berlin, 1890-'91*, to have the composition given below:

1. Val 'de Travers . . . . France.
2. Seyssel . . . . France.
3. Forens . . . . France.
4. Lobsan . . . . France.

	1	2	3	4
Water lost at 90° C.	0.50	1.90	0.20	3.40
Products dissolved by bisulphide carbon	10.10	8.00	2.25	11.90
Insoluble mineral matter	0.45	0.10	0.05	1.25
Alumina and oxide of iron	0.25	0.15	0.15	. . . .
Carbonate of lime	87.95	89.55	97.00	69.00
Carbonate of magnesia	0.30	0.10	0.70	0.30
Sand	. . . .	. . . .	. . . .	3.05
Sulphur (5 per cent.), and iron with sulphur 4.45 per cent.	. . . .	. . . .	. . . .	9.45

The Forens rock (No. 3) can not be used without being enriched by the addition of mastic or other resinous matter.

The asphalt rock of Limmer, which is the largest source of paving material of this kind in Germany, has the following composition, according to a single analysis reported from the School of Mines, Columbia College, New York:

Bitumen (products soluble in bisulphide carbon)	8.26
Clay	4.98
Carbonate of lime	56.50
Carbonate of magnesia	27.01
Oxide of iron	3.21

The limestone in all these cases, whether pure carbonate of lime or magnesian, exists in a finely divided state, and is intimately united with the asphalt. The bond is broken by the application of heat. The reduction to a powder is also facilitated by mechanical means.

In constructing the surface of street pavements, nothing but the limestone itself, properly prepared, is used; in sidewalks, a small percentage of Trinidad asphalt is added.

While traction on these pavements, and the wear and tear of vehicles employed, are reduced to their lowest figures, an important objection to them is their slipperiness. In wet weather, especially, they prove treacherous and injurious to horses, for falling is vastly more frequent on these than on any other kinds of streets in the cities in which they are laid.

No native asphaltic limestone has yet been used for street-making in the United States. The dolomites of Upper Silurian age in Ohio and Indiana frequently carry a notable quantity of bituminous matter in their composition; but they do not apparently reach a high enough percentage to warrant their use for paving purposes, and their structure may also be ill-adapted to this purpose. It is claimed that the Rocky Mountains contain, at several points, limestones of the same character as those of the European localities already named; but no practical demonstration of the claim has been made—at least, none on a large scale. A small amount of Cuban asphalt rock has been laid in the United States during the last few years; but it has not proved in any degree satisfactory.

It may be noted in passing, that the representatives of the

French bituminous limestones have undertaken to monopolize the word "asphalt" for the product of their quarries—a use which neither the scientific nor the practical world will allow. The name already used in this connection is the proper one, viz.: bituminous limestone.

BITUMINOUS SANDSTONES.

Sandstones of various grain are frequently charged with petroleum, oxidized to a greater or less degree, as has been explained and described in the preceding section. American practice has recently demonstrated the possibility of constructing street pavements from this form of the rock, after the fashion of the pavements of bituminous limestone of Europe. The work was begun in California, and, until the last three years, has been mainly confined to that State. But, even there, the first pavements of this character do not go further back than 1880, and no adequate scientific investigation of the materials employed has been undertaken.

Bituminous rock is found in California in large quantities in a belt of country bordering the coast, extending, with more or less interruption, from 50 miles below San Francisco to the southern boundary of the State. The counties of San Luis Obispo, Ventura and Los Angeles are among the chief sources thus far, and within them bituminous rock is found in vast amount. It is found in equally large amount in Santa Clara and Santa Barbara counties, and, probably, in several others as well. Unlimited quantities of material can be supplied, carrying from 12 to 20 per cent. of bituminous matter, binding together sands and clays of comparatively recent geological age, and that, perhaps, have not been consolidated in the form of strata, except by means of the asphalt, since they were accumulated in their present relations. The formations in which these beds have mainly been found are Pliocene and Miocene Tertiary; or, in other words, the latest of all the scale, the glacial drift-beds alone being excepted. As to their exact chemical composition, almost every thing in regard to them remains to be learned. It is to be observed that the asphalt rock, so called, is but one phase of these bituminous accumulations. Considerable bodies of crude asphalt are met with, which run as high as 60 or even 70 per cent. of fixed bitumen. These deposits are known as gilsonite, uintahite, &c.

