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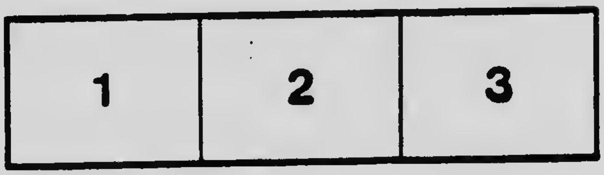
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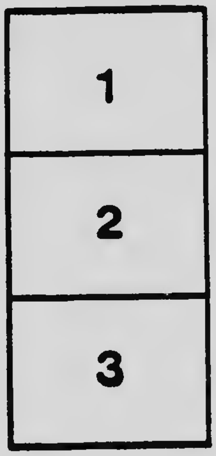
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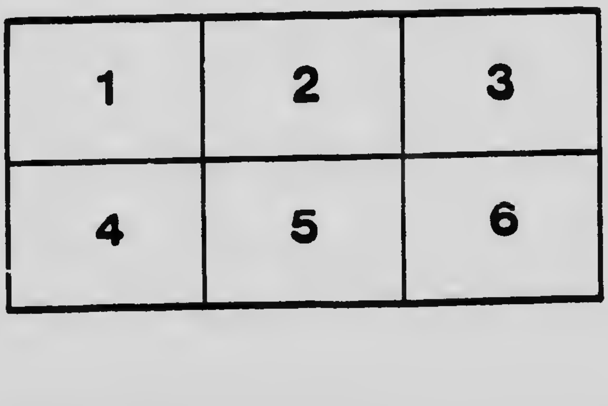
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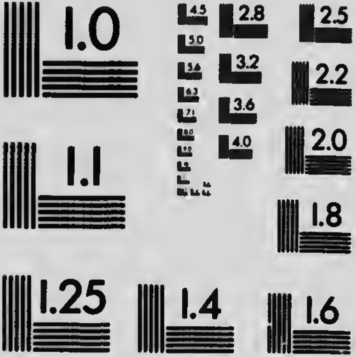

Canadian Mining Institute

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The Volcanic Origin of Natural Gas and Petroleum

— BY —

EUGENE COSTE, E. M., TORONTO

A Paper read at the Annual Meetings of the Institute,
Montreal, 4th, 5th March, 1903

2nd EDITION
Toronto, Ontario, Canada, 1905

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Journal of the Canadian Mining Institute, Vol. VI.

VOLCANIC ORIGIN OF NATURAL GAS AND PETROLEUM

By Eugene Coste, E.M., Toronto, Ont.

Montreal Meeting, March, 1903

Three years ago, at the 1900 annual meeting of this Institute, I had the honor to present a paper entitled "Natural Gas in Ontario" (1) in which it was set forth how my strong belief in the volcanic origin of natural gas and petroleum, had induced me to undertake boring operations in new districts of that province, which resulted in the discovery of the two natural gas fields in the counties of Essex and Welland. In this paper a few facts and arguments in support of the volcanic origin of these products were advanced, but I really then only introduced the subject before this Institute, and I propose now to refer again to this interesting question a little more fully. The importance of the matter scientifically and economically, and the very opposite views to those I champion, generally held by most Canadian, American, German and English geologists, will I trust be held by you a sufficient apology for my taking up your time again with this controverted subject evidently in need of much more light. The necessity of much more discussion on this matter was lately forcibly brought to my notice by a paragraph in a recent paper (2) of Mr. Robert T. Hill of the United States Geological Survey, in which Mr. Hill said: "In endeavoring to interpret the geological occurrence of oil the geologist is confronted by the fact that science has not yet solved the problem of its origin, which lies at the root of the subject. Among the theories in this field are those of inorganic chemical origin resulting from reaction of one mineral upon another, the generation of oil in leaving microscopic organism such as diatoms and the generation of oil from the decomposition and deterioration of dead organic matter, animal or

(1) Journal Can. Min. Inst., Vol. III, pp. 68-89.

(2) The Beaumont and other oil fields of Texas. Trans. Am. Inst. Min. Eng., Vol. XXXIII, pp. 363-405.

vegetable preserved in the rocks. There are facts in nature which can be made to conform to either of these theories, but for the present we must consider oil as a material in the rocks, the origin of which is still unexplained."

Now, I am among those who cannot subscribe to these *terra incognita* statements as to the origin of oil, and as I will endeavor to show below, I think that science has long ago recorded and is recording every day in the newly developed oil and gas fields many facts (among these the valuable records of Mr. Hill himself, in the very paper above quoted), which in my opinion have thrown and continue to throw the clearest light on that origin of the hydrocarbons, whether they be petroleum, natural gas, or solid hydrocarbons.

I will present below a few of these facts under the following heads:

(A). In which I will give examples of carbon and hydrocarbons in ancient plutonic rocks as well as in the present volcanoes, the other associated gaseous emanations of which I will also briefly review, as well as their solfataric phase.

(B). In which I will point out the true analogy of the volcanic emanations and phenomena to the products and conditions found in all the oil and gas fields.

(C) In which I will show the complete inadequacy of all organic theories.

(A). As everyone knows carbon is the fundamental element of the organic world, but this must not blind us to the fact that carbon is also a very important element of the mineral world. Indeed the predominance of carbon in the organic world is one of the strongest evidences that can possibly be adduced to demonstrate its great importance, during past as well as present ages, in the mineral world (including of course the atmosphere) for vegetables and animals alike had evidently no other source to draw from. When one reflects on all the carbon subtracted from the mineral world during the past geological ages by all the representatives of the organic kingdom, especially since the beginning of the Carboniferous, to form not only the coal beds, but the limestones, he must admit that the primitive atmosphere was very rich in carbon.

Therefore large quantities of this element must have been dissolved in the first fluid of magma of the earth, and large quantities of it must still exist in the fluid magma of to-day under the crust of the earth.

To know and demonstrate in just what form the carbon is there, and how, from it, hydrocarbons were produced are not essential geological points, and I will consider it quite sufficient to recall that chemists of high standing in the scientific world, such as Berthelot and Mendeljeff, have long ago (in 1866 and 1877 respectively) suggested very probable forms such as carbides under which carbon could exist in the interior fluid magma, and probable re-actions under which hydrocarbon compounds could be generated. The present great daily production of the hydrocarbon acetylene by the simple action of water on carbide of calcium is very suggestive in that respect, and these considerations together with the further one, now proved and admitted, that eruptive magmas are hydato-pyrogenic, namely, contain the more or less notable admixture of water necessary to suggested possible reactions in the formation of hydrocarbons are sufficient in that respect. The vital point is to actually show the carbon and hydrocarbon in the igneous rocks, lavas and emanations proceeding from these internal fluid magmas. That, geology can do and has done, in a great many instances, at points widely distributed over the whole surface of the globe; and, we will now pass in review a few of these instances, namely:

1st. In the Archaean rocks we find carbon under the form of graphite in gneisses, (1) in pegmatite dykes, in granites, (2) gabbros (3) and other rocks, the igneous origin of which is undeniable. In this connection Dr. A. E. Barlow in his excellent report on the Nippissing and Temiscaming region says: "This gneiss though somewhat remarkable in its chemical composition in that it contains cyanite, garnet and graphite in addition to the biotite which characterises it, does not present any evidence whatever either in its microscopic structure or in its field relations of any

(1) Dr. A. E. Barlow, Geo. Survey of Canada, An. Rep. (N.S.) Vol. X, p. 75 I.

(2) Minéralogie Micrographique. Fouqué et Michel Lévy, Paris, 1879, p. 470.

(3) Geol. Surv. of Can. An. Rep. (N.S.), Vol. X, p. 72 s

other than an eruptive origin." In this same volume of the Geological Survey reports, Mr. E. D. Ingall, in speaking of the graphite in gneisses of the Buckingham Township mines, says: "This graphitic enrichment always occurs, so far as observed, where the gneiss comes in contact with the massive igneous rocks, such as granites and gabbros. The graphite is not confined to the gneissic bands but often extends into the adjacent rock, as in the case of the "Big Pit," No. 8 of the Walker Mining Co., where it is found most abundantly in a gabbro. In the case of the veins of pure graphite the associated rocks are the same as found with the disseminated ore, namely, rusty gneiss and such igneous rocks as granites and gabbros." In the last mentioned report of the Geological Survey, as well as in several reports of Dr. Adams, (1) the association of pyrites with the graphite is often referred to. This association of carbon and sulphur is a constant one in all deposits of igneous origin, as I will have many occasions to show in this paper.

I must add here that I am aware that graphite is still regarded by some as a proof of the sedimentary origin of gneisses, but apatite was once thus regarded before its true igneous nature had been recognized; and, if I add to the above quotations, the fact that Professor Termier, in his thorough study of the eruptions of the Hartz region (2), has found as much as 3 p.c. of graphite in a gray quartz porphyry dyke cutting across Silurian and Devonian rocks, and that graphite has been repeatedly observed in meteorites, I am sure that I will at least throw doubts on the excellency of graphite as a sure criterion of sedimentation of Archæan rocks.

2nd. In the crystals of igneous gneisses and of most granites and other eruptive rocks, (3) gaseous and liquid inclusions are most abundantly found, and these are very often constituted by carbonic acid and hydrocarbons, and also often contain chloride of sodium in solution or in minute crystals.

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(1) Geo. Surv. of Can., An. Rep. (N.S.), Vol. VIII, p. 51 J.

(2) Annales des Mines, 2ième livraison de 1884, p. 307 et 308.

(3) Minéralogie Microghaphique, (Fonqué and Michel Lévy), Paris, 1879, p. 134, 140 et 141.

3rd. Petroleum, or semi-liquid or solid bitumens have often been noticed and cited by many observers as occurring in traps, basalts or other igneous rocks, as for instance, by Sir William Logan (1) in a greenstone dyke at Tar Point, Gaspé, Province of Quebec; by Mr. Rateau (2) in trachytes in Galicia, and by Professor Arthur Lakes (3) in injected volcanic dykes in Archeluta County, Colorado. Other occurrences of this kind have been recently described by Mr. Henry M. Cadell (4), in a paper on the Oil-shale Fields of the Lothians, as follows:—"In 1890, a diamond bore-hole was made near Little Ochiltree, about one mile north of Binny Craig, which, after passing through the Houston Marl, Houston coal and Fells shale, struck a thick sheet of intrusive dolerite situated near the position of the Broxburn shale. It was noticed that the whinstone core, brought up from a depth of over 600 feet, was cracked in places, and the fissures were full of a soft yellow substance like vaseline or wax which melted in the sun and spread in an oily film over the stone. . . . In the summer of 1900, an intrusive sheet of yellow trap about 3 or 4 feet thick was cut while driving through the shale at the mouth of the Albyn mine, on the eastern outcrop of the Broxburn shale anticline. The trap was full of cavities coated with calcite, filled in the heart with mineral wax, yellowish gray when fresh, and brown after exposure to the air. On analysing the hydrocarbon it was found by Mr. Steuart to consist of:—

Carbon, 84.35; Hydrogen, 12.83; Nitrogen, 1.68; with traces of sulphur in some specimens." The above composition is very close to the one of the ozocerite of Boryslaw, Galicia, which is about 85.7 p.c. carbon, and 14.3 p.c. hydrogen. I will yet quote another instance given by Mr. Cadell in the same paper(5):—In referring to a volcanic neck or pipe which was cut through in the underground Broxburn shale working, at Gallowscrook, near Philpstoun, he says: "The tuff itself varied greatly in character and structure. It was mostly fine grained and light colored, and

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(1) Geology of Canada, 1863, p. 402 and 789.

(2) Annales des Mines, 8ième série t. XI, pp. 150, 152.

(3) Mineral Resources of the U. S., 1901, p. 561.

(4) Trans. of the Institution of Min. Eng., Vol. XXII, pt. 3, pp. 347-353.

