PRESIDENTIAL ADDRESS OF EDWARD ORTON

GSA Bulletin, v. 9, p. 85–100 (24 January 1898) *Read before the Society 28 December 1897*

Geological Probabilities As to Petroleum

Annual Address by the President, **Edward Orton**

Contents

INTRODUCTION

It has seemed to me that I can turn the hour that you allow me on this occasion to the best account in the discussion of some subject connected with petroleum and its derivatives.

Petroleum has long been in the world. Man has been acquainted with it though much of his brief day. As soon as he "came to himself," in the earliest stages of civilization, we find him making use of asphalt, one of the best marked derivatives of petroleum. Asphalt took a prominent place in his arts and commerce, and frequent mention of it occurs in some of the oldest records of the race.

In later times asphalt, the representative of petroleum, lost to a considerable extent its relative importance, being replaced in several lines of service by other and more easily obtained substances, but within the last half of the present century the bituminous series, represented by petroleum and gas, has acquired and importance infinitely greater than it ever had before. It has become a factor, and by no means an insignificant one, in the commercial exchanges of the civilized world, and it has made contributions of inestimable value to the well being and particularly to the comfort of the human race.

In this modern development the new world has taken the leading part. What may called a distinct branch of mining engineering, namely, the art of drilling deep wells, has grown out of it here. This art comes into close relations with the science of geology. It is hard to say at the present time which is the more indebted to the other, the art or the science. Each gives and each receives.

The crust of the earth contains but few mineral productions that awaken such widespread interest as the bituminous series. The search for oil and gas is attended with much of the excitement that goes with the search for the precious metals, and success is in many cases as amply rewarded in the one as in the other.

Geologists, especially if they concern themselves with the practical applications of their science, are constantly called on to answer questions with regard to petroleum, its probable presence in any given locality, its modes of origin and accumulation, the duration of its supplies. They have recognized these new demands, and discussions bearing on such questions have made large additions to the literature of the science during the last forty years. These discussions are still in progress, and important contributions to our knowledge of petroleum and its derivatives are being recorded in our own day.

In view of these facts, and despite the well worn and hackneyed nature of the theme, I feel warranted in asking you to follow men in a brief review of the *geological probabilities as to petroleum*. I use the modest word, probabilities, in this connection because it seems in all respects the proper word. Geology is a historical science, and but few demonstrations of the sort that carry mathematical certainty find place in it. We have only probabilities as to all the dates of the science; for example, as to the date of the end of the Glacial period, let alone its beginning; as to the date of the advent of man. Nay, more, we have only probabilities as to the weightier themes of geology; as, for example the cause of glacial periods, the eruption of volcanoes, the formation of mountains, the condition of the interior of the earth. By what right, then, should we expect certainties on a subject that is one of the last to be considered in geology, and that is, by its very nature, complicated because of the fact that the geologist must depend on the chemist for the ultimate decision of many vital points in the investigation? But I must remind you that there are probabilities and probabilities in geology. In other words, geological probabilities are of different orders. Some of them are so strongly supported that they count for certainties with many minds. In what respect they could be strengthened by subsequent discoveries it is hard to see; but we may still style our conclusions, even on such subjects, probable.

ORIGIN OF PETROLEUM

Among the geological probabilities as to petroleum, I mention first those which bear upon its origin. Geologists believe that *petroleum is in all instances derived from organic matter*—that is, they believe that petroleum falls into line with every other combustible body that we know of or beneath the crust of the earth. Everything that burns has borrowed its power to burn from the sun. It burns because it holds some of the sun's heat and light imprisoned in the organic substances formed by these agents. Burning is the rapid restoration of this organic matter to the simpler state from which it originally came.

