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Map of the West Indian Islands.

ORDINARY GENERAL MEETING.*

GENERAL HALLIDAY IN THE CHAIR.

The Minutes of the last Meeting were read and confirmed.

The following election was announced :—

MEMBER :—The Rev. W. P. Schuster, M.A., Vicar of West Lulworth.

The SECRETARY.—We have here, Mr. Chairman, through the courtesy of Dr. Tempest Anderson, of York, a number of photographic slides taken by himself when in the company of Dr. Flett. He was sent out by the Royal Society to report on the volcanic eruptions of St. Vincent and Martinique.

The CHAIRMAN.—We all owe a vote of thanks to Dr. Tempest Anderson, who has lent the slides we have just seen. [Applause.]

The Rev. JOHN TUCKWELL then read the following paper :—

VOLCANIC ACTION AND THE WEST INDIAN ERUPTIONS OF 1902. By J. LOGAN LOBLEY, F.G.S., F.R.G.S. Author of *Mount Vesuvius*, etc.

No. II.

CONTENTS.

INTRODUCTION.

THE disastrous results of the West Indian eruptions of the present year have again powerfully drawn the attention of the civilized world to volcanic action.

With the advance of education, and the development of the means of communicating and disseminating information of those natural phenomena that conspicuously affect the material well-being of mankind, an intelligent interest in these

* Monday, April 20th, 1903.

phenomena will doubtless extend and deepen. In the future, therefore, we may expect that this interest will not be confined as hitherto to the few and these few chiefly men of science, but will be possessed by an ever-increasing number of those who claim to be educated.

The subject of volcanic action requires to a large extent the knowledge of observed facts, and also to a large extent philosophical deductions and conclusions, and consequently it appears to be a subject eminently worthy of the consideration of the Victoria Institute.

Volcanic action is indeed of such a conspicuous and startling character even when not destructive of life and property, that it has from remote times riveted attention and excited the wonder and awe of all those who have witnessed its more violent manifestations.

In ancient times, however, no attempt was made to explain it or ascertain its natural causes. It was readily accounted for, as were other striking natural phenomena, by attributing it to supernatural causes.

Classic fable abounds with allusions to volcanoes associating them with Pluto, Proserpine, Vulcan, and Typhœus. Pluto seized Proserpine in Sicily, near to Etna, and carried her down with him to reign as his queen in his own dominions far below. Vulcan, the god of fire and fusion, forged the thunderbolts of Jove by volcanic fires, and the smoke, and flames, and bellowings, and shakings of an eruption were but the evidences of his industry. The Greek Typhon was the personification of the principle of evil, and described by the Latins, under the name Typhœus, as having a hundred dragon heads, fiery eyes, a black tongue, and a terrible voice, and lying, groaning and uneasy, buried under the volcanic regions of Sicily and Ischia, all obviously suggested by the volcanic character of those islands.

In mediæval times, superstitious dread of the crater of a volcano as an opening to the place for lost souls supplanted the mythological fables of the ancients, and even at the present day this supernatural association lingers amongst the inhabitants of volcanic regions. The denizens of the immediate neighbourhood of Etna so regarded the crater 10,000 feet above them, and think of it with mind-oppressing awe.

With the eighteenth century began the scientific consideration of volcanic action, for in 1700 Lemery, long before the chemistry of Priestly and Davy, ascribed this action to chemical causes. Lemery was followed by Breislak, and later by our great English chemist Sir Humphry Davy, with similar hypotheses since all were based on chemical action. Chemical combination, as the cause of volcanic phenomena, was also supported by Daubeny, but both he and Davy advanced on Lemery and Breislak in regarding water as the source of the supply of the essential element, oxygen.

Cordier was the advocate of the hypothesis that has been favoured for the longest time and by the greatest number. This is based on the popular assumption that the earth is a great mass of fused matter enclosed in a thin shell or crust, through which by fissures the molten matter or lava issues when the interior mass is pressed upon by the adjustment of the exterior crust required by the shrinkage consequent upon the secular cooling of the whole globe.

The difficulty of accepting a thin crust led Sir Charles Lyell and Mr. Hopkins to the conclusion that there were probably portions of the crust in a fused condition, these subterranean reservoirs of lava existing where relief of vertical by lateral pressure allowed of the interior heat exerting its melting power, and that the cause of volcanic activity was supplied by the access of water from the sea.

Dr. Sterry Hunt and my old friend the Rev. Osmond Fisher, contended for a thin exterior crust and a solid central mass with an intermediate ocean of fused matter; and the great seismologist of the last century, Mr. Mallet, attributed volcanic heat to tangential pressure from secular cooling; while, still later, Prof. Prestwich advocated the importance of land surface water as a factor in the production of eruptions, while accepting a central fluid mass as the source of volcanic lava.

