The Origin of Petroleum

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APART from the hypothesis of a cosmic origin (which failed of acceptance because it was not adequately supported by facts), the only important controversy concerning the origin of petroleum has been, for a long time, between the advocates of inorganic and of organic origin respectively. Each of these theories has had a long history of development, and is still being perfected, under the influence of two causes: (1) the increasingly extensive and thorough study of the oil-fields (of which new examples are periodically discovered and opened); and (2) the progress of synthetic experiments devoted to this question. Moreover, the advance in our physical and chemical knowledge of the properties of this peculiar natural product has necessarily modified all criticism of conflicting views.

I. The Hypothesis of Inorganic Origin

That the notion of an inorganic origin of petroleum, first set forth by Berthelot in 1866, and afterward ingeniously developed and formulated by Mendelejeff, should thus have proceeded chiefly from chemists, is quite natural; for the question was one of *possible* chemical processes in the earth's interior, and of imagined chemical reactions to be verified by experiment. Hypotheses of this kind were suggested by many chemists, of whom two, P. Sabatier and J. H. Senderens, may be specially named by reason of their highly interesting chemical experiments.

Among geologists, Mendelejeff's hypothesis was received at first with much interest and favor; for it rested on the assumption of a central terrestrial mass of iron carbide, and the geologists had good reasons for adopting that assumption. Yet comparatively few of them attempted to furnish geological proofs of the hypothesis: the majority either silently believed in it, or for one or another reason rejected it altogether.

An apparently weighty support of Mendelejeff's view was furnished by the American, G. F. Becker, who found in the oil-regions of the United States important and abnormal disturbances of the isogons of terrestrial magnetism, and inferred that in these regions the central iron mass must come nearer to the surface than elsewhere. To my mind, the better explanation is, that in these oil-fields great quantities of magnetic iron have been placed. All iron pipes, especially when set vertically and hammered, notoriously become magnetic; and this is the case with the tubings of the oil-wells—sometimes to such a degree that iron screws, lowered by ropes into the bore-holes, are so strongly attracted by the iron linings that they stick fast, and will not descend further. Moreover, the disturbances of the isogons are not uniform—a circumstance easily explained by the varying amount of iron tubes. Finally, violent irregularity of these curves is shown in places where deposits, either of oil or of magnetite, are not known.

Mr. Becker's conclusions were disputed by W. A. Tarr for other reasons.[1]

The most zealous advocate in America of the inorganic origin of petroleum, so far as I know, is Eugene Coste, of Toronto, who has collected with praiseworthy industry all the facts which support this hypothesis. To give to his many arguments the serious, thorough, and critical examination which they deserve, is the principal purpose of the present paper, as will be seen further on.

During recent decades, no European geologist of authority has advocated the inorganic origin of the petroleum occurring in large deposits.

II. The Hypothesis of Organic Origin

As regards organic origin, the view may first be mentioned, that petroleum is the product of distillation from coal—from which, in fact, artificial distillation had obtained photogene and other products having considerable physical resemblance to kerosene. This view was first expressed in Europe by F. von Beroldingen (1778). Von Kobell, Anstedt, Leon Malo, Romanowsky, Noeggerath, Huguenet, v. Hochstetter and others accepted the hypothesis; but the proofs adduced by v. Beroldingen were soon recognized as inadequate. Since petroleum often occurs not underlain by coal-beds—occurrences of coal and oil being, in fact, usually (as on the northern border of the Carpathians) mutually exclusive;—and since, moreover, the distillation-products of coal are entirely different from petroleum chemically (as Baron Reichenbach proved, as early as 1833), this hypothesis had to be abandoned. So far as I know, it received no support in America, because in Pennsylvania, the mother-land of the oil-industry, there were no coal-beds under the deposits of oil.

Animal Origin

Hypotheses of an organic origin were thus narrowed to the direct transformation of animals or plants to petroleum. Already in 1794, Haquet suspected that the oil of Galicia came from marine mussels, "dis-

[1] *Economic Geology*, vol. vii, No. 7, p. 647 (Oct.–Nov., 1912).

solved" in salt water. L. v. Buch, Quenstedt, Volger, Naumann, Dufrenoy, Posepny, Verbeck, Fennema, and many other eminent geologists, accepted this hypothesis, mostly in view of the circumstance that the bituminous rocks carry the fossil remains of animals. Bertils found in the Kuban district of southern Russia, in a bunch of mussel-shells, a substance partly "petroleous," partly animal remains still undecomposed. R. A. Townsend reported a similar observation from the Tertiary oyster-banks of Assam, in Asia. Ch. Knab somewhat extended the hypothesis; and in North America it found in Whitney, for the petroleum of California, and the brilliant Sterry Hunt, for the oil-deposits in the ancient limestones of Canada, Pennsylvania, and Ohio, its most influential advocates, with whom others allied themselves.

When, in 1876, I visited the oil-fields then under exploitation in the eastern United States and Canada, the question of the genesis of these deposits received my earnest attention. I adopted the hypothesis of their animal origin, and in my report of this journey, entitled, *Die Petroleum-industrie Nordamerikas*, I briefly argued in its favor. Since that report was the first account given in the German language of the geological, technical, and commercial features of this interesting and economically important field, the hypothesis of animal origin (as well as the theory of anticlinals, advocated by me) was tested by observations in the European oil-fields, and, confirmed by geologists such as Tietze, Paul, Uhlig, O. Fraas, v. Gümbel, H. Credner, C. Zinken, and many others, it continued to win more and more advocates.

In 1888 appeared my book, *Das Erdöl und seine Verwandten*, in which I examined critically all the genetic hypotheses known to me, and not only demonstrated that of animal origin, but pointed out certain important factors in the process of transformation, particularly the comparatively low temperature and high pressure, as indicated by geological evidence. An important landmark in genetic hypothesis was thus established, furnishing for the guidance of synthetic experiments two important conditions of the transformation of animal bodies into petroleum.

A few weeks later, C. Engler, of Karlsruhe, tested my theses experimentally, by heating in retorts, under a pressure of 10 atmospheres, and to a temperature of from 300° to 400° C.,[2] first fish-oil, and afterward fishes and mussels. He obtained in this way a product very like petroleum, from which he isolated several members of the methane series. My hypothesis, thus further corroborated, became a theory, known as the Engler-Höfer theory, since both of us had equally contributed to its establishment. It won the support of chemists as well as geologists—whose numerous names it is not necessary to catalogue here.

[2] It is well known that time may replace temperature, so that nature performed the transformation at lower temperature. Moreover, processes of fermentation are involved, and these often produce very high temperatures.