In estimating the practical value of these various deposits, it is considered necessary to distinguish between the asphalt base and the paraffine base in the bituminous rock. Only that portion of the original bitumen, which assumes the first-named form, is counted fully available for street-making materials; but, thus far, the distinction has not been adequately applied. The eminent French engineer, Malo, in his several treatises on this general subject, gives chemical tests for distinguishing asphalt from tar, which he styles "the poison of asphalt;" but the materials, thus far found most accessible, have been used without much regard to their particular composition.

What constitutes the bulk of the rock asphalt? Most persons, superficially acquainted with the native material, would unhesitatingly answer, that the bulk of it is sand, and many would add, coarse sand. There are numerous cases, certainly, in which neither of these statements is true. The results of a careful analysis of the Ventura rock asphalt, by Prof. J. W. Hilgard, of the University of California, show the following composition (Tenth Annual Report of State Mineralogist, 1890, page 766):

1. Main body, 51 feet from surface.
2. Average of four analyses.

	1	2
Loss at 217° F., water and volatile oil	2.45	2.37
Total asphaltum	20.	20.
Ash	75.	77.65

The ash in these specimens is here seen to constitute three-quarters of the mass. Professor Hilgard reports the ash to be a fine silicious clay, containing but little sand, and a small percentage (3 per cent.) of carbonate of lime. Occasional streaks of sand and gravel are found in the clay, however.

In other analyses of the asphalt rock, an excessively fine-grained sand is shown to constitute the residue. In no case, so far as my information goes, does coarse sand constitute the mass of the rock.

Street-making from these materials was begun in Los Angeles a few years since, but their use has since been extended to a number of other cities and towns, as San Francisco, Santa Barbara, San Diego, and Fresno; but the testimony available at the present time is not entirely harmonious as to ultimate value of these streets. The best results thus far are credited to Los Angeles. It is generally believed that a great addition has been made to the resources of cities in street-making material, especially for residence streets, where the travel is light; but it has been demonstrated that the rock in its native state can not endure the traffic of a great business street. The pavements are soft when laid, and never acquire a high degree of hardness. A horse standing on a pavement, or a loaded wagon passing over it, will cause depressions in the surface, but if the pavement is of approved quality, these disappear when the weight is withdrawn, or when it is otherwise applied. Different grades of rock are selected for different localities, the temperature to which the pavement is to be exposed being one of the principal factors. Fresno, for example, demands material that can endure a higher summer temperature than Santa Barbara. The beds have been generally uplifted since they were formed, and presumably since they were charged with petroleum, and they now stand, in many cases, at angles of thirty or more degrees to the horizon.*

As intimated above, it is too soon to draw conclusions as to the durability and real value of these California asphalt streets. The work thus far has been altogether experimental, and the materials used have not, by any means, been mastered. The assurances of permanence that are so confidently offered by companies and contractors are not warranted by any thing that these parties know. Some road-ways seem much better than others, and when proper scientific investigation has been brought to bear on the questions involved, it is to be hoped that ready means can be pointed out for distinguishing and selecting the most desirable materials.