The impossibility of reconciling any one of these hypotheses with all volcanic phenomena and ascertained scientific facts, leaves the question of volcanic action still undetermined and an unsolved problem. It therefore affords a most interesting subject for consideration and discussion.

Volcanic Phenomena.

In estimating the value of any hypothesis it is in the first place necessary that we be acquainted with the phenomena to be accounted for; and each and all of these phenomena must be kept clearly in view.

Volcanic action may be said to be that which ejects material on to the exterior of the globe from below the surface. A volcano is therefore essentially a communication between the interior of the earth and the exterior, and consequently it is not necessarily a mountain or a hill, although the accumulation of the ejectamenta around the vent forms elevations of greater or less altitude and magnitude. Where, however, no accumulation takes place, as when from extreme violence the ejected material is widely dispersed, then a depression rather than an elevation is the result.

Leaving out of account such minor action as that of fumaroles, solfataras, salses, etc., volcanic eruptions may be roundly regarded as of three kinds; (1) emissive eruptions; (2) explosive eruptions; (3) partly emissive and partly explosive eruptions.

The first of these, emissive eruptions, is perhaps best exemplified by the lava flows of Mauna-Loa in the Sandwich Islands. From the two craters of this very extensive mountain mass, one, the summit crater, 13,675 feet, and the other, the crater of Kilauea, 4,000 feet above the level of the sea, a very fluid lava occasionally flows, and spreading out, forms successive sheets of basalt with a very gentle inclination, only from about 4° to 4·75°, and not separated by beds of scoriæ or ash.

In the prehistoric volcanic district of Auvergne in central France, there are domes of trachyte formed by acidic lavas without craters, which have evidently been the result of the cooling of a very viscid lava that has solidified without flowing away from the vent, which has thereby been sealed over with solid rock.

Lava flows in such cases of purely emissive eruptions are unaccompanied by noise or violence, and are merely, as it were, springs of fluid rock-matter rising from the deep interior through conduits to the surface, the lava being of different degrees of fluidity according to its varying chemical composition. The lava of Kilauea, being very basic, has indeed such great fluidity that it is drawn out into capillary glass by the wind, and this is called "Pele's hair," from the same goddess that has given the name to the Martinique volcano.

The explosive eruptions give the most terrific of all volcanic outbursts, although they are sometimes on quite a small scale.

In these eruptions no lava is seen, but instead there is an ejection, either continuously for a short time, or intermittently, of fragmentary material, with explosive violence, and thundering noises both in short detonations and continuous roars, and accompanied with subterranean rumblings and earth tremors and movements.

The material ejected and shot high up into the air—heavy masses, rounded "bombs," cindry fragments or scoriæ most irregular in form and partly vesicular, lapilli, and fine dust or ash—is often so great as to quite take away the light of the day, and the finer particles ascend to great heights and are then carried by winds and upper currents of the atmosphere to long and, in some cases, immense distances. Vast volumes of steam are given off, which condensing, form with the ash a mud, often wrongly called lava, that sometimes rolls down the slopes to the base of the volcano in a destructive torrent. Sea waves of great magnitude are also sometimes produced by displacement, or movement, of adjacent sea-bottoms and land masses either insular or coastal, which may occasion great destruction to life and property. These destructive oceanic waves are invariably wrongly called "tidal waves" by the newspapers, although they are seismic waves, and have nothing whatever to do with the tides, which are periodic. This is an illustration of the little attention paid to even the most elementary science in this country in ordinary education. Electrical phenomena are also produced, for volcanic lightning plays amongst the ascending ash-charged fumes.

The great historical eruption of Vesuvius, in A.D. 79, was an eruption of this class. By it the cities of Pompeii, Herculaneum, and Stabiæ were destroyed, and during its continuance the darkness was complete. Dry lapilli and ash overwhelmed Pompeii and Stabiæ, both at considerable distances from the crater, while a torrent of mud overwhelmed the city of Herculaneum, immediately at the foot of the mountain slopes, and no lava anywhere issued from the volcano. For a long period it would appear that the Vesuvian eruptions were explosive eruptions only, though of much less violence, since it was not until A.D. 1036 that there was any record of a lava-flow there, although in pre-historic eruptions, as shown by the basaltic rocks of Monte Somma, lava was abundantly emitted by this vent.

The Krakatoa eruption of 1883 is the greatest recent example of a purely explosive eruption, and by it the island of Krakatoa was almost destroyed. It produced complete darkness, and ejected by its explosive force the material of two-thirds of an island of thirteen square miles, covering the adjacent seas with floating lapilli of pumice. Its fine ash was carried upwards to a height estimated at 50,000 feet, the finest and highest having been carried three times round the globe, and occasioning the very beautiful sunsets of that time, conspicuously seen in this country. The eruption was heard 3,000 miles away, it produced an ocean-wave that caused great devastation, and an atmospheric wave that affected the barometer of Greenwich Observatory.