It is noteworthy that the geologist and the chemist must co-operate in the solution of genetic problems in geology—the former by investigating the natural conditions attending a given formation, while the latter synthetically performs the process itself. Only when thus confirmed is the theory adequately established.

Vegetable Origin

A great additional service rendered by C. Engler was his tireless labor through many years in the investigation of the various transformations undergone, up to the present time, by the original materials and primary forms of petroleum—a labor which still further perfected the Engler-Höfer theory. These investigations showed that vegetable fats also, by dry distillation under high pressure and at comparatively low temperature, could be transformed into petroleum, as American chemists (Warren and Stoner, Sadtler, etc.) had already proved. Our theory could therefore be extended to include those plants which, like animals, contain fats and albumens, but no cellulose—namely, the microscopically small diatoms. T. Fegräus and A. F. Stahl, who first pointed out this source of petroleum, were followed by G. Krämer and A. Spilker, and, still later, by Potonié. This hypothesis is applicable only where, as in California, the minute and delicate siliceous shells of these fossil algæ occur in connection with oil-deposits.

Many American geologists and chemists like Lesley, Newberry, Ashburner, Shaler, Orton, Peckham, Mabery, etc., had already either advocated a common animal and vegetable origin, or (like the two highly esteemed investigators last named) assigned an animal origin to the nitrogenous California product, and a vegetable one to the non-nitrogenous oil of Pennsylvania. The contrary appears, however, to be the truth, since the diatoms are found in Californian, and not in Pennsylvanian, oil-fields. Probably the advocates of the double origin were not thinking of the microscopic vegetable forms at all; they speak in a general way of "plants." But the more highly organized plants contain cellulose, which would leave after distillation a carbonaceous residuum, such as is not found in petroleum and its deposits. For this reason, the above hypothesis, once so generally favored, could not be finally accepted.

According to our present knowledge, the original material of petroleum is principally fat, and subordinately wax, resin, and albumen. These substances, especially fat and albumen, occur chiefly in both the lower and the higher animal organisms. Petroleum, therefore, is mainly of animal origin, though it may have been formed, here or there, from fatty plants, particularly diatoms.

The foregoing is a brief review of the development and present condition of our knowledge on this subject. In Europe, as in America, most geologists and chemists hold to the organic genesis of petroleum, and L. V. Dalton,[3] in his thorough essay, declares himself an adherent of the Engler-Höfer theory.

III. The Hypothesis of Volcanic Origin

As already observed, Eugene Coste, of Toronto, seems to be the most zealous American defender of the inorganic origin of petroleum. Three of his papers on this subject lie before me: (1) The Volcanic Origin of Oil (*Trans.*, xxxv, 1904, p. 288); (2) The Volcanic Origin of Natural Gas and Petroleum (*Journal of the Canadian Mining Institute*, vol. vi, 1903, p. 73), and (3) Petroleums and Coals Compared in Their Nature, Mode of Occurrence and Origin (*idem*, vol. xii, 1909, p. 273). He sees in petroleum "the product of volcanic solfataric emanation." In the following critical examination of his proofs, I refer chiefly to the interesting paper last named, which is the most recent, and, moreover, takes account of the arguments previously stated in the two others.

I must express in advance my surprise at his statement (p. 275): "The petroleum series includes all the natural hydrocarbons with the exception of the marsh gas." This hydrocarbon is found in every petroleum, though it escapes as a gas very rapidly, as soon as the oil is exposed. Of natural gas, it is generally the essential constituent.

The Proofs Advanced by Coste

Mr. Coste says in one of his papers: "The vital point is to actually show the carbon and hydrocarbon in the igneous rocks, lavas and emanations proceeding from these internal fluid magmas."

As illustrative instances, he cites (on p. 278 and following pages of his latest paper) the following:

1. "Oil in crystalline gneiss: In Placerita Canyon, five miles east of Newhall, Los Angeles county, California, a very light oil, almost naphtha, of a gravity between 50° and 60° B., is produced from crystalline gneisses which overlay the San Gabriel granite."

According to the investigations of G. H. Eldridge and Ralph Arnold, this so-called crystalline gneiss is not gneiss at all, but a metamorphic crystalline schist, perhaps Jurassic, and hence by no means an Archæan rock which could possibly be regarded as eruptive. It is a metamorphosed sedimentary, and can give Mr. Coste no help—rather the contrary. The oil of this locality may be in its primary deposit, or, more probably, it may have found its way thither from the neighboring Tertiary oil-field.

2. "Oil and bitumen in the quicksilver deposits of California."

[3] *Economic Geology*, vol. iv, No. 7, p. 608 (Oct.–Nov., 1909).

Being unacquainted with the geological relations of that district, I can offer no suitable explanation of this occurrence, and will only remark that these bitumens may have been extracted and transported from deeper bituminous rocks by the ascending ore-bearing solutions. Spirek ascribes to bituminous rocks the occurrence of bitumen in the Tuscan quicksilver mines. Since the bitumens occur very seldom in ore-deposits—particularly in deep-seated veins,—they cannot be regarded as a general product of deep volcanic zones. They must have a purely local cause. At all events, such scanty occurrences of bitumen of all sorts prove nothing as to the formation of rich petroleum-deposits. This has been emphasized by Prof. Dr. L. Mrasec, of Bukarest, who is inclined, moreover, not to admit a deep source for the rare occurrences of bitumen in ore-deposits.

3. "Graphite and natural gas in the metalliferous vein of Silver Islet, and graphite in the veins at Cobalt and Ducktown, Tenn."

To these instances also, what I have already said is applicable. No one would dare to infer from the sporadic occurrence of graphite in mineral veins that *deposits* of graphite are of volcanic origin—still less when (as in the Kaisersberg, Styria) the graphite is accompanied by plant-fossils. It seems to me equally audacious to argue the origin of the great deposits of petroleum found in sedimentary rocks, from the isolated and quite insignificant occurrences of bitumen in veins.

4. "Solid petroleums in pegmatite dykes, and other veins, associated with uranium, radium and vanadium."

We are here concerned, not with "solid petroleum" (a contradiction in terms, since petroleum is a liquid), but with a bituminous mineral, the combustion of which left an ash which, in one locality not named, contained uranium, and in another place, in Peru, contained vanadium. The remarks already made under (2) and (3) are applicable here; and I will only add that petroleum is almost entirely free from ash.

5. "Graphite, diamond and hydrocarbons in meteorites."