(5) Loc. Cit., p. 351.

was in place excessively hard, almost flinty in texture, but when exposed to the weather it soon crumbled down into sandy mud. Here and there it was impregnated with iron pyrites and contained large blocks of black shales and other sedimentary inclusions; or, again, it was interspersed with small drusy cavities or veins of pitch or solid paraffin." Describing the beds on the shore of the River Forth, below Hopetoun House, Mr. Cadell says:—(1) "These underlying beds are traversed by a dyke of white or yellowish trap with cavities full of bitumen, such as have been noted in the Broxburn district."

Mr. Cadell, I might add, advances the opinion that in the above cited instances of pitch or solid paraffin in igneous rocks, they "are derived no doubt from the distillation of the hydrocarbons in the shale;" but this, I submit, is an impossibility, and, even more, a direct contradiction, as it cannot be imagined that a hot igneous rock, which would distill or drive away the hydrocarbon from a shale, would drive it away into numerous cavities of itself. Then again, if this distillation had taken place, in the case above cited of the volcanic neck, the bitumen of the black shale fragments in the neck would also be driven away. Therefore, the instances cited by Mr. Cadell cannot be regarded otherwise than as most direct evidences that the origin of the oil of the shales is most intimately connected with the very volcanic rocks in the cavities of which solid remnants of the oil are still left as witnesses. One, indeed, has only to look at the numerous red spots on Mr. Cadell's map, accompanying his paper, and representing the volcanic rocks and intrusive basalts evidently younger than the oil-shale series, to, at once, understand that this oil district, in which the oil-shale quarrying is going on to-day, was, subsequently to the deposition of the shales, subjected to intense vulcanism. During and after this great period of volcanic activity, the whole district must have been for a long time permeated by solfataric emanations coming up through the numerous faults, also shown on the map, and many other minor fissures. No doubt these emanations were composed, as we will see all volcanic emanations are, of chloride, including ammonium chloride, hydrocarbons and sulphuretted hydrogen vapours and gases, and this is clearly how these shales got im-

(1) Loc. Cit., p. 359.

pregnated with the oil now found in them, and also how the Binny sandstone of that district got its joints and cavities filled with ozocerite or natural pitch. The Balm Well Spring, of St. Catherines, near Burdiehouse in that district, situated on the line of the great Pentland fault, and in the waters of which globules of oil are yet found, the natural gas struck in some of the bore-holes near Broxburn and the Bullion Well Spring of sulphuretted hydrogen water rising from a fissure between a volcanic plug and the sedimentary beds are other evidences of this solfataric volcanic action in this district. (1)

4th. Volcanic rocks forming vertical necks and pipes across horizontal strata and containing carbon in the pure form of diamonds are also well known to constitute in South Africa the deposits of these precious stones. These diamantiferous volcanic necks and pipes also contain large cavities filled with gaseous hydrocarbon, as pointed out by Mr. Moulle.(2) Mr. Moulle cites 17 of these volcanic necks situated all in one straight zone 200 miles long from the Hart River to Fauresmith. He also shows that both the diamond and the gaseous hydrocarbon are found in these necks right in the center as well as on the sides, and under the "reef" or black shales as well as above them, or as well as at the places where the vertical volcanic pipes cross these horizontal black shales, which, here also, are not only not distilled but enriched, on the contrary, in bituminous matter by the hydrocarbon emanations, gaseous remnants of which are yet found in the workings, in cavities of the volcanic neck.

5th. I now come to the hydrocarbons and carbonic acid in volcanic manifestations of to-day. Not later than a few months ago the civilized world was suddenly startled and horrified at the report that an explosion of Mount Pelée had wiped away in a few minutes the entire population of the City of St. Pierre, Martinique Island. From the accounts of the catastrophe then published, it is quite certain that a fearful blast or tornado of gases suddenly shot from the side of the volcano, asphyxiating and burning in a moment 30,000 people. Nothing else, I submit, but gas would

(1) Trans. of the Institution of Min. Eng., Vol. XXII., pt. 3, pp. 350 and 351.

(2) Annales des Mines, 2ième livraison de 1885, pp. 237 et seq

carry death so suddenly to so many thousand people, inside and outside of their houses, over a whole city. That these gases were mostly sulphur gases and very inflammable gases (which could be mainly nothing else but hydrocarbons) has also been made quite clear by the accounts of the very few survivors. From among these I will quote the following extracts from the narrative of Count de Fitz James in the New York Herald of May the 27th, 1902, namely:—"Gustave Doré, in his most estatic delirium, never conceived anything so dramatic and so awe inspiring as was St. Pierre after it had been desolated by the whirlwind of fire that swept down upon it from Mount Pelée. . . . From a boat in the roadstead in front of St. Pierre, Baron Fontenilliat and I witnessed the cataclysm that came upon the city. We saw the shipping destroyed by a breath of fire. We saw the cable ship Grappler keel over under the whirlwind and sink as though drawn down into the water of the harbour by some force from below. The Roraima was overcome and burned at anchor. The Roddam, a trifle more fortunate, was able to escape like a stricken moth that crawls from the flame that has burned its wings and left it a cripple to suffer until death relieves. . . . While we were talking, there came an explosion that was beyond anything that ever before happened. I can only liken it to a shot from a mammoth cannon. The breath of fire swept down on the city and water front with all the force that could have been given to it by such a cannon. The explosion was without warning and the effect instantaneous. Cinders were shot in our faces with stinging effect. The air was filled with flames, involuntarily we raised our hands to protect our faces. I noticed the same gesture when I saw the bodies of the victims on shore. The Roraima was all a mass of flames for several seconds. We could see the poor wretches aboard of her rushing about in the vain attempt to escape from the fire that enveloped them. . . . On shore all was aflame. . . When we gave our attention to the panorama that was spread before us, the entire city of St. Pierre was mantled by a dense black cloud. We could not penetrate it, but it lifted a few seconds revealing below it a second cloud absolutely distinct from it. The second cloud was yellow, apparently made up of sulphurous gases. . . Then, as the yellow cloud lifted from the earth, we saw the flames devouring the city from which all life had disappeared, dissipated by the magic worked by Mount Pelée. Part of Carbet had been struck by the wave of fire from the volcano, but the greater portion of the village was left uninjured."

To confirm this narrative I will ask your permission to quote the following attributed in a despatch of May 26th, 1902, from Port de France, to Mr. Robert T. Hill, of the United States Geological Survey, who was then studying the volcanic phenomena at Martinique, for the National Geographical Society. In speaking of the great catastrophe in Martinique, Mr. Hill, in his despatch is quoted as saying:—"There were three well marked zones; 1st, a centre of annihilation in which all life, vegetable and animal, was utterly destroyed. The greater northern part of St. Pierre was in this zone; 2nd, a zone of singeing, blistering flame which was also fatal to all life, killing all men and animals, burning the leaves on the trees, and scorching but not utterly destroying the trees themselves; 3rd, a large outer destructive zone of ashes, wherein some vegetation was injured. The focus of annihilation was the new crater midway between the sea and the peak of Mount Pelée, where now exists a new area of active vulcanism with hundreds of fumaroles or miniature volcanoes." From the above quotations and from other accounts published in the press at the time, we feel quite justified in citing this terrific outburst of Mount Pelée as a wonderful example of the production of large quantities of inflammable gases from a volcano.

We mentioned above that these inflammable gases must have been mainly hydrocarbons (probably mixed with hydrogen and sulphuretted hydrogen), and we draw the above inference from the fact that inflammable or combustible gases thus constituted have often been noticed and observed before in connection with many other volcanic eruptions by scientists of great repute, who were actually able to collect and analyse these gases. For instance, in the Vesuvian eruption in 1855 and 1856, it was observed by Charles Sainte Claire Deville and Leblanc (1), that the lava as it cooled and hardened gave out successively vapors of hydro-chloric acid, chlorides and sulphurous acid, then steam, and finally, carbon dioxide and combustible gases.

(1) A Geikie, Geology, p. 200.

At Torre del Greco, on the sea shore opposite Vesuvius, during the eruption of this volcano of 1861, Mr. Charles Sainte Claire Deville and Mr. Fouqué (1) gathered and studied the gases from the eruptive lava which was then partly flowing under the sea. The combustible gases from it were collected under water before they could oxidize with the following results, namely:—

	From Fissures of the Lava on Land.		From Fissures of the Lava Under the Sea.			
			10 to 15 metres from land	40 to 50 metres from land	About 100 metres from land	About 200 metres from land
	Dec. 23.	Jan. 1.	Jan. 1.	Dec. 18.	Jan. 1.	Jan. 1.
Carbonic acid	96.32	95 95	88.60	59 53	46.78	11.54
Hydrogen and Proto-Carbon	3.68	4.05	11.40	40.47	53.22	88.46

As to the above mixture of hydrogen and proto-carbon, Deville and Fouqué found that the further away the sample was taken from the centre of eruption the less hydrogen and the more hydrocarbon there was in it. They also observed that the hydrocarbon gases grew more abundant and marked, especially the end of the paroxysm of the volcano, for while these gaseous emanations of hydrocarbons were still continuing four years later they had then no more free hydrogen (2). Other gases gathered January 1st., 1862, by Deville, near Santa Maria di Pugliano from an old fissure formed during the 1631 eruption of Vesuvius and at the exact place where he had observed a "mofette" to declare itself during the eruption of 1855, gave him a considerable quantity of nitrogen mixed with carbonic acid, in the following proportions: Carbonic acid, 54.70; nitrogen, 45.30.

In 1865 Mr. Fouqué (3) during the eruption of Etna, in Sicily, of that year, made similar observations as to the carbonic

(1) Comptes Rendus, t. LXIV, p. 107.

(2) Comptes Rendus, t. LXII, p. 1374.

(3) Mémoire sur les phénomènes chimiques de l'Eruption de l'Etna en 1865.

acid and hydrocarbon emanations from the volcano. An analysis of some of the gases taken by him from Lake Palici, at the foot of that mountain, gave him:—

Carbonic Acid, 93.49; Marsh gas, 1.45; Hydrogen, 0.43; Oxygen, 0.68; Nitrogen, 5.11.

It is also by emanations of hydrocarbons and carbonic acid, at a temperature varying between 41° Far. and 91° Far., which were accompanied by salt water and mud and lasted for nine months, that the eruption of the 9th May, 1879, was announced. During all this time neither the principal crater nor the secondary one were giving the least sign of activity, but nevertheless, the hydrocarbon vapours were coming out at the southern base of the large cone, that is to say, very far from the central chimney, between Nicolosi and Paterno, and from small craters one foot and a half to three feet in diameter, and arranged along a north and south fissure(1).

At Santorin, in the Greek Archipelago, in the series of eruptions which lasted from Jan., 1866, to Oct., 1870, Mr. Fouqué(2) repeatedly observed and gathered under the water gaseous mixtures proceeding from the lava of the volcano very rich in combustible gases and containing sometimes as much as 30 p.c. of free hydrogen, this last gas was all the more abundant when the lava was hottest. Free oxygen was sometimes mixed uncombined with the hydrogen. Sulphuretted hydrogen gas with the protocarburet of hydrogen were also obtained together, and these combustible gases, coming out between incandescent blocks of lava, would burn with blue and red flames. In 1875, five years after the end of the four years of the above mentioned eruptions, emanations of gas and vapours were still active on the southern part of Nea, one of the little islands of the Santorin group(3).

From observations made in May, 1878, at Vesuvius, Herr Siemens has been led to conclude that vast quantities of hydrogen gas or combustible compounds of hydrogen exist in the earth's interior(4), and no doubt this conclusion would have been more

(1) A. De Lapparent—Traité de Géologie, Paris, 1883, p. 414.

(2) Santorin et ses éruptions, Paris, 1879.

(3) A. De. Lapparent, Géologie, p. 430.