In the same region, the eruption of Papandayung, in the island of Java, in 1772, was of such terrific violence that a depression fifteen miles by six was formed, the whole mass previously occupying that area having been blown away.

A purely explosive eruption on a small scale was that of Monte Nuovo, near Baiæ on the shore of the Bay of Naples, in 1538, by which a cratered hill was formed by an ejection of fragmentary material from a newly opened vent, from which no lava has ever flowed.

The eruptions that are both emissive and explosive are the most usual, and they exhibit the most varied phenomena, since in these the characteristics of the non-explosive are added to those of explosive eruptions. The modern eruptions of Vesuvius and the eruptions of Etna and Hecla, are good examples of this class. Premonitions are commonly given by earth-tremors and subterranean rumbling noises occurring immediately preceding, or very shortly before, the outbreak; and very delicate and elaborate instruments, such as the late Professor Palmieri's seismograph at the Royal Observatory on Vesuvius, are sometimes employed for the detection and registration of these warning symptoms.

According to their character and relative violence these eruptions may be termed "strombolean," when there is slight but, during a prolonged period of time, continuous eruptive energy; moderate or normal, when the eruption is not a very great one; and "paroxysmal," when it is of much more than usual violence.

A flow of lava may either precede, accompany, or follow, the ejection of scoriæ and ashes, and may flow over a lip of the crater or through a tunnel in the crater-wall, or it may be emitted from an opening or openings on the slopes of the volcano. Eruptive energy may also be manifested at more than one point at the same time on the same volcano. Thus violent explosive ejections of scoriæ and ashes may be going on from the summit crater while lava is being quietly emitted from one or several orifices far below.

The explosive ejections, accompanied by a rushing roar, occur with very small intervals of time between, but they are usually distinctly separated when the eruption is not of great violence. The fine volcanic ash, much of it the result of the trituration of repeatedly ejected scoriæ, is not ejected to the enormous elevation it reaches by the explosive force, but is carried up by the ascending column of hot steam and gases, which in the heavier cold air rises to very high regions before being altogether dissipated or condensed.

THE WEST INDIAN ERUPTIONS.

Probably no volcanic outburst has been the subject of so much descriptive writing as that of the West Indian eruptions of the year 1902. Voluminous accounts have appeared in the daily press of Europe and America, articles containing much detailed description are to be found in the monthly magazines, in one of which the subject occupies 50 pages,* and several special commissions of expert observers have visited the islands and reported on the eruptions and their results. It will, therefore, only be necessary here to very briefly state the general features of the eruptions and to indicate the phenomena that were exceptional and peculiar.

There is no difficulty in classifying the whole of the outbursts, both in Martinique and St. Vincent, as explosive eruptions, for although the early accounts mention "lava," all that has since appeared show that there has been no emission of fluid lava. There were the usual premonitions of eruptive activity after dormancy; subterranean rumblings, accompanied by emissions of steam, had been heard for three months before the outburst; ash-clouds had begun to darken the sky in the latter days of April; and on May 2nd soft ashes lay 16 inches deep over the Savane of the city of St. Pierre. On May 3rd the so-called "smoke" was illuminated, indicating the presence of incandescent matter in the crater throat below. On May 5th a deluge of hot mud poured down not from the summit crater of the Martinique volcano, La Montagne Pelée, 4,000 feet, but from a vent at about 2,400 feet above sea level, where had been the "Etang Sec," a dry depression since the eruption of 1851 until April 27th last, when it held a pool of water 600 feet in diameter.† This great flow of mud overwhelmed the lower grounds and a large manufactory, the Usine Gúerin, at the foot of the mountain, just as Herculaneum at the foot of Vesuvius was overwhelmed by volcanic mud in A.D. 79.

After two days of less violent activity, May 8th (1902) wit-

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* *The Century Magazine*, August, 1902.

† *Fortnightly Review*, August, 1902.

nessed the appalling total destruction of a town with its 30,000 inhabitants in less than a quarter of an hour. This terrible catastrophe was caused by what must be regarded as an exceptional phenomenon. It has been variously described, and it is not a matter for surprise that the descriptions of some eye-witnesses under the terrors of their experiences were not scientifically accurate. It was said there was a "sheet of flame" spreading out horizontally over the city and burning everything beneath. In *The Times* the phenomenon was described as "a combination of suffocating heat, noxious vapours, a shower of burning cinders and a discharge of burning stones." Dr. Flett and Dr. Tempest Anderson, reporting for the Royal Society, say, "The most peculiar feature of these eruptions is the avalanche of incandescent sand and the great black cloud which accompanies it," and again, that "a mass of incandescent lava rises and wells over the lip of the crater in the form of an avalanche of red-hot dust. it is lava blown to pieces by the expansion of the gases it contains. It rushes down the slopes of the hill, carrying with it a terrific blast, which mows down everything in its path. The mixture of dust and gas behaves in many ways like a fluid. The exact chemical composition of these gases remains unsettled. They apparently consist principally of steam and sulphurous acid. There are many reasons which make it unlikely that they contain much oxygen, and they do not support respiration."*