This phenomenon bears no relation to the origin of petroleum, nor is it at all surprising, since in the original cosmic material carbon must have been present (probably as carbonic acid), and must have been segregated in the meteoric masses, as in that of the earth.

6. "Oil and natural gas in volcanic rocks in Europe, Africa and Mexico."

These occurrences, few in number and always very small in extent, may be due to coal-beds or bituminous rocks which the volcanic eruptive broke through, distilling out and absorbing into its own mass some oil and natural gas. This distillation of bituminous material has long been practiced in the Scotch shale-oil industry.

7. "Natural gas in serpentine, Asiatic Turkey" (Chimaera).

Alexander von Humboldt suggested long ago[4] that this emission of gas might be connected with petroleum. E. Tietze,[5] who studied the phenomenon on the spot, adopts this view, and calls attention to the neighborhood of the so-called "Flysch" formation, which so frequently carries petroleum.

8. "The occurrence of oil around volcanic necks, Mexico."

This proves nothing, since the mineral oil of Mexico, and especially of the State of Tamaulipas, named by Mr. Coste, is widely distributed, and occurs both near volcanic necks and far from them. Villarello,[6] Division-chief of the Mexican Geological Institute, and one of those best acquainted with the oil-occurrences of Mexico, concludes: (*a*) that the oil comes from a marine fauna; and (*b*) that, in the districts explored hitherto, it is found only in secondary deposits, situated in highly disturbed terrain, connected frequently with basaltic eruptions. Since the volcanic tuffs are highly porous, it is not surprising that the oil, in its migration, should accumulate there in special abundance.

Of all the foregoing proofs of the volcanic origin of petroleum, only two, No. 1 and No. 8, are really pertinent to the question of the genesis of valuable deposits of oil. The rest are so insignificant that they prove nothing as to the production of oil in large quantities, and have for us only a purely scientific interest. And the two exceptions, adducing the occurrence of petroleum in alleged gneiss, and in connection with volcanic necks, have been shown, I think, to be entirely inadequate as proofs.

As a logical consequence of Mr. Coste's view, deposits of petroleum should always be found in the vicinity of volcanic eruptions. But this is not the fact. In the Carpathians, the "outer bend," through Galicia, the Bukowina, and Roumania, is free from eruptives and rich in oil, while the "inner bend" is rich in eruptives and poor in oil. At Baku, in Alsace, and in North Germany, as in Canada, New York, Pennsylvania, Ohio, West Virginia, Louisiana, Texas, etc., there are no eruptives near the rich oil-deposits. In Java, Sumatra, Borneo, and Burmah, the oil-fields are far from the regions of eruptive activity.

These weighty facts, completely contradicting the volcanic hypothesis, Mr. Coste seeks to deprive of force by the assumption that oil and gases have ascended from greater depth through fissures, and thus were deposited far from eruptive masses. But it is remarkable that the Hungarian Carpathians are much more disturbed than those of Galicia and Roumania, and are, nevertheless, poorer in oil—indeed, for the most part, contain no oil at all. The most important and profound disturbance of the Galician Carpathians—the so-called *Klippenzone*—is barren of oil,

[4] *Kosmos*, vol. iv, Observation 51.

[5] *Jahrbuch der k.k. geologischen Reichsanstalt*, Vienna, vol. xxxv (1885).

[6] J. D. Villarello in *Das Erdöl*, by Engler and Höfer, vol. ii, pp. 643 and 650 (1909).

like its neighbor, the *Weichselbruch*. The Alps are traversed by deep faults and dislocations, many of which still make themselves disagreeably felt as seismic surfaces; yet no noteworthy oil-deposits have been found among them. At the foot of the Alps on the north, the gas-springs of Wels, in Upper Austria, are found in quietly deposited and undisturbed Miocene strata. In the rich oil-bearing flat anticlinals of Pennsylvania, I sought in vain for any dislocations worthy of mention; and not one of the intelligent "oil-men" whom I met could point me to any such thing. East of that oil-region, we find in the Appalachians mighty disturbances of all kinds—deep fissures, sharply arched anticlinals,—but no oil. At Pechelbronn, in Alsace, the slightly inclined oil-bearing sandstones were formerly mined and thus thoroughly explored, without the discovery of a single dislocation, showing that the oil was occupying its primary place of deposit. K. Kalickij[7] proved the same proposition for the oil-occurrences on the island of Tscheleken. Even the photographs accompanying his paper are conclusive.

The Objections Advanced by Coste

In order to weaken objections to his own theory, Mr. Coste urges[8] the following objections to the theory of organic origin:

1. "It cannot possibly explain the large petroleum fields below the Carboniferous."

Can the solfataric hypothesis do that? No: Mr. Coste's proofs—except No. 1 and No. 8—rest wholly upon isolated and minute occurrences of bitumen. No one has ever observed at a solfatara any accumulation of petroleum worthy to be mentioned. On the other hand, F. Quenstedt[9] has shown that 1 square mile of the bituminous Posidonia slates of Suabia, rich in animal fossils, contains 200 million hundredweight of oil. In other words, the animal remains of a single sedimentary bed can furnish enormous amounts of oil. What was possible after the Carboniferous era may have been possible before it also. Biological activity on the earth has been immense, continuous, and widespread; whereas volcanic activity has been local, and often but temporary, discharging here and there comparatively insignificant quantities of hydrocarbon gases.

2. "Neither can it explain the petroleums in the volcanic emanations of today."

No considerable quantity of hydrocarbon has ever been found in a solfatara. And where one or a few per cent. have been found, they can be referred to bituminous strata which have been intersected. Moreover, positive reports of hydrocarbons (usually given as methane, CH_4) are to

[7] Ueber die Lagerungsverhältnisse des Erdöls auf der Insel Celeken. *Mémoires du Comité Géologique*, St. Petersburg, New Series, livraison 59 (1910).

[8] *Journal of the Canadian Mining Institute*, vol. xii, p. 295 *et seq.* (1909).

[9] *Einst und Jetzt*, p. 57.

be received with caution. The gases of the Hawaiian volcano Kilauea are often cited as an example. But when collected directly by L. Day and E. S. Shephard[10] they were found to contain no hydrocarbons at all. So this proof also fails. The small quantities of marsh-gas, produced by Brun at Geneva through the heating of certain lavas, may have formed themselves during the process through the decomposition of other gases, for instance, according to the equation

$$4\,CO + 8\,H_2 = 2\,H_2O + CO_2 + 3\,CH_4.$$

3. Nor can the organic theory explain the petroleums "in the volcanic or igneous rocks in all parts of the world."

4. "Nor in crystalline rocks; in California and New Brunswick, for instance."