Within the last four years the utilization of the Kentucky asphalt rock for street-making has been begun, principally

* For many of the facts pertaining to California asphalts, I am indebted to Messrs. A. S. Cooper and A. T. Bates, of Santa Barbara.

through the agency of Dr. W. J. Breyfogle, of Louisville, to whom the Survey is indebted for every facility in acquiring the facts as to the natural exposures of the rock. Dr. Breyfogle seems to be the first person who recognized or assumed an analogy between the California and the Kentucky rock, or at least the first one who took the necessary steps to put the new material to the proof as paving material. During 1888 and '89 Dr. Breyfogle examined many of the outcrops of the tar sandstone through a half dozen counties within the general belt named above, and concluded his work by gaining possession of many of the more promising beds of this material. During 1889, under his direction, trial blocks of pavement were laid in various cities, and companies were formed at different centers to carry forward the work of street-making by the use of the new material. In 1890 the companies thus organized began their work on an energetic scale, at least in some localities. In Ohio, streets have been laid with the Kentucky rock asphalt, as the new material is designated, in several cities. Two streets, and one or two sample blocks beside, have been laid in Columbus, most of the work having been done in the last three months of 1890. The most conspicuous sample is laid in front of the United States Government Building, in which the post-office and other public offices are established. The test afforded by this block will be a fair one when completed. While the travel upon it is not of the heaviest sort, it is fairly constant, and horses are left standing upon the pavement at frequent intervals through the day. The charge has been made that this sample has been tampered with in spots by pouring coal oil upon it. The present year (1891) will probably demonstrate the character of the new material and its adaptation to street-making in its native state. As to the streets that have been laid in the city, different opinions are entertained, both by property-owners along their lines, and also by experts. The principal criticism is directed to the want of hardness in the asphalt surface.

The reader will perceive that even if California rock asphalt were proved to be a thoroughly successful street-paving material, we should have no right to assume that Kentucky rock asphalt would also serve equally well for this use. The

Kentucky asphalt has a coarse sand for its base, while the California rock, as shown in the preceding statements, consists in the main of clay and very fine-grained sand. Whether the asphalt or the paraffine base predominates in the Kentucky rock has yet to be determined. In other words, this new material must establish its claims independently. The *molasse* of Switzerland is a coarse sandstone, which is sometimes impregnated with a notable percentage of asphalt, but Neale rejects it entirely from his list of road-making material.

I append the careful statement of Mr. Charles B. Palmer, of Columbus, as to the work done on one of the two streets named above. Mr. Palmer was appointed superintendent of the improvement on Woodruff avenue, in the interest of the property-owners, by the Board of Public Works. He brought to his duties not only personal interest and good judgment, but also habits of careful observation. His opinion is, on the whole, favorable as to the possibilities of the new material. His statement bears date January 25, 1891.

STATEMENT OF CHAS. B. PALMER, ESQ.

The paving of Woodruff and Ninth avenues, in this city, during the past season, was an interesting event, as being the first instance of the use of Kentucky rock asphalt, or bituminous sandstone, for paving purposes, in Ohio. The new material has attracted a great deal of public attention, and produced an animated discussion among our citizens as to its merits.

In the construction of these pavements, the wearing surface was laid on a six-inch foundation, made in the usual manner, the road-bed having been first properly graded and rolled with a sixteen-ton steam roller. The road-way was 30 feet wide, with a six-inch crown. The proportion of materials used in the concrete was one part cement to two parts sand, and four of broken stone. Upon this was laid the wearing surface of rock asphalt, two inches in thickness after compacting. The material was prepared by being finely ground, heated by steam, spread on the street and rolled, the intention being to merely change the form, leaving it on the street as nearly as possible in its natural state. The grinding and heating were done by machinery specially constructed for the purpose. The heating was done in a large revolving steam cylinder. On being received from the heater, the material was hauled to the street in gravel beds covered with canvas, dumped on the street, spread with shovels, and raked down to the proper thickness. It was first rolled with a light, hot roller, and then with a 500-pound hand roller. The material compacts by rolling about two-fifths, requiring considerably over three inches of loose material to make two inches after rolling.

Naturally, with a new material, new company, new machinery, and inexperienced workmen, a good many difficulties were encountered, which can be avoided in future work. The contractors made every effort to secure the best results; but, as might be expected, there were some imperfections in their work.

Judging from my limited experience, the most important points to be guarded are—

1. *Quality of Material.*—Like most natural products, the bituminous rock varies in quality, shading off from the best to the worthless, depending upon the proportion of bituminous matter which it contains. The best quality is jet black in color, and adheres like putty, when pressed between the fingers. If brownish in color, and inclining to crumble apart rather than adhere, it should be rejected.