(4) A. Geikie, Geology, p. 53.

often reached by other observers were it not that the very inflammability of these hot gases as soon as they come in contact with the air precludes their being easily recognized. Nevertheless the presence of hydrocarbon gases in volcanic emanations on account of their petroleum odour was conjectured by DeBuch, Ferrara, Poulette, Scrope and Hoffmann; and, according to Serrao, Dolomieu and Ferrara, blocks of scoriæ freshly ejected by Vesuvius showed distinct traces of naphtha. The existence of these combustible gases in the fumaroles explains the volcanic flames which have been seen by La Condamine, Humboldt, Boussingault, Bory de St. Vincent, Soufflot, Verdet, Deville, Fouqué, Janssen and others; they are due to the combustion of hydrogen, sulphuretted hydrogen and carburetted hydrogen(1).

Before leaving this subject of the combustible gaseous products of the volcanoes, I desire to draw particularly your attention to the associated vapours and gases emanated by them from and with the interior fused lavas, namely, what has been called the "dry fumaroles" always emanate from the lava itself near the centre of the lava flow, the temperature is above 500° C., and they are almost entirely composed of anhydrous chlorides, principally chloride of sodium, of which as much as 94.3 p.c. has been found in the gases from Vesuvius. Other "fumaroles" called "acid fumaroles" have a temperature varying between 300° C. and 400° C., and are a mixture of hydro-chloric acid and sulphurous acid with enormous quantities of steam. Finally, the "cold fumaroles," the temperature of which is under 100° C., contain with the steam and hot water about 5 p.c. of carbonic acid and considerable hydrogen sulphide, which, in decomposing, forms deposits of sulphur(2).

I will further draw your attention to the phenomena observed in the volcanic districts where the volcanoes themselves have been dormant either for a short period or for many years, or where they may be considered extinct altogether. In this region of dormant or extinct volcanoes the interior energy still manifests itself through gaseous, steam and hot water emanations exactly similar to those we reviewed briefly above. This is the well known

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(1) A. De Lapparent, Géologie, p. 413.
(2) A. De Lapparent, Traité de Géologie, p. 411.

and most important solfataric phase of vulcanism which may be only momentary, as the active volcanic force may burst out suddenly in a new paroxysm, or it may continue with gradually diminishing force to finally die out altogether, but not without leaving first profound and distinct marks and impress of its former existence. In this last case the gases, vapours and water emanations will often continue to be emitted, not only for many years but for many centuries, from the volcanic vent itself or from its vicinity, first as steam and sulphurous vapours, or as hot and boiling springs, and then as emanations at a much lower temperature, charged principally with hydrogen sulphide and carbon gases. The two first are the "solfataras" and "geysers," while the last category constitutes the continuous series of the "suffionis," the volcanic hot springs, the "salses" and the "mofettes." Each one of these forms of the dying volcanic activity differs somewhat from the preceding one, but they are nevertheless so intimately connected one to another, and so intimately connected often with the active phases of vulcanicity, that the internal origin of their products is as clearly evident as in the case cited above, where the gases were found to form intimate mixtures with the fused lavas themselves from which they were collected and analysed.

It is not necessary to refer at greater length to the "solfataras" and "geysers," but I must say a few words on the "suffionis," "salses" and "mofettes." In the "suffionis" of Toscany, the steam jets, 30 to 40 feet high, are arranged in groups along fissures, and the condensed waters containing boric acid form deposits of sulphur and gypsum. Carbon dioxide is in preponderance in the gaseous emanations of these "suffionis," with sulphuretted hydrogen in notable quantity: hydrocarbon gases mixed with free hydrogen are also present, as recognized by Charles Sainte Claire Deville (1). The "salses" are numerous in the Appenine region of Italy where several have from time to time showed renewed signs of activity (2), such as the "salse" of Sassuno which had a paroxysm in 1839, uplifting the rocks around its mouth; its gaseous mixture includes with the proto-carbon a carburet of

(1) A. De Lapparent, Géologie, p. 490.

(2) Fouqué, Revue des deux mondes, 1er Avril, 1871.

hydrogen richer in carbon; in 1839 black bitumen was emitted. The "salse" of Sassuolo(1) in that same region has had a number of paroxysms already mentioned by Plinus and renewed again in 1660, 1789 and 1835. A very large quantity (ten million cubic meters) of mud and stone were ejected at this last period and was soon covered with efflorescences of salt. Not far from Sassuolo, at Mount Zibio, petroleum springs have been known from all ages.

In Auvergne, in the centre of France, at the foot of the volcanic chain of the "Puys," a spring of bitumen comes out of the "Puy de la Poix," and if one remembers that there are very abundant emanations of carbon dioxide in that extinct volcanic region, at Clermont and Royat, for instance, and that the volcanoes there rest entirely on the granite, the proof is conclusive that the carbonic acid gases and liquid hydrocarbons marking the last sign of the volcanic energy in that region, are of deep, internal origin.

At both extremities of the Caucasus Mountains, at Taman and Kertch, between the Black Sea and the Sea of Azof, and at Bakou on the Caspian Sea, powerful mud volcanoes have been known for centuries, and they are often associated with large quantities of natural gas and petroleum. The Apcheron peninsula near Bakou is of volcanic origin, as eruptions of lavas and projections of stone yet take place from time to time; the height of the mud volcanoes there is very great, some being as high as 1,300 feet. Rivers of oil have been known to boil out from under the Caspian Sea, and explosions of burning oil have taken place naturally, throwing up in the air masses of clay and stones. These explosions have uplifted the bottom of the sea, and have lately given rise to small islands in the vicinity of Bakou(2).

The "mofettes," or carbonic acid emanations, with or without water, are so well known in so many dormant or extinct volcanic districts, such as those near Naples at the "Grotto of the Dog" and at other points in the vicinity; those in the Eifel region, where more than a thousand have been counted; those of Auvergne and the Vivarais in France; those of the valley of Death in Java, etc.,

(1) A. De Lapparent, Géologie, p. 490.

(2) A. De Lapparent, Traité de Géologie, Paris, 1883, p. 490.

that this mere mention is sufficient here, but I wish to point out that there can be but little doubt, from the table of analysis made on the gases collected from the lava on land and under the sea, at Torre del Greco near Vesuvius, by Deville and Fronqué, and given above, that these "mofettes" or carbonic acid emanations are the result of the oxidization of hydrocarbon gases from the interior fluid magma.

To resume this very imperfect review of the volcanic gaseous emanations, I will ask your permission to make another short quotation from Professor A. De Lapparent, he says:—"Volcanic phenomena, from the violent paroxysm to the simple "mofettes," form a continuous and admirably ordained series agreeing in all points with the succession of emanations during a single eruption. Through a few local variations it is always the same law of decreasing energy which from the hot chloride emanations leads through sulphurous ones to the carbonic acid ones with predominance of the combustible gases at the places where there has been no oxidization."

(B.) I now pass to my second paragraph in which I propose to show that all the petroleum, natural gas and bituminous fields or deposits cannot be regarded as anything else but the products of solfataric volcanic emanations condensed and held in their passage upward, in the porous tanks of all ages of the crust of the earth from the Archæan rocks to the Quaternary, or in veins, fissures and seams in the case of solid bitumens. Nothing is so simple and therefore nothing so natural as this origin. It can be abundantly proven, and I will divide the data and proofs I propose to adduce for this under the following heads:—

1st. Direct proofs and rock pressure of natural gas.

2nd. Complete analogy of the products of the oil and gas fields with the products of volcanic solfataric action.

3rd. Location of the oil and natural gas fields along faulted and fissured zones, each one presenting a few particularities of its own, similarly to the systems of volcanoes and to the mountain chains of the globe.

4th. The oil, natural gas and bitumens are never indigenous to the strata or formations in which they are found; their "sands" or other deposits are nothing more than natural rock tanks ranging in geology from the Archæan to the Quaternary, and these extraneous products must therefore come from below the Archæan.

5th. Oil, gas and bitumens are stored products, in great abundance in certain localities, while neighbouring localities often are entirely barren, exactly as volcanic products would be, and the strata among which they are found are so impervious that it forces one to the conclusion of a source, with powerful energy, directly below their fields.

1st. To the direct proofs given above of solid, liquid and gaseous hydrocarbons in lavas or other igneous rocks, or in emanations clearly volcanic, can be added direct proofs of vulcanicity from a few of the oil and gas fields, and these will serve as a link as it were between the volcanoes, on the one hand, and the oil and gas fields where the volcanic origin is not so plainly apparent, on the other.

I have already mentioned above, on the high authority of Professor A. De Lapparent, the direct volcanic manifestations in the great Russian oil fields near Bakou, from which it is quite evident that the source of the oil there is volcanic. Hot waters and hot gases in connection with some of the other oil deposits of the Caucasus Mountains have also been mentioned by Mr. Leproux (1).

But, on this continent, in the newly discovered oil fields of Texas and Louisiana, and also in the California fields, we have many no less direct evidences of vulcanism, though they do not appear to have been understood in their true light. These are, in Louisiana and Texas, the Salt Islands and the "Mounds" of the Coast Prairie, such as the famous "Spindletop," near Beaumont, which are clearly nothing else but "suffionis" or "salses," hardly extinct yet, grouped along fractured lines (2) and marking in that region the dying out of vulcanicity, that is to say, the dying

(1) Annales des Mines, 11ième livraison de 1892, pp. 526, 528.
(2) Am. Inst. Min. Eng., Trans. XXIX, Capt. Lucas, p. 463.

distant echo of that tremendous volcanic energy which, a little further south, in Mexico, Central America and in the islands and along the south coast of the Caribbean Sea, is to this day so powerfully active.

In this connection, Mr. Robert T. Hill, in his paper above quoted(1), points to a very significant fact, though in our opinion it has a different meaning to the one he gives to it, when he says:—"It is an interesting fact that asphalts and oils rich in asphaltum occur in terrigenous (land derived) sediments of the nature, age, and general character of the East Texas Eocene, around the entire perimeter of the Gulf of Mexico and the Caribbean Sea. The asphalts of Tamaulipas, in Mexico, Vera Cruz, the Isthmus of Panama and Cuba, as well as the great asphalt deposits of Trinidad, Barbadoes and Venezuela, all come from beds of this character."

I claim that there is much more indicated by the occurrence of these asphaltum oils along the weak, faulted and broken volcanic margins of the Gulf and Caribbean Sea, and that the terrigenous sediments, not only Eocene but of many other ages, are simply the sandy tanks which happened to be there and which their sandy nature, due to their terrigenous origin, made porous enough to be able to hold the gaseous, liquid and solid products of the abundant, but spotted, volcanic emanations of that region, including not only natural gas and liquid asphalt oils, but also much hydrogen sulphuret gas and large deposits of these eminently volcanic products, sulphur and salt. Abundant proofs of the above statement are to be found in Professor Robert T. Hill's paper, already twice quoted, and to me these proofs are so conclusive that you will pardon me if I again quote copiously:—

"In the generally monotonous monoclinal structure (of the Coast Prairie of the Gulf) there are a few wrinkles or small swells likely to escape the eye of even the trained observer, and yet of a character which may have an important bearing on the oil problem. These are the circular and oval mounds, already described, which were first recognized by Capt. Lucas. When he pointed out Spindletop Hill to me, my eyes could hardly detect it; for it

(1) Am. Inst. Min. Eng., N.Y. & Phila. meeting, Feb. and May, 1902, p. 38. Trans. Vol. XXXIII, pp. 363-405.

rises by a gradual slope only ten feet above the surrounding prairie plains. I was still more incredulous when he insisted that this mound, only 200 acres in extent, was an uplifted dome. But Capt. Lucas said that I would be convinced of the uplift if I could see Damon's mound in Brazoria County. In August, 1901, I visited that place, and returned for a second look at Spindletop, and was convinced that, if these hills are not recent quaquaversal uplifts no other known hypothesis will explain them. Damon's mound is an elliptical hill, a mile or more in greater diameter, rising 90 feet above the surrounding level. . . . The salt islands of Louisiana were described by Capt. Lucas in the transactions of the American Institute of Mining Engineers before his discovery of oil at Beaumont (1). These so-called islands, rising from 80 to 250 feet above the surrounding marshes of the Coast Prairie, are hills beneath layers of stratified clay and sand. They belong to the same group of topographic phenomena as Spindletop hill at Beaumont. By sinking through the superstructure of sand and clay Capt. Lucas located the salt bodies, and determined their horizontal extent, developing also the important fact that, though limited in diameter, they were of great depth, that of Jefferson Island having been penetrated for 2,100 feet without reaching bottom. . . . The bodies of salt discovered beneath the hills of the Coast Prairie are of remarkable size, thickness and purity, notably those of Louisiana, and one discovered within the past few months at Damon's mound which, for its lower 700 feet, is pure rock salt with occasional traces of oil. . . . It was Capt. Lucas who discovered the relation between the sulpuretted hydrogen fumaroles, gas springs, and sulphur incrustations at the surface and the bodies of subterranean oil; and it was his belief in this association that led him to seek for oil on Spindletop hill(2). . . . The oil is closely associated with the mounds, occurring on their slopes or summits. . . . In some localities hot water has been struck below the oil. . . . In the original Lucas well, the oil itself is hot. . . . It had a temperature of over 110° F. The oil seems to occur not in any definite continu-

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(1) Transactions Am. Inst. Min. Eng. XXIX, pp. 462, et seq.