5. "Nor in meteorites."

6. "Nor in metalliferous veins."

These four points have been already discussed, and shown to be invalid.

7. "It is also at a loss to explain why the petroleum fields in every district are found grouped along certain lines and why the petroleums are found there in many horizons, while outside of the lines in just the same strata and over much larger areas all the horizons are barren."

This raises the comprehensive question of the structure of the petroleum-deposits, which cannot be treated within the limits of this paper. I will only say briefly that the oil is found along certain lines, because it occurs (1) in fissures, (2) in folds, and (3) in long-drawn channels of sand. The fissures are directly connected with the primary deposits. In folds, anticlines, monoclines, etc., the position of the oil is determined by the accompanying natural gas and water. The three substances arrange themselves according to their specific gravity, along the lines and surfaces presented by the shape of the fold. If the oil-bearing sands occur in long, slender bodies, as in Alsace, the grouping of the oil "along certain lines" is not surprising. Since the oil-deposits are coastal formations originating under special conditions, it is comprehensible that they cannot follow throughout the same geological horizon.

8. "It cannot explain either how the petroleums can possibly travel out of their supposed organic-remain source in some impervious clay or shale to accumulate in a few porous receptacles far distant laterally and sometimes hundreds and thousands of feet above, or even below as some assert, and this all through most impervious rocks and without any impelling force behind, or any cracks, joints or fissures to follow since the decomposed products of the organisms must naturally be supposed to come from the whole mass of the strata through which the organisms were and there could not be fissures, cracks and joints to all parts of the strata."

If I understand Mr. Coste correctly, this passage is directed, not so much against the theory of organic origin as against the hypothesis, so popular in America, of the regional migration of petroleum. In this re-

[10] *Journal of the Washington Academy of Sciences*, vol. iii, p. 475 (1913).

spect, I heartily agree with him. I too maintain that the migration of oil can take place only in cracks, joints, and fissures, the source of motive energy being (as has been often demonstrated) the accumulation, in the primary deposit, of natural gas under high pressure.

9. "It cannot possibly explain why the petroleums, although found today in their reservoir-rocks under strong pressures, cannot by means of that pressure, return and disperse back to their original sources; they should be able to return the way they came, nothing is to prevent them and there is plenty of pressure for the return voyage if one admits the first voyage from the organic source."

This question might be applied to Coste's hypothesis also. As already remarked, petroleum is driven by gas-pressure to a considerable altitude in fissures; and its removal leaves in the original deposit a space in which the gases collect and keep the oil above them, as, for instance, in the so-called inverted siphon, when partly emptied, the entrance of carbonic acid gas continues to maintain the height of the water in the discharge-pipe.

10. This objection, based on alleged features of the occurrence of petroleum in California, I must leave to my esteemed colleagues, Ralph Arnold, B. Anderson, G. H. Eldridge, and other distinguished investigators of the oil-geology of that State. It will possess for them no difficulty.

11. "It cannot possibly explain again, if the petroleums can travel so freely through the strata as to be able to accumulate under an anticline from organic remains deposited far and wide laterally (at least a mile or two or much more in order to allow for the quantities obtained in many fields), why they did not escape out into the free air only a few hundred or a few thousand feet away at most; the shales above the sands are not any more impervious than the shales below the sands, which on that theory are supposed to be the source of the petroleums, and if they can travel freely through the shales which are the most impervious rocks of the sedimentary series, I repeat, what is to prevent them from getting out into the atmosphere?"

This question properly concerns, not the organic origin of petroleum, but a hypothesis of its migration, advanced to explain the formation of productive deposits—a hypothesis which I reject, holding that petroleum originated in the sands in which it is found, unless it has passed through fissures to other sand-strata.

12. "It cannot account for the continual absence of petroleums in the hard parts of organisms preserved in the sedimentary strata."

Oil can be formed from the soft parts of animals under certain conditions only, among which is the exclusion of air. We find on the sea-shore many hard parts, such as shells and skeletons, of marine animals, from which their organic contents have totally disappeared, having been destroyed by the oxygen of the air. Since this generally finds access to dead animal matter, we find the hard parts without oil very frequently, and oil itself infrequently in comparison, because only under special favoring conditions.

13. "It cannot explain the evident non-connection of petroleum deposits with coal-beds."

Since the latter are land-formations from plants containing cellulose, while the former are marine estuary-formations from animal remains, there can be no connection between the two organic processes or their products.

14. "It cannot account for the continual association of petroleums with strong salt and sulphur waters."

Since the original materials of petroleum accumulated in marine bays, having but limited relations with the ocean, the presence of strong salt water is not surprising, but constitutes, on the contrary, a proof of our theory. Sea-water is known to contain sulphates also, which, in the process of oil-formation, can be reduced to sulphides, or even to sulphur. As a marine formation, petroleum may be accompanied by salt, gypsum, calcite, and dolomite; and this explanation of their presence seems to be more natural than that of a volcanic source.

Further Considerations

I have thus answered in detail both Mr. Coste's objections to the organic, and his arguments for the inorganic, origin of petroleum. The latter, however, constitute, strictly speaking, an incomplete statement; for he contends only that petroleum was brought by solfataras into the cooler parts of the earth's crust. Concerning the questions, *out of what* and *how* it was formed, he is entirely silent. His explanation, even if we were able to accept it as correct, goes only half way, like those of his predecessors, Lenz (1831), Rozet (1835), S. W. Pratt (1846), Choucourtois (1863), Thore (1872), Fuchs and Sarasin. It is at best a plant without a root.

Even if we had proved, or should hereafter prove (as has never yet been done), the presence in solfataras of large quantities of marsh-gas, CH_4, such gas would stream into the air, without forming petroleum. Besides, we know of no process by which CH_4 can be converted into the higher members of the paraffine series, or any member of the naphtha series. This circumstance likewise deprives the very rare occurrence of CH_4 in ore-deposits or volcanic rocks, of all significance as to the origin of petroleum.

As a sincere friend of the petroleum industry, I am heartily sorry that I must reject Mr. Coste's emanation-theory; for, if it were true, we might expect our petroleum-supply to prove inexhaustible, new quantities being continually furnished by solfataric activity. Unfortunately, that is not the case.

Mr. Coste mentions an occurrence of hot water with petroleum in Texas. This is a purely accidental phenomenon; since neither in the great

Yellowstone region of thermal springs nor in any of the European hot springs has petroleum, or even marsh-gas, been observed.