2. *Grinding.*—It should be finely granulated. Lumps of unground material the size of hickory nuts are objectionable, especially if left near the surface of the work.

3. *Heating.*—The specifications under which the contract was executed required a temperature of 250 degrees F. when placed on the street, and, in my judgment, this is a very proper and necessary requirement. It is true that this material can be compacted to a certain extent when cold, and when left in piles after being ground it speedily consolidates into a mass which can, with difficulty be separated with a pick From this it is argued that a high degree of heat is unnecessary; but in practice this idea is found to be erroneous. The hot material makes by far the smoothest and most compact pavement, and will undoubtedly be the most durable. The imperfectly heated material remains rougher and more porous, and will not compact by rolling to the required thickness, or rather *thinness.* Worst of all, such portions of the work show indications of crumbling with use, while the rest remains smooth and tough. I am, therefore, led to believe that the heating of the material is a point of very great importance in making a good pavement with this product. I think that a temperature of at least 200 degrees F., when actually spread on the street, is necessary to secure the best results. For various reasons it was found impossible to maintain a satisfactory temperature, chiefly on account of the street and the heater being three miles apart, with cold fall winds blowing a large part of the time. It seldom exceeded 150 degrees, and often fell below 100. A great many loads were sent back to be reheated. None of the work is, therefore, a really fair sample of what may be expected of the material when handled in the best manner.

4. *Rolling.*—After being spread on the street very hot, it should be thoroughly compacted. It will require further experiment to determine the best way to do this. In the present case, nothing heavier than a 500-pound hand-roller was used in compacting the material at the time of laying. A few days later, a corrugated iron horse roller was used, consisting of ten cast iron wheels, each three inches wide, with alternate spaces of the same width. This machine was said to weigh about three tons. As it seemed to have but little effect upon the cold pavement, it was, at my suggestion, weighted with over two tons of pig iron. In this condition, it produced a decided effect, and was evidently beneficial, working and kneading the pavement—which, though cold, was still somewhat plastic—smoothing out inequalities, and making it more compact. I was strongly impressed, however, with the idea that it should be more thoroughly compressed while soft, than can be done with a 500-pound roller. This opinion was sustained by the City Engineer and the Board of Public Works, and the contractors, therefore, ordered a five-ton steam roller. But, much to my regret, it could not be obtained in time to test it before our street was finished. It was claimed by the contractors that a five-ton roller is

too heavy; that it will crush the material out of place, if used while the work is soft. A very short trial would have settled the question; but it was not done. If five tons is too heavy, it should be determined by experiment what is the greatest weight that can be used without injury to the work, and a roller constructed to meet the case. It is interesting to note in this connection that tamping and ironing seem to produce better results than rolling, and the idea has been suggested of a tamping machine to take the place of a roller.

In conclusion, it may be said that while it is too much to expect that the first attempts to use a new material will be entirely satisfactory, the results so far obtained are, on the whole, sufficiently encouraging to warrant the prediction that Kentucky rock asphalt will be extensively used for street paving. If the present methods of manipulation are not the best, better ones will be found. If it should be found desirable to produce a slight modification in quality by the addition of some substance, there is no reason why it should not be done. It took years of careful experiment to bring the mixture, known as "Trinidad asphalt," to its present state of efficiency; and it will be strange if a material, which exists in great abundance near the center of population of the United States, and which comes from the hand of nature so nearly what is required for a pavement of the best class, shall not, by a little skillful treatment, be perfected, and made to supply this important demand.

NOTE.—The year that has passed since the above statements were prepared has given a fairer opportunity to judge of the merits of the rock-asphalt than had been afforded up to that time. It is a pleasure to report that the streets in Columbus, which were surfaced with it, present a much more favorable appearance than they did one year ago. The asphalt has grown harder and more compact in this interval, while still retaining a measure of elasticity. It now appears to the writer that the rock-asphalt, when properly handled, is likely to become a paving material of great value.