Professor Heilprin has confidence in the report of the officers of a French cable-ship that was about eight miles distant, who while "watching the tall column of 'smoke' issuing from the summit crater, observed a puffing cloud rise from the flank of the volcano, followed immediately by a dense black vaporous mass which with intense rapidity rolled down the mountain slope, hanging close to the surface, and becoming brilliantly luminous as it approached the sea-border."†

On May 20th a similar phenomenon seems to have occurred which destroyed much that had been left standing by the eruption of May 8th, and again during the visit of Drs. Flett and Anderson on July 9th an outburst took place with a similar incandescent avalanche, and still later, on August 30th, when the town of Morne Rouge and three villages were destroyed.

Professor Heilprin is of opinion that the eruption of

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* *The Times*, August 21st, 1902.
† *Fortnightly Review*, August, 1902.

May 8th was not from the summit crater which previous to these events had held a small lake, called the Lac des Palmistes, but from a "lower vent which had opened on the western slope of the mountain," which he appears to think was that from which the mud-flow of May 5th was discharged. He also considers that the "glowing cloud was mainly composed of one of the heavier carbon gases brought under pressure to a condition of extreme incandescence, and whose liberation and contact with the oxygen of the atmosphere, assisted by electric discharges, wrought the explosion or series of explosions that developed the catastrophe."

In these accounts from highly competent observers there is some ambiguity and some divergence. From what follows, the phrase, "a mass of incandescent lava" cannot refer to fluid lava but to solid ejectamenta in a finely divided state, or properly volcanic ash, or, as it is elsewhere called in this report, "dust" and "sand." To this incandescent ash one report seems to attribute the appearance of a sheet of flame, and the other to actual incandescent gas which may rightly be called "flame." All accounts, however, agree in recording the characteristics of explosive eruptions as they have been already here described.*

The eruptions of St. Vincent were generally synchronous with those of Martinique, but the principal outburst took place on May 7th, a day on which La Montagne Pelée was not particularly active, but the day before the great explosion of that volcano. The Soufrière gave a premonition of renewed activity on May 5th by a disturbance of the waters of the lake which then occupied its old crater. On the following day its eruptions commenced, accompanied by violent earthquake action, the issue of great volumes of steam, and by loud explosive thunderings. Then on the next day, May 7th, St. Vincent's great outburst took place. Its terrific explosions could be heard throughout the Caribbean Sea, while immense volumes of steam rose to great altitudes. We are told that "A huge cloud in dark dense columns charged with volcanic matter rose to a height of eight miles from the mountain top, and darkness like midnight descended. The sulphurous air was laden with fine dust, and black rain followed rain of scoriæ, rocks and stones."

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* Many of the phenomena here described were witnessed by Dr. T. Anderson and Dr. Flett, and are described, with illustrations, by the former observer in the *Geographical Magazine*, March, 1903.

It was this dust, or fine ash, of which samples have been brought to this country from the islands of Barbados, where it fell at a distance of 100 miles from its place of discharge. As will be seen from the specimens, this volcanic ash is a fine grey powder, the largest particles being less than $\frac{1}{30}$ of an inch. Under the microscope it is found to consist of crystals of plagioclase felspar, hypersthene, augite, and magnetite with a small amount of volcanic glass. An analysis by Dr. Pollard gave the following result* :—

Silica	52·81
Oxide of titanium	·95
Alumina	18·79
Peroxide of iron	3·28
Protoxide of iron	4·58
Oxide of manganese	·28
Oxide of cobalt and nickel	·07
Lime	9·58
Magnesia	5·19
Potash	·60
Soda	3·23
Phosphoric acid	·15
Sulphuric acid	·33
Chlorine	·14
Water	·37
	100·35

It is an interesting fact that the ash from St. Vincent was carried to Barbados by an upper current of air moving in the contrary direction to the surface wind which was the ordinary "trade wind" of the region, from east to west, the island of Barbados being due east from St. Vincent.

Apart from the extraordinary incandescent avalanches of the Martinique volcano, the West Indian eruptions of 1902 have not exhibited phenomena other than normal. Their magnitude has been often exceeded, and in our own times the Krakatoa eruption of 1883 was a much greater one, with much more topographical derangement, and equally great destruction of human life.

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* *Nature*, June 5th, 1902

Geological and Geographical Conditions and Results of Volcanic Action.