To what other source can petroleum be referred? We are all familiar with the great chemical hypotheses that have been before the world the last 30 or 40 years. The names of their authors are a sufficient guaranty of the soundness of the chemical actions and reactions invoked—that is, of the chemical possibilities concerned. To one of these theories, which has somewhat more to commend it, or, rather, somewhat less to condemn it, than the other theories of the same class, the great name of Mendelejeff, the discoverer of the periodic law, is attached. In what light the postulates of this theory are regarded by chemists I am not able to say. These postulates, in substance, involve masses of white-hot iron, buried miles below the surface in the depths of the original crust, but still reached by water percolating from the surface and charged with carbon dioxide, the whole giving rise to a somewhat complicated series of chemical reactions out of which petroleum at last emerges.

I repeat, I do not know how this theory appears to chemists, but to geologists it sounds like an echo from the eighteenth century. It goes back to Werner's day and takes its place among the "cloud-capped towers and gorgeous palaces" of the speculations of the time when cataclysmic geology was in undisturbed possession of the field.

The law of parsimony of force seems applicable to this case. It is not necessary to go so far as these chemical theories require for a source of petroleum, because there is always an organic source nearer at hand. We can roughly divide the rocks of the earth's crust into two great series; those in which organic remains are more or less abundant and those in which no traces of life are found, either because life had not been introduced at the time of their formation or because metamorphic changes have supervened since their origin, by reason of which all such traces, if ever present, have disappeared.

In the last named division neither petroleum nor any of its derivatives is ever found; all its occurrences are confined to the fossiliferous division. While the Archean rocks do not cover surface areas as large as the vast series formed in the ages of life, they are by no means insignificant in extent. Two million square miles in one continuous body, more than one-fourth of North America, are referred to this series in the Canadian protaxis alone. In the other continental masses a like distribution is recognized.

Now, if the real centers at which petroleum originates are to be found below the Archean, in the primeval crust, according to Mendelejeff's theory, the carbonated waters of the surface, essential to the process, would certainly have a shorter course in reaching these centers when descending through the uncovered Archean than by going down through thousands of feet of the stratified and fossiliferous rocks overlying them. It is hard, therefore, to see why, the whole world over, petroleum is entirely wanting in the Archean and exclusively confined to the stratified rocks. There is not an oil field in the world in rocks of Archean time. To this it may be replied that the absence of petroleum from Archean rocks may be due to the fact that porous rocks suitable for storage are not found in this series; but according to Mendelejeff the process of petroleum manufacture is in constant operation, and certainly any large stock produced within the last 5,000 or 10,000 years, not to speak of the last 50 or 100 years, would have left some clue or token upon the surface.

Further, there seems to have been a notable increase of the bituminous series as the geological ages have advanced. The maximum of their production was apparently reached in the great division that immediately precedes the present order, namely, in Tertiary time; but this increase in the petroliferous series has gone forward contemporaneously with the decrease in the internal heat of the earth. There has been, however, a gain in the total amount of life which the rocks contain, and this roughly corresponds with the increase in the total accumulation of bituminous products above referred to.

That the organic world is an adequate source of petroleum has been abundantly demonstrated within the last few years. The demonstration was begun by Warren and Storer in the distillation of a lime soap made from menhaden oil. In this operation various compounds belonging to the bituminous series were definitely developed. This work was made known to the world about 1867–'68.

Investigation was subsequently carried still further in this line and to still more striking results by Dr Carl Engler, of Carlsruhe, Germany, who has obtained from fish oil, and afterward from lard oil, almost the entire bituminous series to which petroleum belongs. In the list of the products which he thus obtained from the sources named are to be found illuminating oil, lubricating oil, benzene, and paraffine. Engler's results were published in 1888.

The animal world has thus been definitely proved to be, at least in its higher divisions, a possible source of petroleum and its various derivatives. And now comes Dr S.P. Sadtler, of Philadelphia, who has extended a similar line of investigation to the vegetable world as well. In an important paper read before the American Philosophical Society February 5 of the present year he made known the results of the work which he had recently carried on and which he still continues in the distillation of linseed oil under pressure. He obtained by this process hydrocarbon oils analogous to natural mineral oil or petroleum, and, among other products, he produced a good specimen of scale paraffine. It is altogether probable that oils derived from other vegetable seeds would show the same characteristics. The vegetable kingdom is thus shown to be on the same plane with the animal kingdom as a possible source of the bituminous series.