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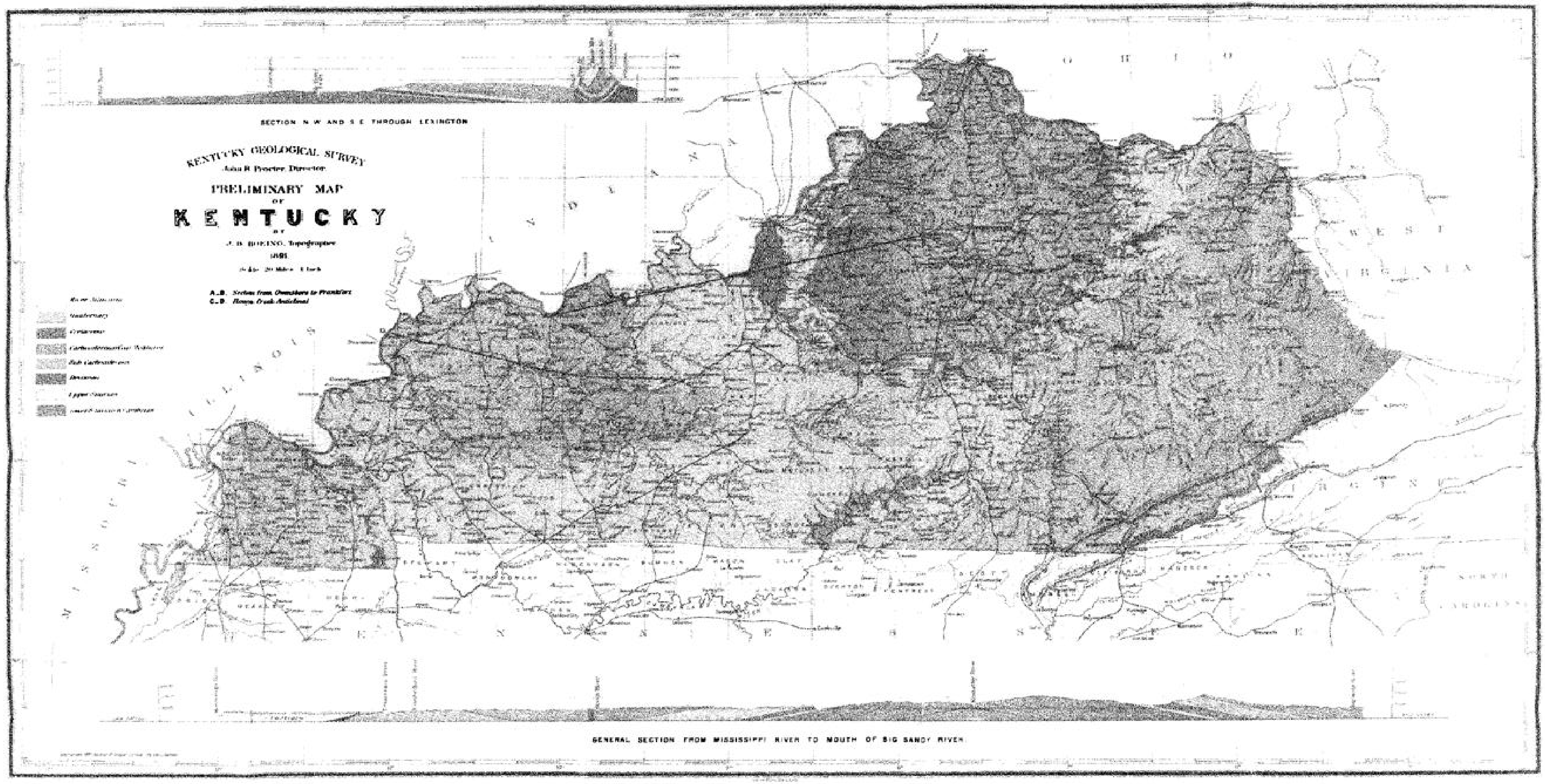
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