For a due estimation of the sufficiency of any hypothesis of volcanic action it is, however, not enough to consider only the phenomena of eruptions. The larger facts, both geological and geographical, consequent upon, or incidental to, volcanic action, not only in the present epoch, but during past periods of the earth's history, must be taken into consideration, and their relative importance carefully valued.

These are so numerous and varied that a volume would be required to do justice to their interesting and important characters. All that can be done here is to give a brief summary, and with this I must now content myself.

The outputs of volcanic eruptions relatively to the bulk of the globe are individually infinitesimal, and in their aggregate form only a small part of even the land surface of the earth.

There is no general constant flexibility of the earth's surface, each subsidence or upheaval being local and of limited duration, while astronomical calculations and the general stability of land and sea during long periods prove great rigidity of the exterior of the globe as a whole, and consequently a great thickness of solid rocky substructure.

The inorganic Palæozoic conditions of the earth's surface were generally similar to those of Neozoic times, as shown by similar organisms, ripple-marks, worm-burrowings, rain-pittings, etc., and Palæozoic volcanic action does not appear to have been greater than Neozoic, while the highest mountain ranges have received a large amount of their present elevation since the close of the secondary period.

The specific gravity of the globe is only 5·5, although that of surface rocks is over 2·5, while the pressure at the centre is calculated by Walterhausen at 2,498,600 atmospheres, and by Laplace at 3,000,660.

Heat increases with depth below the surface at a rate that if continued would give rock-fusion, under atmospheric pressure only, at from 25 to 30 miles, and at half the distance to the centre a temperature equal to that of the sun, an impossible heat, and consequently there is not a continued uniform increase of heat.

Rock-fusion resulting from relief of vertical pressure in subterranean regions would not, with an open vent, be limited in lateral extension, and surface ruptures would be produced with lava outputs on a scale far transcending any catastrophes that have ever occurred; yet volcanic action has gone on for long periods of time in many areas without causing any surface derangements other than the building up of conical hills or the rupture of very small areas.

Areas of great volcanic activity in Palæozoic and even in Tertiary times, although still contiguous to the sea, are, and have been for prolonged periods, perfectly unvolcanic, and insular volcanoes in more recent times have become extinct without change of geographical conditions, as in Madeira and the Canary Islands.

Lavas from different volcanic regions though having a general resemblance, are not the same in composition, and some present considerable differences; while the products of the same volcanic centre at different periods may be respectively trachytic and augitic, as those of the Alban Hills; or may be characterized by different mineralogical features, as those of the Somma-Vesuvian centre; and moreover trachytic and augitic lavas may respectively be emitted by each of two vents in the same volcanic region.

Lava solidifies with a small loss of heat, lava flows of little volume solidifying rapidly, and many lava flows are small.

Eruptive energy may suddenly occur where no volcanic vent previously existed, in some cases followed by a continuance of activity, as at Jorullo, and sometimes after a brief outburst followed by perfect quiescence, as at Monte Nuovo.

Two volcanic craters on the same dome may not be sympathetic in activity, as Kilauea and Mauna-Loa, yet the eruptive axis of a volcano may alter its position as in Vulcano and Vulcanello, and the volcanic foci of Etna and Vesuvius were calculated by Mallet to be only a few miles deep.

The chief *Northern* European Tertiary volcanic outpouring, that of the lavas of Antrim, Iona, Staffa, and Mull, was in the same geological epoch as the great Central European subsidence, and the great *Central* European outpouring, that of the lavas of Auvergne, Central Germany, Bohemia, and Hungary, was contemporaneous with the principal Central European Tertiary elevation. The Andean Central American and West Indian volcanic regions are rising, or geologically recently elevated, areas; and, generally, volcanic action is on *rising* rather than subsiding areas.

Active volcanoes, with few exceptions, are near the sea or water areas, and inland extinct volcanoes were similarly situated at the period of their activity, as in Auvergne and Hungary, while extinction of activity has followed the removal of the coast-line to a very moderate distance, as in the neighbourhood of Rome.

Steam is a most abundant and sea-salt a common product of explosive eruptions, and some volcanic tufas consist largely of marine *Diatomacea* as in Patagonia.

Enormous flows of lava have been poured on to the surface without explosive effects, and there are vast beds of lava-rock not associated with volcanic scoriæ or cones, as in Antrim, Abyssinia, and Idaho; and Plutonic igneous rock-masses and dykes have been also formed without explosive effects.

Volcanoes quite dormant for many centuries have sometimes commenced a new epoch of activity, as Vesuvius in A.D. 79; and sometimes after an eruption have relapsed into complete quiescence, as Epomeo in 1302.

Pressure caused by shrinkage of the earth's crust would be tangential, not vertical, and the heat produced by the crushing pressure of rocks is not localized at the points of contact, but disseminated through the rock-masses synchronously with production.