Daubree, perhaps the most ingenious and successful experimental geologist of the century, advanced the same claim at a still earlier day. He declared that by the action of superheated steam upon wood he had obtained both liquid and gaseous products closely allied to petroleum. In his view the concurrent action of water, heat, and pressure on vegetable matter furnished an adequate account of the natural production. Engler's discovery is worthily supplemental and balanced by Sadtler's. From the latter we see how hasty and unwarranted the conclusion adopted by some, that the origin of petroleum always and everywhere is to be ascribed to the products of the decay of fishes.

Closely related to this latter claim are the facts pertaining to the Trenton limestone oil field of Ohio and Indiana. This is unmistakably one of the most important reservoirs of petroleum that was ever discovered; but it originated long antecedent to the appearance of fishes in the geological scale. In placing it before the introduction of fishes I do not forget the recent discovery by Mr Charles D. Walcott, director of the Geological Survey of the United States, of fish remains in the lower Trenton of Colorado. Geologists have not yet had time to assimilate this remarkable discovery and to give it its due place in the history of the life of the world; but certainly these Ordovician fishes of Colorado might as well not have been, so far as the burial life of the world at large is concerned. Not a hint of the existence of one of them has been found in the well worked formations of Ordovician time in any other part of the globe. Vast periods of time elapsed after this date, periods measured by the deposition of many thousands of feet of the various types of sedimentary rocks, before fishes appeared elsewhere in the world. The petroleum of the Trenton limestone owes nothing whatever to the vertebrate type, so far as its sources are concerned.

While geologists find such a warrant as I have indicated and much besides for believing in the organic origin of petroleum, it cannot be claimed that they hold concordant views as to the manner in which the conversion of organic tissue into mineral oil has been accomplished. They recognize the process as essentially chemical in its nature and are prepared to welcome all pertinent facts and discoveries from students of this branch of knowledge.

It is easy to see how the bituminous series may result from the destructive distillation of either vegetable or animal substances enclosed in the rocks, and wherever conditions can be shown that provide for such distillation we are not obliged to go further in our search. Destructive distillation can take effect on organic matter that has attained a permanent or stable condition in the rocks, like the carbonaceous matter of black shales or coal; but it seems improbable on many and obvious grounds that this can be the normal and orderly process of petroleum production.

This production of petroleum must be in active operation in the world today; at least it seems highly improbable that a process coeval with the kingdoms of life, growing with their growth and strengthening with their strength, a process that was certainly in its highest activity throughout Tertiary time, leaving a most important record in the rocks of that age, should suddenly and completely disappear from the scene upon which it had wrought so long and upon which all other conditions appear to be substantially unchanged.

What geologists would be glad to find in nature as matching to and harmonizing with the facts with which they are obliged to reckon would be a process in which the products of the organic world are transformed into mineral oil at ordinary temperatures and with complete consumption of the substances acted upon, so that no carbon residue would be left behind. They would also expect the transformation to be accomplished while the organic matter still retained essentially its original character.

The demands of the chemists are much the same. For the origination of the petroleum of Pennsylvania, one of them, namely, Professor E.J. Mills, of Glasgow, Scotland, requires "long continued application of a gentle heat to some derived form of cellulose."

Whether such a process as the geologists are looking for is a fact of nature and susceptible of satisfactory proof or whether the demand for it is mistaken and irrational remains to be determined. Once and again support seems to have come to such a view from certain lines of reported facts. The testimony of G.P. Wall in 1860 to the effect that the production of petroleum could be seen going forward on the island of Trinidad, manifestly connected with the decomposition of vegetable tissue, has not been corroborated by later observers. Wall's testimony was in itself impressive and it was used effectively by Dr T.S. Hunt. If it had been or could be thoroughly substantiated, it would go far toward settling the question at issue.