(2) The same relation was shown by me in my paper before this Institute 3 years ago. [Journal, Vol. III, pp. 87 and 88.]

ous stratum but in spots of many strata. Gas in immense quantities and frequently under such pressure as to wreck the wells, has been struck before reaching the oil. This has occurred several times at Spindletop, twice at Sour Lake, and once at Velasco, where the destructive effect was terrific. Sulphur and sulphuretted hydrogen gas occur in intimate association with the Beaumont oil. In fact, the oil itself is said to contain 1 to 2 per cent. of sulphur, and the fumes of sulphuretted hydrogen are strong in the vicinity of the wells . . . Underground bodies of sulphur associated with the oil by natural processes have been found in many localities. The Calcasieu section of Hilgard shows at 540 feet in depth solid sulphur rock similar to that encountered at 1,010 in the Beaumont well. At Damon's mound a bed of sulphur from 10 to 40 feet thick was encountered above the salt. Crystals of free sulphur also occur in the cap rock overlaying the Spindletop oil. Capt. Lucas found the sub-strata of the south-eastern part of Belle Isle, above and down to the rock salt, were heavily impregnated with petroleum. Several calcareous strata containing sulphur were also encountered. . . . The wells at Damon's mound encountered small flows of oil at depths of from 400 to 600 feet. . . . At Keyser's mound, in the same county, about six miles north of Damon's and near the Brazos River, a flow of oil was struck at about 400 feet. . . . Still another interesting phenomenon is the occurrence of dolomite. The oil of Spindletop is said to occur in a cavernous mass of this material. At Big Hill, Jefferson County, which is one of the most conspicuous of the mounds, the drill after going down 300 feet penetrated a mass of coarsely crystalline dolomite, in which it continued to nearly 1,375 feet. At 900 feet a small seep of oil was struck in the dolomites."

Nothing could be more suggestive than the above quotations when one remembers the volcanic phenomena which I reviewed in the first part of this paper. Mr. Robert T. Hill calls the association of oil, sulphur, sulphuretted hydrogen gas, gypsum, dolomite and salt, in the so-called mounds or islands of this region, "the oil phenomena," but it hardly needs this new name, as, by Mr. Hill's own description of it, it is clearly a well known part of the old volcanic phenomena, so clearly that Mr. Hill himself unconsciously uses the word "fumarole" in describing it.

In his last report on petroleum in the Mineral Resources of the United States (1), Mr. F. H. Oliphant confirms the true nature of these mounds, as here indicated, in this significant remark: "The depth of the wells to the productive bed vary from 880 feet, about the centre of the elevation at "Spindletop," to 1,190 feet near the edge of the productive area, indicating that the stratum holding the petroleum is in a general way conical, which condition seems to be verified by the deep wells, less than 500 feet from defined territory, failing to find any trace of the open cellular carbonate of lime and pure sulphur structure encountered on the mounds, at depths of over 2,000 to 2,500 feet. The thickness of the oil-bearing formation is placed by different drillers at from 20 to 75 feet. It is almost pure carbonate of lime with more or less combined sulphur as well as surrounding crystals of pure sulphur.

To the volcanic solfataric phase of phenomena these mounds, or rather as we see, real vertical chimneys, must surely belong. How else could be explained their hot oil, their hot water, and especially their vertical chimney-like masses of sulphur, salt, limestone and dolomite permeated and impregnated with natural gas, oil, and hydrogen sulphuret gas? Is it not also a well known fact, as we have seen in the first part of this paper, that all these products associated together are the essential characteristics of the solfataric phase of vulcanism?

Mr. Hill has attempted to explain his so-called "oil phenomena" by the following hypothesis, "offered with hesitation," as he says himself: "The oil and salt pockets of the Texas Coastal Plain are probably not indigenous to the strata in which they are found, but are the resultant products of columns of hot saline waters which have ascended, under hydrostatic pressure, at points along lines of structural weakness, through thousands of feet of shale, sand and marine littoral sediments of the Coastal Plain section, through which oil and salt are disseminated in more or less minute quantities. The oil, with sulphur, may have been floated upward on these waters, and the salt and dolomite may have been crystalized from the saturated solution."

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(1) United States Geol. Surv., Mineral Resources of the U.S., 1901, p. 568.

The main point of that hypothesis, namely the hydrostatic pressure, is, I submit, absolutely disapproved by the simple fact that the "Spindletop" wells are now already pumping wells instead of gushing flowing wells as they were when first struck; an hydrostatic pressure behind them would be constant, and would continue to make them flow now as at first, especially if it was "a tremendous hydrostatic pressure" as Mr. Hill says it must be.

This simple evidence then is conclusive that the saline waters, oil and gases under these mounds are not under an hydrostatic pressure.

I beg to submit also that carbonated and oxidized meteoric cold waters descending and permeating through the sediments of the Coastal Plain would condense and fix oil and sulphur in these strata from hydrocarbon vapours and sulphuretted hydrogen gases diffusing through them from beneath, but would certainly not do the reverse, namely, gather and float these upward as proved by the barrenness in oil and sulphur of the artesian springs mentioned by Mr. Hill to the westward. The fact that, at Marlin, the water, from 3,200 feet only, has a temperature of nearly 140° F. and is excessively saline and sulphurous is to me only another proof of the expiring vulcanism of that region, and of the admixture of hot emanations from below into the descending water at that place, as the normal rise in the isogeotherms alone could never account for that temperature in circulating descending water(1). That water cannot diffuse through sedimentary strata carrying mixed with it and gathering small quantities of petroleum, as also suggested lately by Geo. I. Adams(2), is fully indicated, as remarked by Dr. David T. Day, in his discussion of Mr. Adam's paper, by the fact that "the diffusion of crude petroleum through fuller's earth and shales is accompanied by a partial separation of the constituent oils." "*A fortiori*," would oil and water promptly separate in diffusing through sediments,

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(1) In this connection see Prof. Kemp in Trans., Am. Inst., Min. Eng., vol. XXXI, p. 19[7] et seq.

(2) Principles controlling the geologic deposition of the hydrocarbons, N.Y. and Phila. meeting of the Am. Inst., Min. Eng., 1902, and discussion.

especially if the water was meteoric and oxidized, when the oxygen and the low temperature of these waters would surely, as shown in many springs, condense and fix oils from gaseous hydrocarbons and also sulphur from sulphuretted hydrogen gas.

Then again, where does the oil, salt and sulphur come from, which according to Mr. Hill's theory a.. disseminated in abundance in the sediments from the Ordovician to the Post Eocene of the Texas section, and which, under his hypothesis, are now carried by these artesian waters and become the source of these products of the mounds? It is evident that the question of origin is not solved by Mr. Hill's hypothesis, and that it is only put back and shirked as it were. Why should that be done when the fact of a volcanic solfataric origin, as developed by the phenomena of these mounds, is so glaring? If these glaring facts are not seen and recognized, then "*a fortiori*," it will be impossible to know from where the oil, more or less disseminated through the whole Texas section, comes from; and, it is no wonder that the claim is made that science has not yet solved the problem of the origin of oil.

If we now transport ourselves from Texas to the Island of Trinidad, at the other end of the circle of oil and asphalt deposits, which, as it has been remarked, border the Gulf of Mexico and the Caribbean Sea, what do we find there? According to Clifford Richardson(1) and to Edward W. Parker(2), of the United States Geological Survey, "the chief source of the supply (of asphaltum) is a lake of pitch filling the crater of an extinct volcano. This lake lies 138 feet above the sea level, and has an area of 114 acres. The supply is being partially renewed by a constant flow of soft pitch into the centre of the lake from a subterranean source." The solfataric volcanic emanations at Trinidad are also abundantly attested by the many mineral springs on that Island, by the strong thermal waters with borates, iodides and sulphur compounds intimately mixed as an emulsion with the bitumen of the pitch lake, by the gas issuing from the cracks in the bitumen,

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(1) On the Nature and Origin of Asphalt. Long Island City, N.Y., October, 1898.

(2) U.S. Geol. Surv., 21st An. Rep., part VI, p. 327.

and by the indurated clays, burnt red shales and porcelanites to the southward of the lake(1).

Similarly, in California. through all the extensive oil fields of that country situated along the coast Range which has been only recently uplifted, the solfataric volcanic phenomena are most abundant to this day in connection with the oil deposits which are found in very disturbed and dislocated strata of the Cretaceous, Tertiary and Quaternary. Here, the shales, interstratified with the bituminous and oil sands, have become reddened and burnt or bleached to white shales, and changed to porcelanites by the solfataric vapors, and they have also been greatly calcified and salicified by the hot calcareous and silicious waters. Hot natural gas and hot sulphuretted hydrogen emanations, as well as hot and boiling waters, issue yet from the hot ground in a number of places as at the Calera Rancho, six miles west of Santa Barbara, where, on the ocean shore, an area of twenty acres has lately subsided some 25 feet, and from the hot ground of which heavy petroleum oil oozes out with sulphurous and other vapors and hot saline waters. Mr. A. S. Cooper(2), State Mineralogist of California, in a paper on "the Genesis of petroleum and asphaltum," devotes a great deal of space to these red burnt and white bleached shales as connected with the genesis of bitumen in California, but he attributes the evidences of heat and heated vapors and steam everywhere shown by them to chemical heat engendered in the shales themselves in some mysterious way, or generated in some even more mysterious way in the metamorphic rocks below the Cretaceous.

This "chemical heat," according to Mr. Cooper, distils the carbonaceous vegetable matter in the rocks and the resultant gas, oil and asphalt migrate upward into the Cretaceous, Tertiary and Quaternary rocks to fill there the gas and oil sands and to form the asphalt veins.

But why this "chemical heat" should have been so accommodating as to have waited until the Tertiary and Quaternary formations were deposited before metamorphosing and distilling the

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(1) California Mines and Minerals. San Francisco, 1889, p. 143-144.

(2) The Genesis of Petroleum and Asphaltum, by A. S. Cooper, California Mines and Minerals, p. 114, et seq.

lower formations is not clearly explained. Nor does Mr. Cooper show us any coke beds as residue of that distillation, nor does he give any reason why this "chemical heat" has not also distilled into gas, oil, asphaltum and coke the coal beds and lignites of the Cretaceous and Tertiary. Until these facts are more clearly explained and the mysterious cause of the "chemical heat is also established, I will persist in seeing in the prolific "oil phenomena" of California, accompanied by so many evidences of the so called "chemical heat," direct proofs of the intervention of the solfataric phase of vulcanism, which phenomena are, and were, evidently connected here with the orogenic uplifts of the Coast Range.