2,000,000 tons pressure are removed from every square mile of the earth's surface when the barometer falls two inches, and observations of the activity of Stromboli and Vesuvius seem to indicate an approximation to periodicity of eruptive energy coincident with (1) autumn and winter; (2) the lunar syzygies; and (3) with hygrometric atmospheric conditions.

Antecedent to eruptions, earthquakes, or earth-tremors, occur, especially, and more violently, previous to the opening of new vents, as at Jorullo and Monte Nuovo, and after long dormancy, as before the first historic eruption of Vesuvius.

Though great volcanic activity may occur at particular periods, yet no sympathy between the eruptive energy at two well separated vents has been with certainty found to exist.

This statement of governing facts to be kept in view when an endeavour is made to explain the cause of volcanic action, though brief and incomplete, is perhaps sufficiently comprehensive to prevent a too ready acceptance of inadequate hypotheses, while it may serve to show as well the difficulty as the highly interesting character of the subject. So difficult, indeed, does it appear to the authors of geological works, that for the most part they content themselves with a description of phenomena and a statement of some hypotheses, while refraining from giving any explicit opinion of their own.

The Cause of Volcanic Action.

The due consideration of the cause of Volcanic Action would require a treatise and, therefore, all I can do here is to give an outline that may be useful, and to refer my hearers or readers to where I have dealt more fully with the subject.* For the sake of brevity and clearness it may be well to proceed by the method of elimination.

The hypothesis that must first be disposed of is that of all lava being derived from one great central source, or, in other words, that the globe contains in its interior a vast central body of fused rock-matter that gives to all volcanoes their lava and other ejectamenta.

This is based on several considerations. The increase of temperature with descent from the surface, found in mines and borings, will give a rock-fusing heat at from 25 to 30 miles depth if continuous. The Nebular Hypothesis of the origin of the Solar System gives an original heat to the earth-mass equal to that of the sum at the time of detachment, and which heat would be greatly above the fusion point of rocks. This high temperature would be very largely retained in the interior of the earth-mass, while the exterior would cool and solidify, and

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* Report, British Association, Bath, 1888, p. 670.
"On the Causes of Volcanic Action," *Proc. Geol. Assoc.*, 1889, vol. xi, p. 1.
Mount Vesuvius, 1889, chapter viii, p. 212.
Report, British Association, Oxford, 1894.
"On the Climate of the Cambrian Period," *Knowledge*, November, 1894, vol. xvii, p. 260.
"On the Mean Radial Variation of the Globe," *Quart. Jour. Geol. Soc.*, 1895, vol. li, p. 99.
"On the Cause of Earthquakes," *Knowledge*, July 1895, vol. xviii, p. 161.
"Volcanic Phenomena," *Jour. City of Lon. Col. Sci. Soc.*, 1896, vol. iv, p. 1.
"The Foldings of the Rocks," *Knowledge*, 1896, vol. xix, p. 162.
"On the Source of Lava," and
"On the Post Cambrian Shrinkage of the Globe."
"The Mean Radial Variation of the Globe." Rep. Brit. Assoc., Liverpool, 1896.
Presidential Address, 1896, *City of Lon. Coll. Sci. Soc.*, *Jour. of Soc.*, vol. iv, p. 69.
"On the Depth of the Source of Lava," *Quart. Journ. Geol. Soc.*, 1897.
"The Crust of the Globe and its Disturbances."
Presidential Address, 1897, *City of Lon. Coll. Sci. Soc.*, *Jour. of Soc.*, vol. v, p. 1.

thus it was concluded a fused mass would remain in the interior enclosed in a solid crust. There is, besides, a general similarity in the character of volcanic ejectamenta in all parts of the world.

It has, however, now been ascertained by physical research and astronomical observation, that the rigidity of the earth as a planet is so great that it must either be a solid sphere or have a solid crust of very great thickness, from 400 to 800 miles at least, a thickness of massive cooler rocks obviously far too great for lava to pass through. Lord Kelvin is of opinion that the earth is solid to the centre. The increase of heat with descent will in its fusing effect be counteracted by the enormous pressure of the exterior rocks, and thus solidity may be maintained at a very high temperature. The general similarity of volcanic ejectamenta may be explained by the general similarity of the crystalline rocks which form the platform, as it were, upon which the clastic or sedimentary rocks are superimposed, and which, therefore, we must conclude, underlie the derived rocks everywhere around the lithosphere of the globe. These primordial rocks are made up of minerals that are combinations of but a few chemical elements in the aggregate, and so on being melted will give generally similar products. And it is only a general similarity that exists, since there is a considerable divergence in specific chemical composition to be found in the outputs of different volcanoes.