Considerable weight has also been attached to the recent observations reported by Dr Oscar Fraas, of Stuttgart, on the occurrence of petroleum in certain coral reefs of the Red sea. Dr Fraas confidently refers the petroleum to the decomposition of the organic matter of the reef. This claim also, if fully sustained, would solve the problem as to the mode of origin of petroleum; but unfortunately the interpretation of the facts is not beyond question. Other explanations of the presence of the observed petroleum can be offered, which have at least a show of probability. If, however, further examination should confirm the claim of Fraas that petroleum is now forming in these reefs at the normal temperature of the sea and out of the organic remains of dead corals, the long controversy would be closed.

The occurrence of petroleum or its derivatives in fossil corrals and shells has long been noted. The facts have been used by some as decisive proof of the conversion into oil of the organic matter represented by the fossils; but to this it is objected that the petroleum found greatly exceeds in amount what the organic matter in question could supply. The objection seems to me well taken.

Its occurrence in peat bogs, as recorded by Binney, is not proof conclusive that it originated there.

Any theory of petroleum production to be acceptable to geologists must provide for the use of the organic substances elaborated by the lower divisions of animal and vegetable kingdoms as well as by the higher. To limit the process to the fatty acids derived from the decomposition of vertebrates or to the oils contained in the seeds of the highest groups of plants would be ludicrously inadequate. As in the doctrine of orthodoxy, the geological test must be, *Quod semper, ubicunque, ab omnibus*. The great stocks of petroleum on which the world depends are practically independent of both these higher sources. As we have seen, some of the oil fields antedate these divisions, not by millenniums alone, but by eons.

We must not forget that the chemical actions and reactions which we set in motion laboriously and with great expenditure of force in our laboratories, in the great laboratory of nature appear to be the simplest and easiest possible character. Witness, for example the decomposition of carbonic acid in the cells of every growing plant.

INABILITY OF PETROLEUM AND GAS TO DESCEND IN THE GEOLOGICAL SCALE

It is probable that *neither petroleum nor its derivatives ever descend in the geological scale*. Petroleum is specifically lighter than the liquids associated with it in the rocks. These liquids are generally saline waters, and their gravity is greater than that of fresh water, sometimes by as much as one-tenth. Oil consequently rises in the rocks by means of this well-nigh universally distributed water just as far as the possibility of movement is allowed to it. Natural gas, the most common derivative of petroleum, in like manner rises as far as it finds any open was, but no agencies are known by which either petroleum or gas can be carried to lower horizons than those in which they originate.

You will not fail to note an important consequence that follows from this principle, namely, that petroleum gas is as old as the lowest stratum in which it is found.

In the town of Parish, Oswego county, New York, a well was drilled two years ago to a depth of 2,160 feet. It was begun in the Medina sandstone. The drill stopped in red granite seven feet below the surface of this last-named formation. The granite was of the same character that is found in the nearest outcrops of Archean rocks—that is, on the western boundary of the Adirondack region. The series through which the drill was descended was normal in every respect. There was found, successively, the Medina sandstones, red and white; the Medina shale, in characteristic showing; the Oswego sandstone and Pulaski shale of the Hudson River group; the Utica shale and a series of Ordovician limestones, 600 feet of which are referred to the Trenton. Below the Trenton, at a depth of about 100 feet and in accordance with the usual stratigraphical sequence of the district, a stratum of white Potsdam sandstone was reached. It was 47 feet thick, and a gas vein of fair strength and volume was found in it. The gas attained a rock pressure of 340 pounds when shut in.

Immediately below the Potsdam a stratum of dark Cambrian limestone was found. It contains rather obscure traces of animal life, apparently referable to Cambrian trilobites, and below the limestone, at a total depth of about 2,150 feet, the granite was reached, as above described. The discovery of gas in the Potsdam sandstone aroused considerable interest among the parties in charge, and it was deemed best to try the effects of a torpedo on well. A light shot was lowered, designed for the horizon in which the gas was found; but by a slight miscalculation the explosion took place somewhat lower than was planned, and, as it proved, in the granite formation in part. A quart or two of granite fragments, some of them an inch in diameter, were brought up by the sandpump. The gas supply was increased somewhat by the torpedo, but nothing came from the well in the way of practical results. But there are certain facts and suggestions on a scientific side that are not without interest.