Why are oil-deposits lacking in the highly fissured true Archæan rocks of Scandinavia, Bohemia, the central Alps, the Appalachians, etc.; and why do they appear first in the sedimentaries deposited at a time when the earth had become populated with organisms? This can be construed only as a proof of the organic origin of petroleum.

If this oil had ascended from great depths, it would have impregnated all porous strata. But, on the contrary, we find repeatedly, between two oil-bearing horizons, porous rocks containing no oil, like, for example, the Jamna sandstone in the Galician Carpathians. Underlying the oil-sands themselves, there are porous, yet barren, rocks.

If petroleum were the product of distillation at high temperature, it could not contain any primary paraffine, and it would be richer in olefins. Neither of these conclusions is confirmed by the facts.

The occurrence of free nitrogen (not in the form of air) in many petroleums and (often in considerable amount) in natural gas, cannot be explained by any volcanic hypothesis, but furnishes another strong proof of organic origin. The same may be said of the optical properties of petroleum, and of the presence of cholesterin, which seems to be a condition of the polarization, and is a special indication of animal origin. Moreover, the high-molecular pyridin bases, observed in many oil-regions (Galicia, Alsace, Baku, Fergana, Roumania, Sumatra, California, Egypt, Algiers) speak conclusively against a volcanic, and in favor of an organic—particularly an animal—origin. The general chemical character of petroleum as an unstable mixture of hydrocarbons bears similar testimony against any supposed pyrogenic process at high temperature.

All geological and chemical facts concerning the occurrence of petroleum bear unanimous witness in favor of its organic origin, and hence conclusively against its production from inorganic substances, and the collateral hypothesis of emanation. The doctrine of the volcanic origin of petroleum deposits must therefore be pronounced to lack scientific foundation.

To demonstrate this fact in a review of the publications of Mr. Coste, one of the most meritorious and zealous representatives of that hypothesis, has been the purpose of the foregoing remarks. Hence I have adduced proofs of organic origin only so far as they contradicted the opposite view. For a detailed exposition and defense of the former theory, I refer to my two books: *Das Erdöl und seine Verwandten* (3d ed., published by Vieweg at Braunschweig in 1912), and *Die Geologie, Gewinning und der Transport des Erdöls* (published by Hirzel at Leipzig in 1909), the latter of which constitutes vol. ii of the comprehensive monograph issued by Engler and myself under the title, *Das Erdöl.*

Discussion

A. F. Lucas, Washington, D. C.—I have long held the opinion that igneous rock in the form of laccoliths, batholiths, or sills may underlie the salt domes of Louisiana, Texas and elsewhere, and have advanced the hypothesis of the volcanic origin of these domes. In the face of the apparently conclusive arguments presented by such authority as Prof. H. v. Höfer, it takes much courage or almost convincing proofs to still advocate such an hypothesis, but when one travels over the Coastal Plains of Texas, Louisiana, and Mexico, one needs still more courage, as there are certainly no visible evidences of vulcanism for hundreds of miles, only perfect and level plains of unconsolidated sedimentary materials.

Over these plains there rise some elevations of various heights which by comparison with the wide extent of the plain may be likened to a pin prick on the floor of this room. A series of these elevations appearing in perfect alignment northwest to southwest are now known as the Salt Islands in Louisiana, and others scattered through the Coastal Plain are known as hills, mounds, or domes. On some of these elevations there exude from low depressions solfataric emanations from pools of acidulated water, while on others there are no indications of disturbances coming from below.

I pioneered the drilling on all these islands and most of the domes and invariably found them to be underlain in whole or in part by salt masses. This is the case also at Belle Isle, Anse la Butte, Spindletop, Bryan Hights, etc., on whose domes oil and sulphur were also found.

On Belle Isle strong indications of solfataric emanations were more apparent than on other domes of the series, and therefore this property was more extensively exploited than any other, with the exception of Spindletop, first for salt, and then for oil.

I have held the opinion with Mr. Coste that the emanations of gas through these domes constitute evidences of volcanic origin, and I have in consequence been desirous of making a practical demonstration to prove, if possible, whether or not the salt masses of the Coastal Plains rest on volcanic plugs. Accordingly I induced I. N. Knapp to drill a deep test well to ascertain, first, the total depth or thickness of the salt mass, and second, the character of the rock formation upon which the salt rests.

This was easily said, but not easily done, as in one of the early bore holes drilled by me some 18 years ago at Jefferson Island, for Joseph Jefferson, drilling was carried to a depth of 2,100 ft. without passing through the salt. The total thickness of pure rock salt, as far as explored, was nearly 1,900 ft.

Since the drilling of the discovery well by me on Spindletop, a salt dome, in 1901, creating a new precedent in oil exploration on the Coastal Plains, many attempts have been made to find oil by drilling on all sorts of elevations, however slight, in hope to strike another Spindletop, which was only 12 ft. above the surrounding prairie. In most instances the drill encountered either rock salt or dolomite which continued to considerable depth. As oil was not supposed to be present below these substances, the drill was stopped and the well abandoned.

There was therefore at that time no precedent at hand and no geologist willing or able to advance a possible hypothesis as to how deep the salt mass may continue, or upon what kind of rock it might rest.

Many theories and hypotheses have been advanced by students or geologists to account for the origin of these wonderful salt masses. In studying the interior of salt mines which have been carried to a depth of several hundred feet, and also in considering the perimeter of the salt domes, one cannot help concluding that the salt was not deposited by evaporation, but must have been deposited by saline waters ascending from great depths. In looking over a vaulted chamber in a salt mine of the Coastal Plains one is struck by the dazzling whiteness of the salt, which is interspersed, however, by dark streaks resembling the grain of oak or chestnut. These dark streaks are caused by very fine grains or stringers of gypsum, making it appear as if the whole mass was at one time in a plastic condition.

The Knapp well at Belle Isle passed through the salt at about 2,900 ft. and then continued in calcareous rock to a depth of 3,171 ft. At this point the drill encountered a formation so hard that no impression could be made with the ordinary fishtail bit and consequently no sample of the rock could be obtained. While endeavouring to obtain a diamond drill outfit, the well (which was at that time in great distress owing to gas pressure and caves) was lost and no other deep well has been drilled since that time.

The information this well gave is or should be gratifying, for although it failed to furnish a sample of the hard rock at 3,171 ft., it is likely that it would have proved to be an igneous rock, probably basalt, for in all my experience no sedimentary rock, even a hard limestone, would have worn the drill as this rock did. A new and very hard drill was repeatedly lowered and efforts made to drill into it, but with the same result.