There remains now one more direct proof of vulcanicity in the oil and gas fields to which I desire to especially draw your attention. This proof is general and present in all the oil and gas fields, and therefore of primary importance in a consideration of the origin of oil and gas; I refer to what has been called the rock pressure of natural gas. This great force, which often has thrown out of a well high above the derrick an entire string of tools weighing thousands of pounds an which often gushes the oil and the pebbles of the oil sands with terrific force hundreds of feet high in the air cannot be explained in any other way than as a remnant or spark of the initial volcanic energy, the stupendous force of which in volcanoes has so often caused most tremendous explosions, appalling in their magnitude and effects, blowing out enormous craters and sometimes whirling out without warning, as from the mouth of a mammoth cannon, a destructive tornado of inflammable and irrespirable gases over a whole city, as in the recent memorable instance of St. Pierre, Martinique. In some of the oil and gas wells this pressure of the gas has registered as high as 1525 lbs. to the square inch, or over 100 tons to the square foot, but it is generally considerably less and ranges ordinarily between 200 lbs. and 1000 lbs. in fresh fields when first struck, at depths of from 500 to 3,000 feet. It varies greatly in the different fields from wells of the same absolute depth, even though the two fields are not far distant, as for instance in the case cited by the late Professor Edward Orton(1) where a well in Oswego County, New York, only gave a pressure

(1) Bull. Geol. Soc. of Am., vol. 9, p. 92-95.

of 340 lbs. to the square inch from a depth of 2,100 feet, at which the gas was struck in the Potsdam sandstone, while another well in Onondaga County, N.Y., the "Munroe" well, where the gas was struck in the Trenton limestone at 2,370 feet, gave a pressure of 1,525 lbs. to the square inch. But, and this is a very significant fact, which indicates plainly the internal origin from below, in the same field when gas is found in different strata, as it very often is, the strongest pressure is always in the lowest stratum, and the rate of decrease of that pressure from the lowest stratum to the upper ones is very irregular, evidently depending on the more or less open channels of communication between these strata which existed at the time of the solfataric volcanic activity under that field, channels which have now long ago been closed up as a rule. The other significant fact of the rock pressure of natural gas is that it is a continually decreasing pressure from the time the gas is first used in a new field until finally it is all exhausted. This shows, without a doubt, that there is nothing now behind that pressure, no hydrostatic column or anything else; the gas possesses this energy, *per se*, it is its own life, and it imparts it to the water, or to the oil sharing the sands with itself to make them flow violently at first, but before long this decreasing pressure becomes powerless and the oil has to be pumped. This would not be the case if a constant hydrostatic head was behind it; therefore, this fact alone is enough to condemn absolutely Professor Orton's and Professor White's theory of hydrostatic or artesian water pressure as an explanation of the rock pressure of natural gas. I refer you to my former paper before this Institute (1) for figures, showing that the pressure of the gas in the Welland County field of Ontario is not in any way imparted by an artesian water pressure. As I also remarked in this paper the Paleozoic oil and gas rocks of North America are far from being porous enough to form permeable sheets arranged in basin form between impervious layers and with porous outcrops, and thus never fulfil all the conditions necessary to constitute artesian basins. These rocks, ranging in geology from the Potsdam all the way to the Pittsburg sandstone, just above the Pittsburg coal, have in many cases furnished oil and gas sands forming in shale series irregular

(1) Journal Can. Min. Institute, Vol. III, p. 85.

bodies, unconnected and without outcrop. In this case, how can any one seriously adduce an artesian water pressure to account for the rock pressure of the gas? But, even in the case of the Trenton limestone, which is a thick continuous stratum with long outcrops to the north, and forming a basin under Ontario, it is far from being pervious enough and therefore some of the conditions for an artesian basin are not there, as absolutely proven by a number of wells which were drilled right through the whole series down to the Archæan below, and never found any water. Even, at Collingwood, where the Trenton limestone outcrops under the town and under the Georgian Bay, a number of wells, drilled there, have found only sulphurous and saline waters in small quantities below 130 feet; and, three wells which were drilled under the Mountain, fifteen miles south of Collingwood, pierced the whole Trenton limestone, from 1,160 to 1,750 feet, without finding a drop of water in it, though the top of the Trenton in these wells, situated miles one from the other, was about 275 feet below the level of the Georgian Bay in each instance. Where is Professor Orton's artesian water column here? wanting absolutely, right where it should be on the track between Ohio and the outcrops of the Trenton. It is only fair to add here that Professor Orton himself, in his presidential address(1) read before the Geological Survey of America, Dec. 28th, 1897, abandoned as untenable his theory of artesian water pressure as the source of the natural gas rock pressure. Yet, there is surely a cause for these great pressures going up sometimes as high as 100 atmospheres, recorded by natural gas. If it is not a volcanic energy, what is it? Svante Arhenius(2), the distinguished Swedish physicist, has figured out that the crust of the earth is solid down to about twenty-five miles, and that at this depth, where the temperature must be 1200° C. and the pressure about 10,840 atmospheres, commences the fluid magna; also that, at the depth of about 186 miles, the temperature must without doubt exceed the critical temperature of all known substances, when therefore the liquid magma must pass to a gaseous magma subject to extremely

(1) Bull. Geol. Soc. of Am., vol. 9, p. 99.

(2) Zur. Physik des Vulkanismus (Geol. Fören Förh.) Stockholm, 1900.

high pressures. Here then, only twenty-five miles, at most, below the gas fields, is an adequate source for the natural gas pressures, and this is the only adequate source we can possibly find. We also know that light hydrocarbon or natural gas is emanated abundantly in all the volcanic regions from these interior masses. We therefore have there, below the crust and there alone, the source of both the natural gas and of its strong energy and life called rock pressure.

2nd. Complete analogy of the products of the oil and gas fields with the products of the volcanic solfataric action.

It is well known, and our brief review in the first paragraph of this paper shows, that the great volcanic solfataric products are water, chloride salts, sulphur, sulphuretted hydrogen, carbonic acid and hydrocarbons with often an admixture of hydrogen, oxygen and nitrogen. That all oil and gas fields in every part of the world present the above products in a remarkably constant association, though of course, occasionally a few of them may be missing, is a fact so well known that it is unnecessary for us to do more than refer to it briefly. We have already seen, that in the case of the Texas and Louisiana fields this association, mainly, of salt, sulphuretted hydrogen, sulphur, and hydrocarbons is most pronounced. So it is clearly in the Lima oil fields, including the Canadian fields, and in the California fields.

But, even in the Appalachian fields of New York, Pennsylvania and West Virginia, where the oil is free from sulphur and the gas is generally free from sulphuretted hydrogen, yet it is not always so and sulphur waters are very often found in the wells of that region almost as generally as salt waters and constantly associated with the oil and gas. The occasional presence of sulphur in the oil and gas at a few places along the Appalachian belt, especially in New York State, where it is found in lower formations, confirms Dr. David T. Day's suggestion that, if as a rule the Pennsylvania oil and the Lima oil differ in their sulphur contents and color, it is probably due to a filtering process which the Pennsylvania oil has been able to undergo in its passage upward through Devonian and Carboniferous fine-grained shales and sandstones.

The following table of analysis which was published in Professor Edward Orton's geology of Ohio, volume 6, page 137, eloquently demonstrates that every one of the products which characterizes volcanic gaseous emanations is present in the natural gas of Ohio and Indiana, except water and chlorides, and these are to be found abundantly in the salt waters always accompanying the gas and oil.

GAS.	Table of Analysis of Natural Gas from Ohio and Indiana						
	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	0.20	0.35	0.20	0.25	0.49	0.30	0.15
Carbonic oxyde	0.55	0.41	0.44	0.45	0.73	0.55	0.60
Carbonic acid	0.20	0.25	0.23	0.25	0.26	0.29	0.30
Oxygen	0.35	0.39	0.35	0.35	0.42	0.30	0.55
Nitrogen	3.82	3.41	2.98	3.03	3.02	2.80	3.42
Sulphuretted hydrogen	0.15	0.20	0.21	0.15	0.15	0.18	0.20
Localities	1.—Fostoria, Ohio. 2.—Findlay, " 3.—St. Mary's, "			4.—Muncie, Indiana. 5.—Anderson, " 6.—Kokomo, " 7.—Marion, "			

In all the European and foreign oil fields, without exception, the same association, mainly of salt, sulphur and hydrocarbons is constantly found; I will only cite one more instance of this, here; but in Russia, Sumatra, Java, Japan, China, etc., in every field, it is always the same. About the associated minerals in the oil fields of Galicia and Roumania along the Karpathe Mountains, Mr. Rateau (1) says "the characteristic accessory materials in the petroliferous strata are, besides petroleum and salt, gypsum, native sulphur, and several sulphides, namely, zinc blende, pyrites and galena. Frequently also sulphurous springs with much free sulphuretted hydrogen are struck. These strata along the Karpathe also often contain, in cavities, large quantities of the following gases:—hydrocarbons, and carbon dioxide and sometimes sulphuretted hydrogen and sulphurous acid. These gases are

(1) Annales des Mines. 8ième série, t. XI. p. 154.

under very strong pressures, going up into the ten of atmospheres."

This fact that the oil and gas fields always furnish the same associated, though diversified products, as given out in the volcanic regions, is unquestionably one of the strongest possible evidences that could be adduced to demonstrate the vulcanicity of the oil and gas.

3rd.—Location of the oil—and gas—fields, and of the solid bitumens along faulted fissured zones, similarly to the system of volcanoes, and to the mountain chains of the globe.

Few geologists are to be found to-day who do not admit, at least, a liquid sub-stratum under a solid crust for the constitution of our planet, be the centre of it gaseous, liquid or solid; and who do not also recognize the cooling and shrinking of this interior fluid mass as the grand cause of vulcanicity including not only all the direct volcanic phenomena but also all the dislocations, movements, faulting and fissuring of the crust of the earth, except possibly some local and minor displacements. The mountain chains, therefore, and the volcanoes stand out as the chief results of one profound cause in which the entire central mass of the whole sphere is in operation. It is only natural then to find the mountain chains and volcanoes of the earth in such long straight lines marking the much faulted and fractured grand circle zones of least resistance of that sphere. But, in the resulting effects, on the earth's crust, of the pressures causing these great orogenic and volcanic dislocations, we must expect to find all degrees of intensity from the immense parallel folding, fracturing and faulting, so grandly illustrated in so many of the great systems of monntain chains, to numerous zones much less dislocated and fractured, generally parallel to the neighboring mountain range or to some main offshoot of it, and in some cases possibly hundreds of miles away from it, and marking the progressively dying out efforts and effects of that particular great orogenic revolution from the mountain chain outward. These minor fissured and fractured zones may be of such slight disturbances and fracturing that this fact may hardly appear, especially when the surface is largely drift covered. Yet, the pent-up gases and vapors of the interior may during the active period or periods of these disturbances have succeeded in forcing their way up along these zones to or near the surface. Even in North America, where so much deep drilling for oil and gas has so long ago taken place, several of these disturbed and fractured zones have only been indicated in the last few years in the drilling operations connected with new discoveries of oil or gas. Such was the case in the North Western Ohio gas and oil fields as shown by the late Professor Edward Orton (1) in these words:—"Up to a recent date it was not known that the underlying rocks failed to share the monotony of the surface, but the explorations of the last two years have revealed the surprising fact that the rocky floor of the Black Swamp of old time is characterized by far greater irregularity of structure and by far greater suddenness and steepness of dip than the strata of any other portion of Ohio. The entire floor of North Western Ohio, including the Lake Counties, as far east as Lorain County, is seen to lie in a disturbed and uneasy condition. . . The Findlay break is abrupt and well marked, and is indeed the most remarkable fact in the structural geology of Northern Ohio. The occurrence of petroleum and gas, but especially of the latter, in North Western Ohio has been found to be associated with greater irregularities of structure than are known elsewhere in the State, except in a single locality. It is in Findlay that the most marked disturbance occurs, and the great supplies of gas that are found there appear to be closely connected with this disturbance."

In my paper "Natural gas in Ontario"(2) I pointed out two faults, established by the drilling, in the Essex County, Ontario, gas field, one to the North and the other to the West of the "Coste Well No. 1," and I have no doubt that the gas in that field came up along these faults.

Mr. Robt. T. Hill in his paper on the Beaumont oil fields, previously referred to, says:—"There is some evidence that the Coast Prairie overlap conceals a line of serious deformation, which may be a sharp fold, with an increased dip coastward, or a zone of faulting." Concerning this same region, Mr. E. T.