The gas struck in this well is of Cambrian age. It is thus practically coeval with *Linguelella*, *Dicellocephalus*, and their allies. It is probably the equivalent but altered form of a small stock of petroleum derived presumably from the decomposition of Cambrian trilobites and brachiopods. The Cambrian gas belongs, we may be sure, where it is found. It is in its original home. There is no source from which it could be derived in the granite foundations that underlie, and it cannot have come from above. Let alone the constant and insuperable opposition of gravitation to its descent through heavier liquids, the shale roof of the Potsdam, which proves itself able to withstand a gas pressure of at least 340 pounds to the square inch, would have had to be penetrated if any supply had come from above.

No; we have reached at last a point of beginning. There are no mysterious depths below on which we may draw in imagination for the material from which the petroleum represented by the gas here found, could be generated or for the heat that should effect the dry distillation of organic matter or for a hiding place for the carbon residue that must necessarily attend the process of destructive distillation. If the dark color of the limestone is referred to the carbon residue, then such residues are found without end in all dark colored rocks.

The stratum that here underlies the Potsdam sandstone is, as I have already said, a dark limestone, never more than 40 feet in thickness and sometimes much less. Fragments of the limestone 2 to 3 inches in length have occasionally been brought up from the wells, and in them we are able to study the character of the stratum. Like most deep limestones, it is compact and hard to drill. Because of this character, it has sometimes been named "black granite" in the well records; but there is not a trace or hint of metamorphic action about it. The contrast between the dark limestone and the red granite that underlies it is always immediately apparent to the driller. Innumerable but unidentifiable fragments of trilobite crusts make a prominent part of its substance. There seems to be very little material in it from which petroleum production could be maintained even by dry or destructive distillation.

A dozen or more other wells have been drilled to the granite in the same region. All of them agree in their records. The two principal strata below the Trenton limestone are the Potsdam sandstone and the dark limestone, already described. The drillings brought from these horizons seem normal in every respect. Certainly there is no hint of any transformation by heat. "The smell of fire has not passed on them." There is no carbon residue. The bituminous products found in them cannot therefore owe their origin to the usual form of destructive distillation.

In following the discussion to this point, I come upon a theory that is sometimes met in the speculations of our day. It is to the effect that the great stocks of our oil fields—the oil fields of Pennsylvania, for example, distributed through a half dozen distinct horizons and through thousands of feet of vertical range—have all been derived from a common and deeply buried source; and, further, that both gas and oil have been purified in the process of ascent, the highest oil in the vertical series being the highest in chemical character as well.

INABILITY OF PETROLEUM AND ITS DERIVATIVES TO RISE FROM ONE FORMATION TO ANOTHER

I remark, therefore, in the fourth place, it is probable that *petroleum and its derivatives are unable to rise in the geological scale from one porous formation to another*. In other words, the principal deposits are hermetically sealed in the strata that contain them.

I have already recognized the obvious fact that in a homogeneous and permeable formation there must always be the movement that gravity would cause in separating at different levels the oil, gas, and salt water contained in it. Such differentiating movement would of course go on when oil rocks are, by the warping of the crust, bent into low arches or monoclines. Oil rocks also rise to day in natural outcrops, and more or less movement of their contents is rendered possible and necessary in this way. There are also numberless fractures and faults beside, by which the contents of porous rocks can reach the surface. The "surface indications" of gas and oil, of which we hear so much, are principally due to these last-named facts. Characteristic examples of such fractures are found in Pennsylvania and Ohio fields; but sound observation seems to show that every deeply buried oil and gas rock is, in a normal state, hermetically sealed, and no communication in the vertical scale is possible between the porous rocks of a single section.