From these considerations, the central source hypothesis must be regarded as quite inadmissible, and ought now to be looked upon by all writers on the subject as obsolete, and yet this hypothesis is implied in much that is written on volcanoes in recent works and especially in newspapers.

The wide-spread opinion, however, that lava is derived from a distance of about 30 miles from the surface, is not dependent on the central source hypothesis, since it is compatible both with separated reservoirs of fused rock matter in a thick crust, or in an otherwise solid globe, and with an intermediate Ocean of fluid lava between a solid central mass and a solid crust.

Lateral pressure relieves and lessens vertical pressure, and so at places in a thick earth's crust it was said the great vertical and fusion preventing pressure of the exterior rocks may be so much lessened by lateral pressure that the internal heat may exert its fusing effect, with the result of converting solid rock-masses into subterranean lakes of molten rock-matter, from which the surface volcanoes receive their supplies of lava.

To this it may be replied. that a thickness of 30 miles of rocks cooler than lava at their base and becoming continuously cooler to the surface, even with a conduit throughout, is much too great a thickness for lava to pass through unsolidified. A lava column of 100 feet diameter would give a much greater flow than the great majority of lava emissions either in the present epoch or in past geological periods. Yet this would be a mere thread in proportion to its length of 30 miles. From the records of many eruptions, I find that an ascending movement of 1 foot per second will give an unusually rapid flow of the more mobile or basic lava, yet at this rapid rate the lava would require 44 hours to travel from a base of 30 miles depth, all the time in contact with cooler and, as it rose, with increasingly cooler rocks. Fluid lava has little excess of heat over the fusion point and consequently with little loss of heat it solidifies. Such a column of lava would therefore solidify long before reaching the surface. But the great majority of lava-flows are much smaller than one from 100 feet column, and in a great number of cases are very small flows. These must, therefore, be from very thin columns or from very slowly ascending columns, and in either case the possibility of the fluid lava reaching the surface must be dependent on a comparatively small depth of source.

There is, again, another objection that seems to me to be even more conclusive against a 30 miles depth of the source of lava. This is that there could not possibly be a fissure or conduit through 30 miles of rocks, or, indeed, through rocks at all approaching that thickness. The weight of a column of ordinary rock of 1 square foot section is 400 tons per mile, or 800 tons for two miles. This exceeds the crushing weight of granite, which is 720 tons per cubic foot. Although in great mass, from lateral resistance of the contiguous rock-masses giving a counteracting resultant force, the full weight of 800 tons would not be exerted at 2 miles depth, yet it would at a somewhat greater depth, and thus, as M. Tresca has shown, at a depth of more than a few miles from the surface, the rocks, although solid, will "flow," or move horizontally, if laterally unsupported, and consequently cracks or fissures at these depths are impossible. Hence it will be quite safe to say that no openings exists below a few miles from the surface.

Thus it would appear that both the central source of lava and the 30 miles distant source of lava, must be given up, and with them, of course, all hypothesis founded on those bases. This narrows and simplifies the inquiry very greatly, since, with the elimination of these hypotheses, we can no longer regard the internal planetary heat of the globe as that which fuses rocks and gives volcanic lava, for the internal heat at less depths than 25 miles is altogether inadequate for the melting of rocks even under the small atmospheric pressure of surface conditions.

But the rock-fusing temperature that gives fluid lava has to be accounted for.

This at the moderate depth which will alone allow of communication by a conduit with the surface, it seems to me, can only be explained by chemical action being brought into play. This, however, does not exclude whatever effect the planetary heat existing at that depth is capable of exerting. At a depth of five miles there is doubtless, in accordance with the Report of the British Association Committee on Underground Temperatures, a temperature of about 500° F. Heat favours chemical action and will cause it to arise where under cooler conditions no chemical action would take place. But chemical action may be prevented or checked by pressure, and the normal pressure at five miles depth is enormous. Then this vertical pressure may be greatly relieved by lateral pressure and other causes, and when so relieved, chemical reactions that had been prevented at a favouring temperature by greater pressure would commence. This chemical action will give an accession of heat that may give rise to further and more intense chemical action that will still further raise the temperature. By this action and reaction heat may be augmented until a rock-fusing temperature is reached. Such action, of course, would only take place where the contents or composition of the rocks gave suitable elements for chemical reactions, and for only so long as those conditions continued. Thus volcanic action in definite and limited areas, as well as the local extinction of volcanic action where geographical conditions are unaltered, may be readily explained.

Although lessened, the pressure of the exterior rocks may yet be great, and this together with the increase of volume by fusion and the expansion of adjacent rocks by the neighbouring great heat, will force the lava upwards through any conduit available. Such a rise of lava may bring it into contact with the water of the exterior rocks, when hydrothermal conditions, or the sudden production of steam, will cause explosive effects and give the earth-tremors and thunderings of incipient eruptions, and may also produce rendings of the surface rocks, and so form passages for great and sudden influxes of sea or lake water, that will then cause the greater explosive effects of eruptions, and produce the vast volumes of steam that ascend above the eruptive craters.