(1) Geology of Ohio, Vol. VI, p. 40 et seq.

(2) Journal Can. Min. Inst. Inst., Vol. III.

Dumble(1) says:—"While the Coastal Plain is now just what its name implies, during Tertiary times, it was subjected to oscillations, accompanied by certain phenomena which marked the dying out of vulcanism in this region."

In the theory, which he formulates to explain "the oil phenomena" of the Texas mounds, Mr. Hill suggests that artesian saline waters bring up the sulphur and oil along this indicated line of faulting in that region; I simply go a little further and claim that this line of faulting gave access to volcanic emanations bringing the water, salt, sulphur, oil and gas from the interior in the state of vapors and gases, which condensed more or less near the surface, some escaping yet in their gaseous state as the hydrogen sulphuret and the natural gas.

In the famous Appalachian oil and gas belt bordering and following the Appalachian Mountains from the Eastern shore of Lake Ontario to Alabama, for the distance of 900 miles, the evidences of parallel folding, faulting and fracturing are most numerous, as shown in the reports and maps of the Pennsylvania, Ohio and West Virginia Surveys, and, if so many anticlines, slopes, synclines and terraces have proven to be good oil and gas fields all through this vast extent of country, and from rocks ranging from the Potsdam sandstone to the Upper Productive Coal Measures, it is certainly not because these hydrocarbons have moved sideways to the anticlines (as we will see below they cannot do on account of the imperviousness of the strata) but because this region being, at certain geological periods, a dislocated and fractured zone, the hydrocarbons have then moved upward from below through these faults and fissures. This is plainly evidenced by the solid vertical core of hydrocarbon at the Ritchie Mine, Ritchie County, West Virginia, where a straight vertical fissure, 4 feet wide in the sandstone, but much smaller and more irregular in the shales, is completely filled with a mineral pitch or inspissat l petroleum, called Grahamite by Wurtz(2), and first described by Professor Leslie(3) in 1863, and lately fully

(1) Am. Inst. Min. Eng. Mexican meeting, 1901—Discussion of Capt. Lucas paper on "The great oil well near Beaumont."

(2) Am. J. Sci., 1866, ii, xiii, 420; Proc. A.A.A. Sci., xviii, 124

(3) Proc. Am. Phi. Soc. IX, 185.

reported on by Geo. H. Eldridge (1) of the United States Geological Survey who seems to admit, with Professor White of the West Virginia Geological Survey, that the source of the Grahamite is the oil in the Cairo sand 1,300 feet down, but, that does not explain the source of the oil in the Cairo sand which, we will see, can be traced to below the Archæan. Therefore, the Ritchie Mine Grahamite vein, though only badly defined when traversing the shales must, nevertheless, have extended at one time to below the Archæan.

The great Burning Springs, Volcano, Horse Neck and Eureka "break" of West Virginia, in the vicinity of which the oil and gas deposits of that State were first exploited, on account of these products coming up nearer the surface near the "break," is another strongly marked evidence of the dislocations which have affected the oil and gas rocks of the Appalachian belt.

A great many similar evidences of dislocation and fracturing can be cited in other oil and gas fields, or in solid petroleum or bitumen deposits, which like the oil and gas fields, have been shown to be also local impregnations along zones of great fracturing, evidently connected with orogenic uplifts:—such as the Ten Mile, Page, Fourche, Buckhorn and Brunswick districts in Indian Territory and Arkansas. In his valuable and very full account of the asphalt and bituminous rock deposits of the United States, Mr. Eldridge (2) fully describes the connection of the bitumen deposits of the above districts with the Ouachita Mountains and Arbuckle Mountains uplifts, in the vicinity of which they occur, in zones of great folding and faulting; for instance of the Brunswick district, he says:—"The Brunswick district of bituminous rocks, one and a half miles square, lies immediately north of Rock Creek, four miles north-east of Dougherty. The topography is rough, developed in strata highly crumpled and faulted. The structure is a part of that involved in the eastern end of the Arbuckle uplift."

Similarly, as reported by Dr. Bailey (1) in the "albertite"

(1) The Asphalt and bituminous rock deposits of the U.S. 22nd Ann. Rep. U.S. Geol. Sur., p. 232.

(2) 22nd An. Rep. U.S. Geol. Sur.

(3) Geol. Sur. of Canada, 1876-77. p. 354. et seq. and Vol. X (N.S.) p. 68 M.

district of New Brunswick, "the rocks of the Lower Carboniferous formation show evidences of profound disturbance, being very generally tilted at considerable angles, while at many points they are nearly or quite vertical. These softer beds in most instances exhibit numerous and abrupt corrugations, while both they and the coarser sediments are broken by numerable faults and dislocations." Cutting very fine-grained dark gray to black shales of these disturbed Lower Carboniferous or Devonian rocks, the hydrocarbon "albertite" is there found filling a strong vertical fissure, as much as seventeen feet wide in places, which was mined to a depth of 1,300 feet; and, filling also numerous branch veins in the enclosing rocks. It was also found in the underlying Pre-Cambrian metamorphic slates, in the overlying unconformable Coal Measures and forming veins and irregular masses in the pure white and stratified gypsum of the Hillsborough quarries, all of which shows the injected character of this hydrocarbon from below the Pre-Cambrian slates. A little natural gas and petroleum, as is well known, is associated with the "albertite" in that district and the Albert shales are often very bituminous, showing that instead of being drained to form the albertite vein, they have been on the contrary impregnated and filled with petroleum from the numerous fissures and faults of that district.

In Utah, the Uintaite (Gilsonite) district, as shown by Mr. Eldridge(1) occupies a fractured zone in the middle of the Uinta synclinal basin sixty miles long from the Colorado-Utah boundary to Fort Duchesne, and some forty miles wide. In this zone many parallel vertical veins of Gilsonite, from one-sixteenth of an inch to eighteen feet wide, and from a few hundred yards to eight or ten miles long, have been found running North-West and South-East in the general direction of the mountains. In this same general direction, to the South-East sixty miles, on the other side of the Colorado-Utah boundary, oil is now being found at Debeque, on the Denver and Rio Grande Railroad. This Gilsonite zone, containing a number of most powerful veins in every way similar to metallic veins, filled with hardened petroleum, is to us most suggestive and illustrates grandly how the oil and gas sands of the oil and gas belts have been filled from below with

(1) Loc. cit.

their hydrocarbons. To suppose that these powerful Gilsonite veins are mere cracks stopping in the shale series below, namely, the Green River shales, from which the oil drained into the veins, as Mr. Eldridge does, seems to me impossible as the closed texture of the shales would surely not permit this drainage which, on account of the great quantity of Gilsonite in some of the veins, would necessitate the drainage of an immense area of fine-grained sediments and the friction would not permit it. On the contrary, the powerful energy of highly pent-up gases from the volcanic reservoir below, alone could furnish the necessary pressure to drive the hydrocarbons through the poorly defined, shattered and almost entirely closed-up portions of the veins through the shales. Besides, if these so-called cracks only extend to the Green River shales, where does the oil in these shales come from?

Similarly, the oil fields of California belong to much disturbed and fractured belts bordering the Coast Range on each side for 650 miles. There also, the migratory upward movement of the hydrocarbons through fractures of the strata is most plainly attested by the numerous asphalt veins, and by the tar and gas springs(1). And at several places there, in the Santa Cruz district and near King City in the Galivan range, the bituminous sand rock rests directly on the granite(2), plainly showing that the fissures must extend through the granite to the only possible source of the bitumen underneath. If there is much less gas in the California fields, and if the oils are as a rule considerably heavier than along the Appalachian belt it is no doubt due to the much more disturbed and fractured state of the strata, as well as to their more unconsolidated conditions, which permitted the light oils to escape. Each separate zone or belt of oil—and gas—fields will thus show differences with other belts, not only on account of the volcanic solfataric products which in general are likely to be the same along the entire length of the one belt and will on the contrary vary somewhat from belt to belt, but also on account of the dissimilar geological and physical conditions of the strata from one belt to the other.

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(1) A. S. Cooper. California Mines and Minerals, p. 120 et seq.

(2) Geo. H. Eldridge, 22nd Ann. Rep. U.S. Geol. Survey—The Asphalt and bituminous rock deposits of the U.S.

In the foreign oil and gas fields we find exactly the same phenomena, namely, the dislocated and fractured belts along the mountain chains furnish the oil and gas fields, as grandly exemplified, in the case of Galicia and Roumania along the Karpathe Mountains, where the oil fields, following in that the mountain range, turn in a grand sweep of more than 500 miles from a north-west to south-east direction in Galicia, to an east and west one in Roumania. There also, the deposits of solid petroleum or ozocerite of Boryslaw, Galicia, illustrate the mode of deposit and the source of the oil which in its more fluid states of oil and gas is never so apparent and so easily made out as it is in its solid state. The large mining developments by shafts and galleries in the ozocerite deposits of "Boryslaw" (furnishing several millions of dollars worth of it annually) have shown conclusively that the solid petroleum exists there in veins cutting the strata in every direction, but the most important and principal veins, from which evidently the others are derived, are parallel true faults. Mr. Rateau(1) and Mr. Babu(2) have each published interesting papers on the Boryslaw ozocerite in the "Annales des Mines" and Mr. Babu concludes as follows:—"The principal faults have brought up from below the hydrocarbon emanations which have filtrated through existing fractures and saturated porous sandstones; the nearer to these faults the richer the deposits." These faults, Mr. Babu says,—have the direction of the mountain range North 50 degrees West and are true "paraclases" of Daubrée.

As to the Russian oil fields, they are, of course, no exception to the general rule, being situated on much dislocated and fractured zones on each side of the Caucasus uplift, from the Tamansk Peninsula in the North-West to the Apcheron Peninsula in the South-East, 750 miles apart. For further evidences of this we will refer you to Mr. Leproux's(3) report already mentioned. The same association of naphtha to a dislocated zone along the Kurdestan chain in Persia has been well described by J. De Morgan.(4) Finally I will close the evidence under this head, by

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(1) Mr. A. Rateau, Annales des Mines, 8ième série, t. XI.
(2) M. L. Babu, Annales des Mines, 8ième série, t. XIV. p. 69
(3) Annales des Mines, 9ième série, t. II pp. 522, 532.
(4) Annales des Mines, 9ième série, t. I.

mentioning that Japan, Java, Sumatra, Borneo and Peru are all well known volcanic regions, and that they constitute also to-day the other principal foreign oil fields, thanks, also, to the dislocated and fractured state of their strata along parallel belts to the main volcanic chains of these regions.

4th. The adventitious character of gas, oil and bitumen in any and all the strata in which they are found is a most easily proven proposition; in fact, it is a self evident proposition when the ever present strong pressure of natural gas is remembered. Such elusive fluids, ready to gush out with such a force the moment the drill pierces their reservoirs and evidently ever impelled upward through disturbed, faulted and fractured strata by the strong pressure of their gas can never be in their original home and the evidences that they are not is most abundant. In my paper "Natural Gas in Ontario"(1) I gave a table, which I reproduce here, with the Cambrian oil rocks of Newfoundland added—it is a list of the oil and gas producing sands in Eastern North America.

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(1) Journal Can. Min. Inst., Vol. III.

PALEOZOIC OIL AND GAS "SANDS" OF EASTERN NORTH AMERICA.