For the establishment of this probability I must again draw upon the experience that has been accumulated in New York within the last few years. In Oswego and Onondaga counties, of this state, natural gas has been found in large volume in wells drilled into the Trenton limestone. Near Baldwinsville, Onondaga county, the Monroe well was drilled in the late autumn of 1896. It reached the surface of the Trenton limestone at 2,250 feet. At a depth of 120 feet in this stratum a vigorous gas vein was struck, the rock pressure of which reached the amazing figure of 1,525 pounds to the square inch. I read for myself in August last a pressure of 1,370 pounds to the square inch on the gauge of this well after its gas supply had been drawn steadily for up to four months.

A rock pressure of 1,500 pounds to the square inch stands for, nay, demands, a hermetic seal. Think of it a moment! If there had been a drill to go down 150 years ago, when northern New York was still covered with the primeval forest, the same pressure would have been found here; if when Columbus discovered the New World, 400 years ago, it would have been the same; the same when the Christian era was begun, 1,900 years ago, by the birth of the babe in Bethlehem; the same when Romulus and Remus were herding their flocks on the seven hills of Rome; the same when the Pharaohs were quarrying the nummulite limestones out of which the pyramids were built. Can even the semblance of a reason be given why the pressure should have been any less when the nummulites were growing in the Tertiary seas?

All the events and epochs which I have named are "but as yesterday when it is past and as a watch in the night" compared with the ages that have gone by since the petroleum from which the gas was derived was store in the Trenton limestone of northern New York.

Now, if the rock cover of a gas field is to any extent permeable, it would certainly seem that a pressure of over 200,000 pounds to the square foot, for this is what 1,500 pounds to the square inch means, ought to be able to find the open way. Any rock which withstands such a pressure for thousands and millions of years might as well be labeled "no thoroughfare." Similar reasoning will apply to pressures of one-half, one-fourth, or even one-tenth of the 1,500 pounds which was registered in the Monroe well.

If it had been possible for this imprisoned gas to escape at any measurable rate with a pressure of 1,500 pounds to the square inch, then the present figures must indicate a remainder of pressure after thousands and millions of years of waste. If the gas has ever escaped it should be escaping now. If it is now escaping, the pressure must be steadily falling unless the supply is being constantly replenished; but there is no source of supply except by the destructive distillation of the organic matter of the rock, and there could be but the feeblest possible supply from this source. The underlying rocks show no indications of having been subjected to the process of destructive distillation or to any unusual degree of heat. In fact, they distinctly negative such a supposition. In the case of the Monroe well, the 2,800 feet of overlying rock included several sandstones which could well enough become gas rocks if there were any source of gas at hand. In fact, these very strata are found to be important gas rocks in numerous instances in this immediate region. In the Monroe well, however, while the sandstones were normal, as respects thickness and grain, all of them were found wanting in gas to any unusual degree. In other words, while the reservoirs were present they were practically empty, and yet a great volume of gas under a tremendous pressure lay securely stored only a few hundred feet below them. Not a sign of the presence of this gas had ever escaped through the thick cover already noted, and probably no one would claim that oil would pass through strata impervious to gas. These facts, I submit, do not seem consistent with any freedom of ascent of the bituminous series from stratum to stratum. I accordingly repeat the proposition with which I set out, namely, that it is probable that neither petroleum nor the gas derived from it can rise through the impervious rocks that cover them. In other words, by impervious we mean impervious.

STRUCTURE OR ARRANGEMENT OF STRATA THE DOMINANT FEATURE IN ACCUMULATION OF GAS OR OIL

It is probable that *in all accumulations of oil and gas the structure or arrangement of the strata involved is the dominant feature*. This conclusion is clearly a probability of the first order. A dozen years ago there were a few voices raised against certain applications of this doctrine, but at the present time I know of no opposition whatever to it. It harmonizes so well with the teachings of physics and its applications are so obvious and convincing that reasonable men cannot easily find standing place for an attack upon it.