This well has, however, established certain facts, to wit: (1) the total depth of the rock salt, a thing heretofore unknown; (2) that oil and gas under heavy pressure exist under the salt; and (3) the existence and beginning of a very hard formation, necessitating better drills than the best fishtail bit then in use (possibly a Sharp & Hughes drill might cope with the situation, and if not that, the Calyx drill, or even a diamond drill); (4) that the depth so far attained is not at all beyond limits of economic drilling as practiced to-day, and that with a proper drilling outfit and heavy casing a station could be made to set the casing on the extreme bottom in order to proceed unhampered by gas and caves through a greater depth, say at least 6,000 ft. This would give a latitude of nearly 3,000 ft. of territory still to be explored; and in a zone of such wonderful activity very important facts may be brought to light which may prove conclusively whether or not petroleum comes from igneous rock and consequently is of volcanic origin.

Through the many holes drilled on this dome to ascertain the dip of the salt, there were invariably encountered, overlying the salt, lenses of limestone containing from 10 to 35 per cent. of sulphur. In some instances the drill dropped several feet, thus showing that the limestone is cavernous. This is also evidenced by the fact that in some wells many wheelbarrows of clay were dumped in the hole in the effort to get return of the drill water.

Nearly the whole mass of the salt seems to have been impregnated with gas and oil globules, which are often visible without the aid of a lens. In emptying a bailer of its fragment of salt into a trough, the fragments in liquefying would pop like so many jumping jacks, proving that the salt containing the gas and oil is under heavy pressure. Throughout the drilling of this well gas under heavy pressure, oil, impure gypsum, anhydrite, and sulphur were obtained, and at a depth of 2,745 ft. a ledge of magnetic iron. Where did this magnetic iron come from? Certainly not from the outside of the dome, which is surrounded and hemmed in by muck sand, gumbo, gravel, etc.

The cost of a well like this was of course high, because one did not know what to expect next, but now within the limit of depth attained by this well the cost would be considerably less, and if proper preparations were made the drilling of a well to say a depth of 6,000 ft. would not be excessive, considering the possible results that might be attained.

William C. Phalen, Washington, D. C.—What is the approximate thickness of calcium carbonate and gypsum after you passed through the salt?

A. F. Lucas.—We have the data; to wit, from 2,900 to 3,171 ft.

William C. Phalen.—It seems to me that these are normal solutions. We should have a calcium carbonate, then gypsum and salt on top. You mentioned the presence of these substances.

A. F. Lucas.—Yes, within the confines above given, although some may have come above the salt, as the well was not cased at this point.

I. N. Knapp, Ardmore, Pa.—We established the fact that there was a ledge of magnetic iron. I think there was 4 ft. of magnetic iron at a depth of 2,745 ft. The bit wore faster than the ore. The magnetic iron consisted of small particles cemented together, and it fairly hissed when it came out of the hole.

George S. Rice, Pittsburg, Pa.—Was an analysis made of the gas?

A. F. Lucas.—No, sir; we were after more valuable or important data than the composition of the gas.

C. W. Washburne, Washington, D. C.—In calling attention to this salt, which Captain Lucas said hopped about when it was thrown on a shovel, that is what they call knister salt. If this salt is put in water it practically explodes, and blows the water around. The gas in it is under very high pressure. It has been measured, and the pressure is under several hundred pounds. These gases could not have gotten in there under steam or water pressure. That salt crystallizes under ground and the gas gets into it at the time it crystallizes. It would crystallize in a shallow dune, and it formed there under pressure of the rocks, and the gas, of course, is under pressure still.

Eugene Coste, Calgary, Canada.—I am sincerely grateful to Dr. v. Höfer for this paper discussing the origin of petroleum, and opposing the view of that origin which I have supported on many occasions since 1900. It is only by such discussions that all the facts and arguments in the case will be brought clearly forward; the members of the Institute, mining engineers and geologists, are the best of jurors to decide on both the facts and the arguments; and thus we may hope to arrive at the solution of this scientifically and economically most important problem.

Before answering Dr. v. Höfer's points against the solfataric volcanic origin, I may be permitted to *résumé* what I understand from his paper to be his own views, and what he frankly states as his position on the question. He narrows the origin of petroleums to the direct transformation of animals or fatty plants (such as diatoms) without cellulose; and he considers that the organic matter was originally in the "sands" in which the petroleums are now found, unless in the cases where petroleums have passed afterward through fissures to other sand strata. Dr. v. Höfer also considers these sands to be coastal marine formations, deposited in shallow bays of the sea, where, under special favoring conditions, the oxygen of the air did not destroy as usual the animal or fatty plant matter, which was therefore entombed, and afterward through the agency of long time was gradually distilled at low temperature and under high pressure, and became petroleum.

The clear statement of these views forcibly suggests at once the following objections to them:

I. Why is not this process in active operation in the world to-day? Why can we not abundantly verify it, and witness it in numerous cases in some of the millions of shallow bays of the sea teeming with life, where sands are being deposited to-day, and have been deposited in recent ages under similar conditions? It is not enough to cite in support of this hypothesis a very few cases, in which empty shells, or organic matter partly decomposed, were evidently impregnated with petroleums by seepage through fissures or seams from underlying reservoirs.

II. It is also erroneous to say that this hypothesis (p. 483 of Dr. v. Höfer's paper) was accepted by eminent authorities, "mostly in view of the circumstance that the bituminous rocks carry the fossil remains of animals." As a matter of fact, the fossil remains of animals or plants are found mostly in shales which are, as a general rule, absolutely barren of petroleums. It is only very occasionally, surely not in 1 per cent. of the cubic contents of the strata, that bituminous rocks, or rocks (either shales, sands or limestone) containing petroleums, are found; and, as a rule, these spots are comparatively small and are very poor in fossils. The other 99 or more per cent. of the strata really contains the fossil beds; and these fossil beds, as is well known, are barren of petroleums. Although some of these shales may be carbonaceous, they are not bituminous or petroliferous.

III. This brings one to the third serious objection to the view of Dr. v. Höfer, namely, that the "petroliferous sands" are so poor in fossils, and the petroliferous sand-reservoirs are so limited in extent and thickness, with impervious rocks all around them (since we find heavy gas pressures in these reservoirs), that the enormous quantities of petroleums they have produced cannot possibly be accounted for in that way. I will cite only one instance: viz., the example of the small dome of Spindletop at Beaumont, Texas, where from a little over 200 acres, some 50,000,000 barrels of oil have been produced up to date. The oil "sands" under that dome are secondary crystalline limestone or dolomite masses, found only under the dome area of a little over 200 acres, the surrounding strata being impervious clays and sands and "gumbo" beds, with fossils but without oil. The secondary crystalline limestones or dolomites under the dome, containing these enormous quantities of oil, are not fossiliferous; but even if they were, the oil in them could not be indigenous in such quantities, and undoubtedly came up the chimney under the dome from below, since it cannot have come from the impervious sides.