Pittsburg sandstone just above the Pittsburg coal.		
Fifty foot Macksbu.g sandstone	160 feet below the Pittsburg coal	
First Cow Run or Joy Sand	240 " " "	
Mahoning sandstone	300 " " "	
Middle Cow Run or Freeport sandstone	410 " " "	
Upper Second Cow Run sandstone	600 " " "	
Lower Second Cow Run sandstone	650 " " "	
Tionesta, Homewood or 700 feet Macksburg sandstone	810 " " "	Lower Carboniferous and Subcarboniferous.
Upper Connoquenessing or 800 feet Macksburg sandstone	910 " " "	
Lower Connoquenessing or Upper salt sand	1000 " " "	
Lower salt sand or Sharon Conglomerate or Olean Conglomerate or Maxon sand	1050 " " "	
Keener sandstone	1200 " " "	
Big Injun sand	1280 " " "	
Squaw sand	1350 " " "	
Berea grit	1700 " " "	
First sand or Butler Second sand or Gantz		
100 foot rock		
50 foot rock		
Second sand or thirty foot rock		
Blue Monday sand or Gordon		
Boulder sand or Hickory		Upper Devonian white sands
Stray third sand		
Third sand		
Fourth sand		
Fifth sand		
Elizabeth sand		
Warren slush oil sand		
Warren third sand		
Clarendon third sand		
Speechley sand		
Cherry Grove and Sheffield sand		Middle Devonian
Cooper oil sand		
Bradford oil sand		
Lower Waugh and Porter sand		
Elk County group of sands, two or three in number		

Hamilton limestone	The Petrolia and Oil Springs, Ont., upper show	Lower Devonian
Corniferous limestone	Oil Springs and Petrolia fields	
Oriskany sandstone	Euphemia Fields, Ont.	
Guelph limestone	At least 3 different horizons in Essex and Welland Counties.	Silurian
Niagara limestone	Seneca Falls, Alden, New York State and in Indiana.	
Clinton limestone. Clinton sandstone	At Lancaster and other parts of Central Ohio and in Welland Co., Ont.	
Medina red sandstone	Two different horizons in Welland Co. and in New York State	
Medina upper white sand Medina lower white sand	Welland Co., Buffalo, Alden, Oswego & Onondaga Counties	
Trenton limestone, upper part	Several horizons in Ohio and Indiana.	
Trenton limestone, lower part.	Several horizons in Welland Co. and Oswego and Onondaga Counties, N.Y.	
Calciferous & Potsdam sandstone	St. Catharines, Ont., Oswego and Onondaga Counties, N.Y.	Cambro-Silurian
Quebec Group	Newfoundland	Cambrian

The above table shows more than 50 different "sands" (by this term we mean any gas or oil rock, as in the parlance of a driller, whether it is a sandstone, a limestone or any other rock) in which oil or gas-fields have been found along the Appalachian belt, and we have no doubt that as a great many so-called "stray sands" were left out of the table and, as the different "pay" or "pay streaks" of the same "sand" are only counted as one, that the real number of different sands which have been found containing gas or oil along this belt, from West Virginia to New York State, cannot be less if any than eighty. Let us take you along this belt in a rapid survey of what the drill really teaches us:—in the oil region south-west of Pittsburg the drill starts (where the upper measures are the thickest) in the Upper Barren Coal Measures and inside of 3,500 feet to 4,000 feet passes through the 26 oil and gas "sands" of the Lower Carboniferous, Subcarboniferous and Upper Devonian shown in the above table; but, here it will tap the illusive oil or gas in one of these sands, there in another, in the most indiscriminate fashion. Occasionally it will tap them in the same field in two, four, six or even more of the "sands" like at Macksburg. Which is going to be the producing sand? is always the question! Will it be the shallow or Cow Run sands? or the Salt sands? or the Keener, Big Injun or Berea? or the deeper Gordon or 5th sand? It is quite evident that the oil and the gas are wanderers and that their home is not in any of these sands. We now go north-east of Pittsburg to the Middle and Northern oil-fields:—here, a good many of the upper strata of the south-west have outcropped (the general dip being south) and the drill starting, we will say, on the Upper Mountain or Salt sands will reach the Elk County group of sands in about 3,000 feet. Here, the Cow Run sands are gone and the Salt sands, Big Injun and Berea are too near the surface and therefore as a rule not productive any more, though they were among the big producers of the south-west; and the drill finds the oil and gas (in the southern part of this district) in the Venango-Butler oil group:—the same oil, the same gas, in the same sands as in the deeper strata of the south-west. Then further north, in and around the famous Bradford field, these Venango-Butler oil group "sands" are in turn too near the surface and the drill to find oil or gas has to descend lower into the Middle Devonian dark sands. Who doubts that it is the same oil, the same gas and that the home of the wanderers is not located yet? Let us continue the survey of our drill still further north. We are now in N.Y. State and we start say in the Lower Devonian about 500 feet above the Corniferous limestone:—we will reach the Archæan rocks after going through in the average about 4,000 feet of strata. Here, all the prolific oil sands of the other districts to the south-west have outcropped but, for all that, our drill goes down and finds oil and gas in the Corniferous, in the Niagara, in the Clinton, in the Medina, in the Trenton and finally in the Calciferous and Potsdam. Who doubts but it is the same oil and the same gas and that our drill is still searching, near the bottom of the stratigraphic scale, for the home of our wanderers? No one will argue that the Potsdam sandstone constitute this home. We have then at last reached the Archæan crystalline floor without finding this home and on the top of it we record the highest pressure for the gas yet recorded, namely:—1,525 lb to the sq. inch, at the Munroe well of Onondaga County, N.Y., above referred to. Our gaseous wanderer has still some life left in him, in fact he seems to have more the nearer we get to its source. Now, what is that source? It is evidently not the Archæan below, for we know without the shadow of a doubt that the Archæan rocks were crystallized, or "metamorphosed" as many geologists call it, ages before the 10,000 feet of sedimentary strata we have just drilled through were deposited, and therefore any distillated products from Carbonaceous matter in the Archæan would have been lost in the air long before our oil rocks were there to receive them. Our negative proofs then become a most positive conclusive proof that the home of our wanderers is below the Archæan in the fluid magma. This conclusion which the drill along the Appalachian belt teaches us is emphasized by the evidences in all other oil regions:—in Texas, for instance, Mr. Hill shows, in his paper previously referred to(1), that the oil sands range from the Ordovician to the Upper Tertiary; in California, Mr. Cooper has shown that they range from the lower Cretaceous to the Quaternary, some of them Eldridge has shown to be resting right on the granite(2).

In the Indian Territory along the Ouachita and Arbuckle mountains the strata are impregnated with bitumen not only in the Cretaceous but in the Coal Measures and also in the Ordovician(3)—a very great stratigraphic range of thousands of feet of sediments—showing the common source of origin of the bitumens from below.

Finally, not to tire you out with too much repetition, I will only further mention the Russian fields where oil and gas pools have been found from the Jurassic to the Quaternary(4).

Surveying therefore this question in the different fields all over the world, as one must do to arrive at the truth instead of looking only at the oil in a diatom, I find the wandering, elusive oil and gas in the sands of all ages above the crystalline flour of the Archaean and I even find "Albertite" in that crystalline floor in King County, N.B.(5). I therefore wonder why so many geologists are always looking for the "horizon" which has given birth to the oil or gas of this or that particular field for evidently there

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(1) The Beaumont and other oil fields of Texas. American Institute of Mining Engineers, New York and Philadelphia meeting, 1902, p. 14 et seq. Trans. Vol. XXXIII.

(2) 22nd An. Rep. U.S. Geol. Surv., 1901—Eldridge—The Asphalt and Bituminous rocks deposits, p. 369, 404 and 408.

(3) Eldridge Loc. Cit., p. 262 et seq.

(4) Leproux—Annales des Mines, 9ième série tome II, pp. 523-532.

(5) Dr. Bailey.—Geol. Survey of Canada. Report 1876-77, p. 390 and An. Rep. (N.S.), p. 16 T.

is no such "horizon" and we have only to do in every case and in every field with natural rock reservoirs or tanks belonging to any and all "horizons" and to which the American drillers have given the characteristic name of "sands."

5th. Another and last proof which I want to adduce is that the petroleum and natural gas deposits are such locally separated and accidental accumulations, often in such very large quantities, that their source must be from the deep-seated vulcanic reservoir directly beneath, which, alone, is abundant enough and was powerful enough to force such large quantities of hydrocarbons through most impervious strata during periods of volcanic activity under these fields.

In discussing the origin of petroleum and natural gas, the mistake has often been made to suppose and admit that certain "horizons," especially of shales, are entirely "bituminous" over very large areas and are to be found spreading out uninterrupted, like coal beds for instance, over wide regions. In fact, in most of the papers which I have read discussing this subject, some more or less extensive bituminous shale horizon, sometimes situated above strangely enough, is always pointed at as the source of the oil; but, that, of course, as I have already remarked, does not solve the question of origin:—it only defers it and shirks it as it were. But furthermore, I submit, that the evidence to be gathered in all the oil and gas fields show how localized and accidental the deposits of these products are and that in no case do they form widely and uniformly spread "sheets." Carbonaceous shales sometimes form such "sheets" but not bituminous shales. Hunt(1) has long ago denied that the so-called bituminous shales "except in rare instances contain any petroleum or other form of bitumens." These two words "carbonaceous" and "bituminous" are very far from being synonymous, and this fact has too often been lost sight of. But even when shales are really bituminous (that is contain hydrocarbons) they contain these only in spots, as well illustrated in the oil-shale fields of Scotland where, in the different quarries, different beds of shales occupying a series under the coal 3,000 feet thick, are worked, the same bed not being found rich or "impregnated with oil" in more than one locality or two(2).

(1) Essays, p. 169.

(2) Henry M. Cadell, Trans. of the Institution of Min. Eng. Vol. XXII, part 3, pp. 316 et seq.

We have seen above how well the mounds and salt islands of Texas and Louisiana illustrate this localization of oil and gas deposits in a few small spots, here and there, with extensive barren stretches of the same formations between; and that the abundance of the oil obtained from under little "Spindletop" at Beaumont is so remarkable that it entirely precludes the admission of an indigenous source from the sedimentary strata under or near this mound.

The evidence to be deduced from the hundreds of small separate pools found by the drill during the last forty years in the Appalachian oil belt is no less conclusive in showing the spotted nature of these deposits, notwithstanding that the many sands or strata in which they are found often continue uninterrupted between these different pools and beyond, but there they are found quite barren of hydrocarbons over areas scores of times larger than those covered by the oil or gas pools. Then again, the oil region of Pennsylvania is altogether confined to a certain zone or belt in the western part of the State and all the central and eastern parts, though also underlaid with fossiliferous strata, are barren of hydrocarbons. But the facts here lead yet to another important conclusion. When it is further remembered, as previously noticed, that often different pools, quite near and in the same "sand," have different rock pressures, that the oils themselves often differ considerably from one pool to the other, and that in the same field two "sands" only separated by about 125 feet of strata [as the Clinton and Medina "sands" of Welland County, Ont.(1)] showed original rock pressures varying 125 lbs. to the square inch, it will then be clearly realized how impervious, even to highly pent-up gases, the Paleozoic strata of North America are and how it is that all these numerous neighbouring pools, in the same district, do not communicate one with the other. This is further strongly exemplified by the fact that many oil and gas pools have been found with strong rock pressures only a few hundred feet down and quite near the outcrops of the producing sands. How then can it be argued that oil and gas which, in these conditions, cannot escape to the surface could have travelled long distances sideways, upwards and downwards through the strata,

(1) Journal Can. Min. Inst., Vol. III., pp. 68-89.

to accumulate on a distant anticline, from disseminated organic remains spread far and wide in some fine-grained shale strata where, surely, no sufficient force or pressure could originate to overcome the countless frictions bound to take place in this long travel? These long travels through the pores of such impervious strata, especially without a strong impelling force behind, are absolutely impossible. Therefore oil and gas must have come from immediately below their fields, through fractures, fissures and faults, but not from the sedimentary strata below these fields which could not possibly produce, from a limited fossiliferous area, either the quantity of these products or the rock pressure of the gas. We are thus forcibly led for the origin of oil and gas to the deep volcanic source from where we know that abundant hydrocarbon vapours emanate and where alone the energy is sufficient to drive these up through such impervious strata. Even this tremendous interior energy which, as mentioned above, has been figured up into the ten thousands of atmospheres, or 150,000 lbs. to the square inch, had evidently all it could do to force the hydrocarbons and other associated gases and vapours up to so near the surface sometimes and yet not out altogether; and this was only possible and accomplished during special periods of activity producing faulting and fracturing. This wonderful impermeability of the sedimentary strata of the oil regions was well recognized by J. P. Lesley (1) and John F. Carll (2) of the Pennsylvania Geological Survey, and also by the late Professor Edward Orton (3); and, when properly understood, I submit that this impermeability is one of the strongest proofs of the vulcanicity of petroleums, gas and bitumens, as explained above.