I will not weary you with a repetition of the thrice-told tale of anticline, syncline, and monocline, but will only add that the controlling influence of structure comes out more and more clearly as the oil and gas fields of the world are adequately studied. The latest confirmation comes from Burma. Dr Fritz Noettling's excellent work on the Geological Survey of India, brought down to 1895, fully establishes the fact that the oil fields of the Irawaddy, famous for more than a century, conform in all particulars to the laws of structure that have been worked out more fully than elsewhere in the great oil fields of the United States. He shows, what we might have been ready to accept without demonstration, that anticlines and domes of Miocene sandstone exert the same influence in the accumulation of gas and oil that like features exert in the Devonian sandstones of Pennsylvania or the Ordovician limestones of Ohio.

EQUALITY OF PRESSURE ON THE CONTAINED LIQUID AND GASES

In the sixth place, and finally, it is geologically probable that *in the fields where salt water rises from deeply buried porous rocks under artesian pressure the same pressure will be exerted on the gas and oil which with the salt water, are the join tenents* [*sic*] *of the rock*. In other words, the rock pressure of gas wells in certain districts is due to the salt water that follows the gas, and it can be measured by the height to which this water rises above the gas reservoir. In my judgment this probability, when duly qualified, also belongs with the few that are of the first order. The facts derived from the gas fields of Ohio and Indiana seem to me to constitute a demonstration of this claim, but as several well known geologists, especially interested in petroleum, have emphatically dissented from this view, we are not warranted in claiming more for it, to say the least, than for the conclusions which have been previously stated.

The theory referred to was from the first restricted in its application to districts in which the water found in the porous rock with the gas and oil rose under unmistakable artesian pressure and to the same height throughout the field. Shale gas was from the first distinctly recognized as demanding a different explanation of its pressure.

In regard to the salt-water fields, there is probably but one date in their history when the artesian theory can be fairly applied or tested. That date is at the very opening of the field. There are great differences in the degree of permeability in different portions of what is essentially a porous rock, and vast periods of time have been available for the pressure of the distant head to make itself felt in every pore of the water-bearing stratum. The first wells drilled in a district may be able to avail themselves of the normal pressure and to exhibit the normal rise of the salt water, but it is conceivable that after wells have been drilled in the same field by the score, the hundred, or the thousand, the original conditions may be materially interfered with, at least for the time being. The gas and oil, in the storage and adjustment of which ages have been used, may have been released and brought to the surface in weeks or even in days, and the salt water may be altogether unequal to the task of occupying the new territory open to it on such short notice. Years may be required for its movement where minutes are allowed.

So far as known, but a single important gas field has been taken in time to furnish a thoroughly reliable record. In the Trenton fields of Ohio and Indiana all the facts were noted at the beginning of their development, and the record accompanied the development, *pari passu*. From the facts thus gathered the artesian theory of gas pressure finally grew. I find it impossible to believe that the remarkable coincidences between observation and theory in these cases can be fortuitous. That the theory does not find support in the latter experience of the Pennsylvania fields is no ground for surprise. Two explanations of this want of agreement are possible, as well shall presently see. The theory would not find support in the later stages of the very field from which the initial facts for its foundation were gathered. The salt water still rises in some wells to the same height as formerly, namely, 600 feet above tide, but the rock pressure of the gas ranges from a quarter or an eighth of the original figure to zero; but every step of the decline has been observed and noted. The figures that entered into the original theory were facts at the time they were used, and a rational explanation can be given of the conditions that have since supervened and are now existing. That another element can enter into this rock pressure I have always recognized. This element is the expansive power of the gas itself. It is seen especially in shale gas fields, where no water, fresh or salt, is associated with the gas. In such cases the artesian theory, of course, is not applicable.