Should the lava not find a conduit extending to the surface, Plutonic dykes may be formed far below; and should lava reach the surface without meeting with water, a purely emissive eruption will be the result.

The great paroxysmal explosive eruptions, such as the recent West Indian outbursts, may, therefore, be regarded as due to the formation and rise of an unusually large body of lava, together with the supply to the volcanic conduit of sufficiently large bodies of water, to transform the whole into solid fragmentary ejectamenta. As the fusion temperature of rocks is above the critical point of water, some of the water may be decomposed by the disassociation of its elements, and free hydrogen being thus evolved some of the effects stated in the reports of the recent eruptions might be produced by the inflammability of that gas.

The time of an eruption may, I consider, be determined by one or more of several factors, that will be sufficient to give the requisite relief of vertical pressure. Amongst these factors will be lateral pressure, secular elevation, planetary or lunar attraction, and hygrometric atmospheric conditions. In illustration of the relief of pressure consequent upon the last-named factor, it may be mentioned that a fall of the barometer of two inches will remove pressure from the area of the base of Mount Etna alone, to the extent of two thousand millions (2,000,000,000) of tons. The islands of Martinique and St. Vincent, with the other islands of the Lesser Antilles, are on the crest of a long ridge that has been elevated in comparatively recent geological times, and the elevatory movement has apparently not yet altogether ceased. It is this elevation with its consequent relief of pressure that has most probably been the cause of the renewed volcanic activity in the Windward Islands of the West Indies.

The explanation of volcanic action which I have here ventured to give is in accordance with an hypothesis I brought before the British Association so long ago as the Bath Meeting of 1888. As I have not since become acquainted with anything to shake that hypothesis, perhaps I may be pardoned for having some confidence in its soundness, which appears to me to be supported and illustrated by the West Indian eruptions of 1902.

DISCUSSION.

The CHAIRMAN.—Our Secretary, who has had to leave, has put into my hand his remarks on the two papers.

The SECRETARY much regretted that neither of the authors of these two valuable papers were present. He had hoped that both would have been with them this evening—as the date for reading had been originally fixed in order to meet their convenience. But Professor Spencer's arrival in England had been delayed owing to various causes. He was, in fact, at that moment crossing the Atlantic, and is expected to arrive about the 28th of this month. Professor Logan Lobley writes that he was obliged to leave England for France and Spain on the 14th inst., and that he greatly regrets not being able to read his paper and take part in the discussion, which he hopes will be interesting.

We have to express our thanks to Dr. Tempest Anderson, of York, for the use of the lantern slides of photographic views taken by himself when in company with Dr. J. S. Flett. He was engaged in reporting, last year, for the Royal Society on the phenomena displayed by the volcanic eruptions in the West Indian Islands. These will have given members a better idea of the character and effects of the eruptions than any oral or written description; they are well reproduced in Dr. Anderson's paper, published in the *Geographical Journal* for March, 1903.

The two papers before us this evening appear to be complementary. Each deals with an aspect of the subject not treated in the other. Professor Spencer's paper gives us very precise details regarding the physical structure of the West Indian Islands, which have, for several years past, been the objects of his special and arduous investigation. He has shown us that these islands have undergone great vertical movements of elevation and depression; that there were volcanic outbursts on a much larger scale than those of recent times at a period which cannot be definitely fixed, beyond the fact that they are older than the Tertiary period, and it is satisfactory to know that the volcanic eruptions have decreased in intensity into recent times. He also maintains his view that the plateau of the West Indian Islands formed a great causeway during the Pleistocene epoch (which was one of great elevation of the sea-bed and land) by which the two continents were joined, and by means of which land animals migrated from one continent to the other, and finally he points out the connection between the oscillations of level and the outbursts or subsidence of volcanic activity.

Professor Logan Lobley, while referring to the West Indian volcanoes, deals with the source and origin of volcanic action on broad principles, which can scarcely be gainsaid. By his work on *Mount Vesuvius*, and his numerous papers in scientific publications, he has taken a high place amongst authorities on vulcanicity, and I quite agree with him that the central-source theory is untenable. I do not think, however, that he sufficiently recognizes the necessarily distinctive sources of the heavy basic, and the lighter acid, lavas as originally determined by Durocher, nor does he account for the sequence of these varieties of lava at apparently the same source as in the case of the Siebengeberge in the Rhine Valley, where the light acid trachyte was succeeded by the basic basalt lava. These, however, are minor points, and do not detract from the intrinsic value of the essay, and they may not have come within the scope of his communication.