This reasoning from indisputable facts, patent in many fields, long ago forced the American geologists to the conclusion that the petroleums cannot have been produced in the sands they now occupy. On the other hand, most of the American geologists, and many others, conceive a regional migration of oil out of the impervious surrounding sediments into the sands—which, of course, is also impossible. Dr. v. Höfer agrees with me (p. 490 of his paper) that there is no possible regional migration of oil through the pores of such impervious clays and shales as surround the "sands," and "that the migration of oil can take place only in cracks, joints, and fissures;" but his primary deposits, "the porous sands," are evidently altogether too small in cubic capacity, and too poor in organic contents, to furnish the enormous quantities of petroleum which have actually been produced from them.

Moreover, in the different fields of the world we can trace these primary sand deposits of Dr. v. Höfer lower and lower down in the geological scale, until we find them not only in the Devonian and Silurian but also in the Cambrian (Potsdam sandstone in N. Y. State) and in the crystalline rocks (Newhall, Cal.). This forces us to admit a still lower source, namely, the volcanic magma; and when these volcanics everywhere give so much evidence of containing large quantities of hydrocarbons either in their associated solfataric gases or in the lavas themselves, why should we reject that source to which we are forcibly led by the full consideration of the geological evidence mentioned above?

IV. If the petroleum deposits were coastal marine formations, deposited in shallow bays of the sea, they would be found under geographical alignments entirely different from the straight oil belts *in which they are actually being found.* The oil belts are evidently connected with the tectonic and orogenic disturbances of each region, and not with the ancient shore lines of the different formations. Moreover, along the same belt we find the petroleums impregnating sands of many different ages. In California, for instance, from and including the crystalline rocks to the Quaternary, there is a thickness of some 30,000 ft. in which productive sands are found. Yet, outside of the productive narrow belts along the Coast Range these 30,000 ft. of strata are barren of petroleum. Surely it cannot be imagined that marine bays of the ancient seas could align themselves in that way along fault lines or straight disturbed zones, and juxtapose themselves, one on top of the other, in formations of so many different ages, according to just the same tectonic zones of disturbance.

V. In shallow bays of the sea, in which sands are deposited, the organic matter is generally observed to have totally disappeared, having been destroyed by the oxygen of the air. Dr. v. Höfer admits this (p. 490); but he speaks of vague special favoring conditions which *occasionally* permitted the preservation and entombment of the organic matter. Would such special favoring conditions explain the enormous quantities of petroleums in the world? And why should these special favoring conditions occur at repeated periods during long ages in the same district along fault lines or disturbed zones; and what are these special conditions, anyhow? If petroleums were deposited in shallow bays, what about the deep vertical chimneys of Texas and Louisiana with several thousand feet of thickness of salt impregnated with petroleums?

VI. Admitting, for the sake of argument, that the soft organic tissues of animals, or the fatty tissues of plants, were occasionally entombed, how did the transformation of these into petroleums take place? Dr. v. Höfer says it was by the action of long time, which permitted a slow distillation at low temperature; and, strange to say, as a synthetic proof of that proposition he gives the experiments of Engler, in which oils similar to petroleums were produced from organic fats by heating in a retort at temperatures from 300° to 400° C.—experiments made under conditions of temperatures entirely different from those which obtain in nature, and therefore not in the least to the point. If long time distilled some of the organic matter of the sediments into petroleums, how is it that it did not produce any other effect on these sediments, and on the "coals" contained in them, which are unaltered and undistilled? And if long time could replace temperature in bringing about distillation, should not everything on this earth be in a gaseous state, as there has been all the time imaginable in the eternity behind us to bring about the same effect as the highest imaginable temperature? Phenomena of physical or chemical changes of state in elements require certain temperature points and will not take place at a lower temperature, no matter the length of time. One might as well say that by leaving a turkey long enough in cold storage it would cook itself!

I will now take up in their order Dr. v. Höfer's criticisms of my proofs as contained in his paper.

1. I, of course, never intended to state anywhere in my papers that there was no methane in petroleums; what I did say was, that the marsh gas formed from the decomposition of plants is quite apart and different genetically from the methane of petroleums.

2. Whether the crystalline schists or gneiss, from which a very light gravity oil is produced near Newhall, Los Angeles county, Cal., is a metamorphosed sedimentary or not, and is of Jurassic age or of Archean age, makes absolutely no difference in the point which I raised about this occurrence of petroleum, namely, that the petroleum is found in crystalline rocks and therefore cannot possibly be indigenous, and must come from the San Gabriel granite or the magma below. If these crystallines are ancient sediments, they must certainly have lost all their organic matter during the metamorphosis, and especially such light gravity oil as is found there must have an extraneous origin. To attribute that origin to the neighboring Tertiary oil field is altogether impossible; since light oils of that nature, full of gas, never go down in the strata but always ascend.

3. To suppose that the oil and bitumen in the quicksilver deposits of California and elsewhere may have been extracted and transported from deeper bituminous rocks by the ascending ore-bearing solutions, is to reverse the problem without the shadow of a proof. One might as well suppose that the quicksilver itself in these veins had its origin in the

wall rocks, instead of the ascending ore-bearing solutions. It is well known to mining geologists that ore-bearing solutions, circulating in veins and fissures, sometimes impregnate the wall rocks and become diffuse in them; but they cannot do the reverse, and receive their contents from these wall rocks.

4. I must differ entirely with Dr. v. Höfer when he says that the occurrences of bitumen, petroleums, or graphite in metalliferous veins, pegmatite dikes, or volcanic rocks, are scanty or sporadic occurrences. I maintain, on the contrary, that they are frequent all over the world and constitute positive and overwhelming proofs that these products, in all such cases, have an inorganic origin. To suppose that volcanic or eruptive rocks can distill and absorb into their own mass petroleums or natural gas from bituminous materials in the wall rocks, is again to reverse the question without the semblance of a proof, and moreover, involves an impossibility. One cannot look for distillates inside of the hot mass which produces the distillation. The very word "distill" means "driving away."

5. The occurrence of oil around volcanic necks in Mexico is questioned by Dr. v. Höfer, who says that it is widely distributed. From all the records of reputable geologists who have examined the occurrences of oil in that country, and even from the records of Mr. Villarello, quoted by Dr. Höfer (p. 487), it is quite clear that the petroleum deposits are always intimately connected with the volcanic necks. In fact, this is one of the clearest evidences in the world of the solfataric volcanic origin of oil in enormous quantities.