All other fields show the same spotted and local feature of impregnation in their petroleum deposits. Even in North-Western Ohio and Indiana where the oil and gas stratum is a limestone and where, therefore, solfataric waters could partially dissolve and dolomitize this limestone, thus rendering it more porous and spreading the subsequent oil and gas deposits more than usual, yet even there the 300 million barrels of oil and the enormous quan-

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(1) An. Rep. Pa. Geol. Surv., 1885, p. 665.

(2) Oil and Gas Region Report, Pa. Geol. Surv., 1890, pp. 12 and 13.

(3) Bull. Geol. Soc. of Am., Vol. 9, pp. 95 and 96.

tities of gas, which have been obtained in the last 18 years, have been produced from very limited areas in these States, though in many other counties of these and adjoining States the same fossiliferous stratum, viz., the Trenton limestone, has proven barren of hydrocarbons notwithstanding that the organic source (if such there was) would be available there just the same as in the neighbouring oil fields, as well as many anticlinal domes and other varieties of flat structure which have been regarded as necessary and sufficient to the accumulations of oil and gas travelling through from fossil sources.

The Berea grit in Ohio affords another most striking example of the localization of oil and gas pools. Notwithstanding that it underlies most uniformly 50 counties of Ohio and 20,000 square miles (1) and that it overlies the greatest shale formation of the entire State, viz., the Ohio shales, ranging in thickness from 300 to 2,000 feet, and that it is covered by some 400 feet of impervious shales, viz., the Berea and Cuyahoga shales, yet it is only productive of oil and gas at a few points. How is it that since, as Professor Orton said, "There is everywhere underlying the Berea grit an abundant source of oil" (the shales) and that, since the impervious cover is mostly always there over this vast territory protecting a good continuous, often porous, sandstone reservoir, that in point of fact, as Professor Orton also said:(2) "There are but very few localities in these 20,000 square miles where any noteworthy value has thus far been obtained from the formation in the line of these coveted supplies, and but a single field of large production?" A few more fields have been found in the Berea grit since the above was written, such as Corning, Scio and others, but yet, after very considerable drilling, not one per cent. of the 20,000 square miles has been found productive; and, where it has been, as remarked also by Orton in the same report, an "abnormal structure or dislocation of the strata" was noticed, like at Macksburg. This indicates the fracturing of the strata necessary for the local impregnation of the Berea grit and other "sands" with oil and gas.

But where the localization of oil is most striking is in the

(1) Edward Orton, Geol. of Ohio, Vol. vi, p. 311 et seq.
(2) Ibid., p. 327.

famous oil field of the volcanic peninsula of Apscheron, near Bakou, Russia, where from a small area of not over eight square miles a production of oil of over 900 million barrels has now been obtained.

I may yet cite another instance of this local distribution of oil, and this is an interesting one for two reasons: first, because it is of oil in the shales, and it will prove that even shales are far from being bituminous all over, and second, because the explanation of why the shales are bituminous in one section and not in the other is here quite apparent and instructive. I refer to the oil-shale fields of the Lothians in Scotland. In his paper on these oil-shale fields, previously cited, Mr. Cadell(1) says:—"Although the Calciferous Sandstone series is well developed in other parts of Scotland it has not as yet yielded any oil-shale outside of this area. It is also a remarkable circumstance that the beds of the oil-shale group which are well developed along the western side of the Dalkeith basin, emerge in East Lothian on the opposite edge of the trough, quite barren so far as oil is concerned. In the same way, the shale-measures of West Lothian, which dip westward under the Stirlingshire coal-field and crop out again under the limestone some miles to the west without any oil-bearing shale, prove that during a long period in the Carboniferous age the necessary physical conditions for the deposition of oil-shale were confined within this limited area." We have here both the facts in regard to the localization of the oil in the shales and also Mr. Cadell's rather vague explanation of them. With this last I cannot agree, as I do not see how the physical conditions in organic growth and decomposition (which, I take it, is Mr. Cadell's meaning) could be so different during a long period in districts so close one to the other. But in looking at Mr. Cadell's map I at once notice that the oil found in the shales of the districts where the red spots or volcanic rocks are, while, where these are not represented, the shales are quite barren, as in East Lothian on the east side of the Dalkeith basin. That, I have already submitted, is the explanation—the hydrocarbons and other emanations accompanied the volcanic rocks which, as we have

(1) Trans. of the Inst. of Min. Eng., Vol. xxii, pt. 3, pp. 316 and 318.

seen, contain in their intimate texture solid witnesses and proofs of it in the form of ozocerite.

This very local and accidental distribution of the oil and gas fields is very unlike what would be expected from deposits of organic origin, which like the coal beds would naturally spread out uninterrupted over wide regions. On the other hand, volcanic products are "*a priori*" found localized along the lines of volcanic activity and there in large quantities, while the neighbouring localities or districts not subjected to this volcanic action are barren. If we now recall the well known geological fact that volcanic activity is, and has been during all geological ages, shifting and intermittent along the fractured zones of the earth crust, that is to say that, while it manifested itself intermittently in a certain region during a certain period, in subsequent ages it died out and became entirely quiescent in that particular region to break out anew in other portions of the earth, then we will realize that natural gas and oil, though volcanic products, are today in most every field where they are found, stored products not now renewing themselves in the recesses of the earth. We will also thus understand why the rock pressure and quantity gradually decrease as we take these products out of their deposits, the volcanic activity which brought them there, through faults and fissures, was active, as it always is, only for a time, and now that this activity has expired these faults and fissures have closed up and the volcanic force is unable to refill the reservoirs, just as it is in most mining regions of the earth where a similar volcanic energy was, at one time, the immediate cause of the filling of fissures, veins and lodes now long ago solidified with quartz and other vein-stones more or less mineralized.

(C.) Complete inadequacy of all organic theories of origin.

I have shown that volcanic emanations of hydrocarbons are a natural geological process of to-day, abundantly verified and witnessed in actual operation in volcanic eruptions and phenomena all over the world.

Can as much be said of any of the organic theories generally advanced to explain the origin of the hydrocarbons? Evidently not! None of the processes called on by these organic theories are to be witnessed in operation anywhere in nature to-day. The late Professor Edward Orton, a profound believer in and a strong defender of the organic origin of petroleum, acknowledged this point plainly when he said in his presidential address before the Geological Society of America(1):—"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 in 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 to-day; 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." We have seen above how far from having disappeared from the scene is the volcanic process of petroleum production, but Professor Orton was only looking to find in nature a petroleum production process "coeval with the kingdoms of life," and that he could not find simply because it does not and never did exist. To me this is most clearly proven by the simple consideration of the natural geological processes of decomposition of organic remains and of the conditions pertaining in the oil and gas fields.

First. It is quite certain that the decomposition of animal bodies, as taking place in nature to-day, and we may, no doubt say during all ages, is so rapid that the decay or combustion is complete before the entombment in the sedimentary rocks of these animal bodies, preserved in any way, can possibly take place. This is no doubt why instances are so rarely cited in geology of partially decomposed and preserved remains of animal bodies

(1) Bull. Geol. Soc. of Am., Vol. 9, p. 60.

being found; only most exceptional cases, such as a few remains preserved in the antiseptic waters of peat bogs or a few frozen remains of Elephas, are given; but these exceptions only confirm the rule which is, viz., when there is anything left at all it is the shell or bones or their moulds or casts and no trace of the body is to be found. The fact that a few shells are sometimes found full of petroleum is a conclusive proof that this oil is a subsequent infiltration into the shell, as in the case of silt, silica, pyrites, calcite and many other minerals filling shells, a modicum of oil is all each shell would contain if the petroleum originated from the body, and invariably, when petroleum is found in fossil shells, it is also found in the porous or seamed strata in which the shells are embedded, showing the infiltration and impregnation from without.

Second. It is also equally certain that there is only but one normal process of decomposition and preservation of vegetable organic matter in nature to-day and in ages past, and that is the decomposition of it into carbonaceous matter, viz., peat, lignite and coal. This process is in active operation in the world to-day, as it has always been, and it is the only normal process "coeval with the kingdoms of life" that geology teaches us. Not one single authentic instance can be adduced, from the actual normal processes of nature. of any decomposition of organic matter "primarily" into petroleum. How could it be? The same conditions of low temperatures and of all other factors entering in the normal decomposition of vegetable remains must give only the one result and cannot possibly give two different ones, especially in the same strata and at the same places, for oil sands and coal beds are often contiguous. If then we do not find carbonaceous matter in any quantity below the carboniferous period, as the A B C of geology teaches us that we do not, the simple reason of it is, as long ago admitted by geologists, that, before that period. the favourable conditions for vegetable growth had not yet developed to any extent. and not that it was transformed into petroleum, as attested by the small quantity of carbonaceous matter found in the Devonian and Silurian strata. which are witness and proof that the one normal process of decomposition of vegetable matter into coal was then already going on.

Then, since animal organisms were never entombed in the rocks, and since vegetable life was quite insufficient before the Carboniferous Age, how can the organic theories of origin be adduced to explain all the oil and gas found below the carboniferous, and that means all the enormous quantities of oil and gas of the Lower Silurian limestone of Ohio and Indiana, and it also means almost all of the very large quantities of oil and gas developed in the last 40 years along the Appalachian belt which has been found under the coal in the lower and Sub-Carboniferous and in the Devonian and Silurian; and, much more in other fields. The fact often cited by the numerous exponents of the organic theories, as in the above quotation of the late Professor Edward Orton, that, by destructive distillation, petroleum and gas can be obtained from coal or carbonaceous matter, and also from fish oil, lard oil or linseed oil, etc. (1), will not serve here at all, for not only there was too little to distill in the rocks prior to the Carboniferous, but, what little there was, was not distilled and is to be found there to-day, undistilled, as the Paleozoic oil rocks of the oil regions of North America have, without the shadow of a doubt, remained unaffected by metamorphic agencies, and have never been subjected to the heat necessary to effect this distillation of organic matter. Nor have the rocks of the Texas section, and yet we have seen that petroleum, gas and asphalt are found in them from the Ordovician to the Quaternary. This destructive distillation of carbonaceous matter (and, we repeat, there is no other organic matter entombed in the sedimentary rocks but carbonaceous matter) could not possibly take place without leaving a residue of coke and of ash, and not only these residues have never been found under the oil and gas fields, but we know for certain that they do not exist.

In fact, if this distillation had taken place, there would be no coal fields anywhere as they would all have been changed into coke-beds.

We see, therefore, to what absurd deductions we are led by the organic theories of origin of petroleum, viz., 1st. Abundance of vegetable life before the Carboniferous. 2nd. No coal anywhere on the globe.

(1) Prof. E. Orton, Bull. Geol. Soc. of Am., Vol. 9, pp. 88-89.

No doubt the late Prof. Orton felt the force of the absurdity of the above first proposition when, after the discoveries of oil and gas in the Lower Silurian limestone of Ohio, he wrote in 1888 (1): "When required to believe that certain phases of this Trenton limestone make one of the great oil-rocks of our geological scale, one which produces from single wells, 5,000 barrels of oil and 15 million cubic feet of inflammable gas in a day, it is hard to prevent our surprise from passing into incredulity." Yet ten years later the same able geologist said (2) :—"Geologists believe that petroleum is, in all instances, derived from organic matter."

This forcibly demonstrates the wonderfully enduring strength of "faith" but we humbly submit that Science wants more than "faith" and demands demonstration.

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(1) Geol. of Ohio, Vol. VI, p. 101.
(2) Bull. Geol. Soc. of Am., Vol. 9, p. 87.