The highest pressure that I have noted in shale gas wells previous to the last summer was less than 200 pounds to the square inch. During the present year I have had an opportunity to study the gas production of central New York, and to my surprise I found that the gas derived from the Trenton limestone in that region exhibits the unmistakable characteristics of shale gas. One anomalous and thus far inexplicable fact, however, comes into view in connection with it, namely, its amazing rock pressure. I have already stated the initial rock pressure of a single well as 1,525 pounds to the square inch, a higher figure than ever recorded before in gas wells of any description, so far as my knowledge goes.

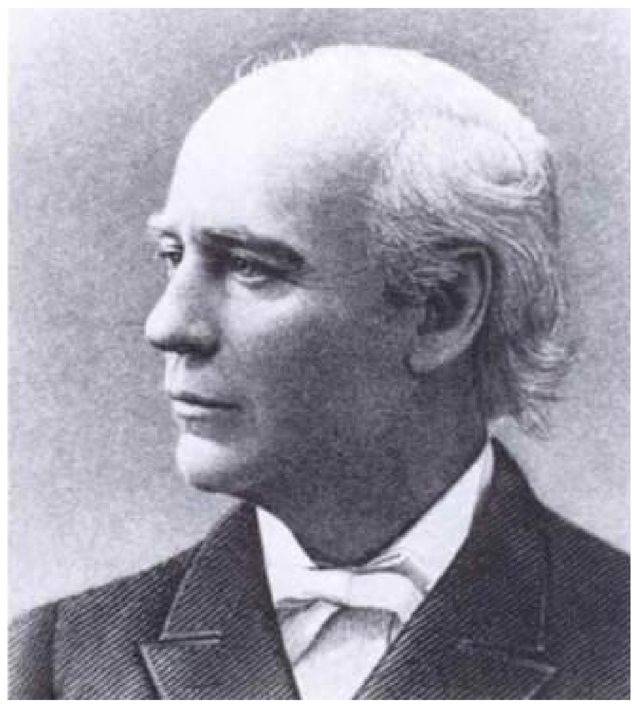
This rock pressure bears a certain relation, thus far undetermined and unexplained, to the depth at which the gas is found. I do not propose to consider this subject now, but it is evident that the extraordinary figures found in this field require us to add an important qualification to the artesian theory of rock pressure.

Trenton limestone gas, whether found in reservoir rocks associated with salt water or in thin bedded limestones or shales which carry no water, has the same chemical and physical properties, and the compression under which it is found must have the same root in both cases. That root, as the later facts show, is not the weight of the salt-water column, as I once believed, but the expansive power of the gas itself, modified in some unexplained way by the thickness of the overlying section. In cases where the artesian theory of rock pressure is applicable, the compression due to the expansive power of the gas is less than that which the weight of the salt water gives, and is therefore marked and measured by the latter elements. This is the qualification which the new facts oblige us to add to the artesian theory.

DURATION OF PETROLEUM SUPPLY

I have now completed the task which I set for myself. I have pointed out some of the principal geological probabilities as to petroleum and its derivatives. I hope that you will not find reason to complain of an undue amount of subjective color in my statements.

I am well aware that there are within the limits of our ever widening science many larger and more important subjects than that which I have brought before you, but this, too, deserves its "day in court." In fact it has some peculiar claims on geologists. Petroleum is a form of stored power, and geologists know better than other men the priceless value of such accumulations. They know that on them the well being and progress of the race largely depend, and that without them civilization cannot long maintain the pace which the nineteenth century has set. They know that these stocks of buried light and heat and power are small at the best and demand the most careful husbandry. They know, too, that petroleum and its derivatives, by virtue of their essential characteristics, are especially exposed to the wastes that come through ignorance, recklessness, or speculative greed, or through all combine. It is this liability that constitutes the peculiar claim of which I made mention a moment ago. It will be a reproach to our science to have the experiences of Oil Creek, Pittsburg, Findlay, and Baku indefinitely repeated. It will be a lasting reproach to have the important exploitation of petroleum restricted, by the exhaustion of its stocks, to the century in which it has begun and 50 years of which still remain.



Edward Orton

Transcribed from the original GSA Bulletin *article for posting on the Web in June 2013.*