6. Dr. v. Höfer says that, as a logical consequence of my views, deposits of petroleums should always be found in the vicinity of volcanic eruptions. As we have just seen, when it is found in such vicinity in enormous quantities, as in Mexico, the proximity and connection of the volcanics and the petroleums are denied. But when the volcanics are not plainly to be seen, then their occurrence in the petroleum fields is demanded. Faulting and fissuring connected with volcanic manifestations take place all over the world, not only in mountainous regions but also in regions of plains, and may be, and are, often accompanied with solfataric emanations, though the lava or volcanic rocks themselves do not appear at the surface. It is clear upon careful consideration of these phenomena that any belt of country very rich in eruptives, such as the "inner bend" of the Carpathians cited by Dr. v. Höfer, might be too much faulted and fissured to permit the storage of the gaseous emanations in the greatly disturbed and broken surrounding sediments, while another belt of the same country such as the "outer bend," which is sufficiently fissured to permit pent-up vapors and gases to force their way through to the porous portions of the sediments, and yet not so much as to permit their complete escape to the surface, would naturally

furnish the best and richest petroleum fields. Even in such oil fields as those of Pennsylvania and northwestern Ohio, where the strata are apparently undisturbed, we find such well-marked breaks as the Eureka-Volcano break and the grahamite vein of solid petroleum near Cairo, in West Virginia, and the famous Findlay break in northwestern Ohio, so well described in several of Orton's reports as the most pronounced disturbance in that State. In the greatest number of oil fields, the elongation of the different pools or fields, all in one direction, clearly demonstrates that they are connected with fissuring and faulting.

I believe it is unnecessary to prolong this discussion and to take up Dr. v. Höfer's remarks on the objections advanced by me in my paper, Petroleums and Coals, to the theory of organic origin, as I consider that these objections still stand and have not been sufficiently answered. Most of these points are also covered by my remarks in this discussion, or in my new paper, read at the same meeting of the Institute with Dr. v. Hofer's, and written before I had seen the latter.

Prof. Dr. H. von Hofer (communication to the Secretary*, translated by R. W. Raymond).—The remarks of Captain Lucas, the Chairman of the Committee, are highly interesting for the geologist and the miner of saline deposits; yet none of the facts he mentions can be regarded as evidences of the volcanic origin of petroleum. The emanation of gas from salt deposits has long been known, as Mr. Washburne, in the present discussion, has already observed. At various places, in Galicia (Wieliczka); in the Alps (Hallstadt); and in the German potash district (the Desdemona mine near Ahlfeld), natural gases in salt deposits have been the cause of gas explosions. In the salt mine of Szlatina, Hungary, natural gas was encountered in 1783, and used for several years to light the workings. The natural gas occurring in connection with the salt deposits in the Chinese province of Sz'tschwan served for centuries as a source of heat.

Petroleum also is found in salt, though mostly only as an impregnation, or in pockets, in the Carpathians and the salt deposits of northern Germany. In the latter, it has occurred sometimes in considerable quantity. For instance, oil to the value of 35,000 marks was obtained last year from an intrusion of petroleum into the Hope salt mine, near Schwarnsteck. Yet, at the present time rock salt and potash salt, without any admixture of oil, are won at this mine.″

At all the European localities above named, there is no trace of volcanic activity, and no plausible ground for inferring it.

During the Third International Petroleum Congress, held in 1903 at Burcharest, I first proposed, as generally applicable to deposits of pe-

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* Received Apr. 18, 1914.

″ *Petroleum*, Berlin, vol. ix, p. 981 (1914).

troleum and natural gas, the "dome theory," which has since received manifold confirmation, and has proved highly useful in practice. I was able at that time to support my new theory with facts observed in three continents, and showing without exception the favorable influence of the dome-shaped structural form. Most of these cases could be referred to one type—that of a locally elevated anticline. The salt domes of Louisiana and Texas constitute a class by themselves. The cause of their genesis has remained unknown hitherto, and will be difficult to discover, so long as the salt deposits have not been explored outside as well as inside of the domes. Captain Lucas assumes a laccolite, which has elevated the dome; but of this he has no evidence to offer. If a volcanic laccolite, as such, were the source of the oil formation, we would naturally expect the occurrence of petroleum likewise in connection with other laccolites, such as those of Utah, Colorado, New Mexico, Dakota, etc. But nothing of this kind is known, so far as I am aware. In fact, I think that nothing at all is yet known, as to origin of these salt domes. I can only refer to the "Ekzem-hypothesis," which is becoming more and more popular in Europe, as stating the simplest way in which, under the influence, perhaps, of other abnormal genetic conditions, these domes may have been formed.

The Knapp boring proved conclusively in the dome the regular saline series; first (at the bottom) lime; then gypsum; and then rock salt—as it occurs in all such *stratified* saline deposits. Hence it is impossible to conceive a volcanic process for the formation of the salt deposit.

The solid and tough rock reported at the bottom of the abandoned bore hole was never determined, and can therefore furnish no basis for a hypothesis. Perhaps it may have been, not even a rock, but a piece of iron which had fallen into the hole.

I am sorry that I must answer my friend, Captain Lucas, by saying that I cannot change my mind according to his suggestion.

From Mr. Coste I expected a more detailed reply, dealing, point by point, with my criticisms. But he has but a few things for remark.

Regarding his comments, I would observe that in a genetic question it is not a matter of indifference whether a given gneiss is, in Rosenbusch's sense, an orthogneiss or a paragneiss; that is, whether it was formed from granite, or from a post-Archæan sedimentary rock. Mr. Coste, for the benefit of his volcanic hypothesis, makes the California gneiss granitic, whereas it is evidently sedimentary in origin, and can therefore furnish no evidence of the volcanic origin of petroleum.

The origin of the petroleum found in the quicksilver deposits of California, I leave, as I have already said, to be discussed by my American colleagues. I could say it came from some oil deposit not far below the place which it now occupies, with as much reason as Mr. Coste has for saying it came from great "volcanic" depth. One ignorant opinion would simply contradict the other.

It is notorious that in Mexico extensive oil fields are now known, which are far from any volcanic eruptives.

The various attacks of Mr. Coste upon the theory of the organic origin of petroleum and natural gas, I leave unanswered, until he shall have kindly offered a thorough and coherent criticism of my arguments, such as I made in the interest of science, concerning his.