THE ERUPTION OF PELÉE

HEILPRIN

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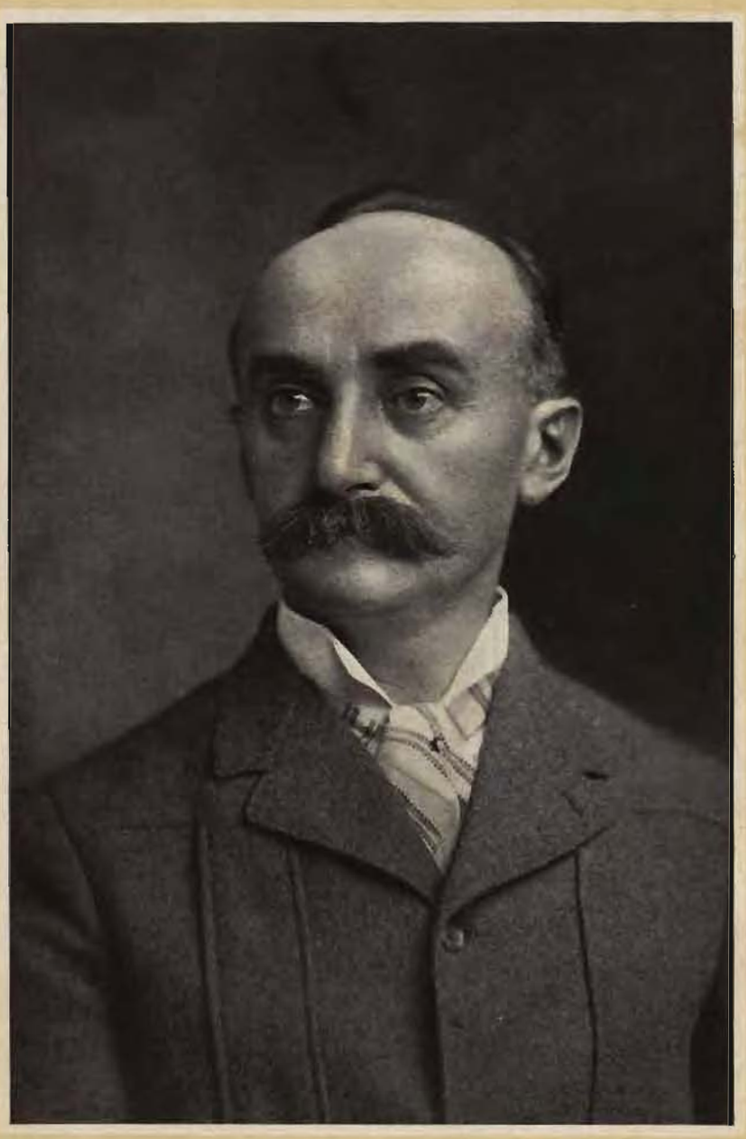

Angelo Heilprin

THE ERUPTION OF PELÉE

A SUMMARY AND DISCUSSION OF THE PHENOMENA AND THEIR SEQUELS

BY

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Publishers' Note

THE present volume was wholly in type at the time of the author's death on the 17th of July, 1907. It embodies the main scientific data contained in his "Mont Pelée and the Tragedy of Martinique" and the "Tower of Pelée," and presents the results of the observations made in his fourth and last visit to Martinique, in February, 1906, when it was found practicable to descend into the crater of Pelée and examine the fragments of the tower, an investigation which confirmed Professor Heilprin in the theory, previously put forward, that the giant obelisk was the ancient core of the volcano. The sequels of the great eruption of Pelée—the remarkable afterglows and other atmospheric phenomena visible in all parts of the globe—are described in the light of the most recent scientific observations and reports. In the concluding chapter the author sets forth his views regarding the inter-relationship of volcanic and seismic disturbances.

The plates are mainly taken from the two works above mentioned (some of them enlarged) but there are several that are not contained in these volumes.

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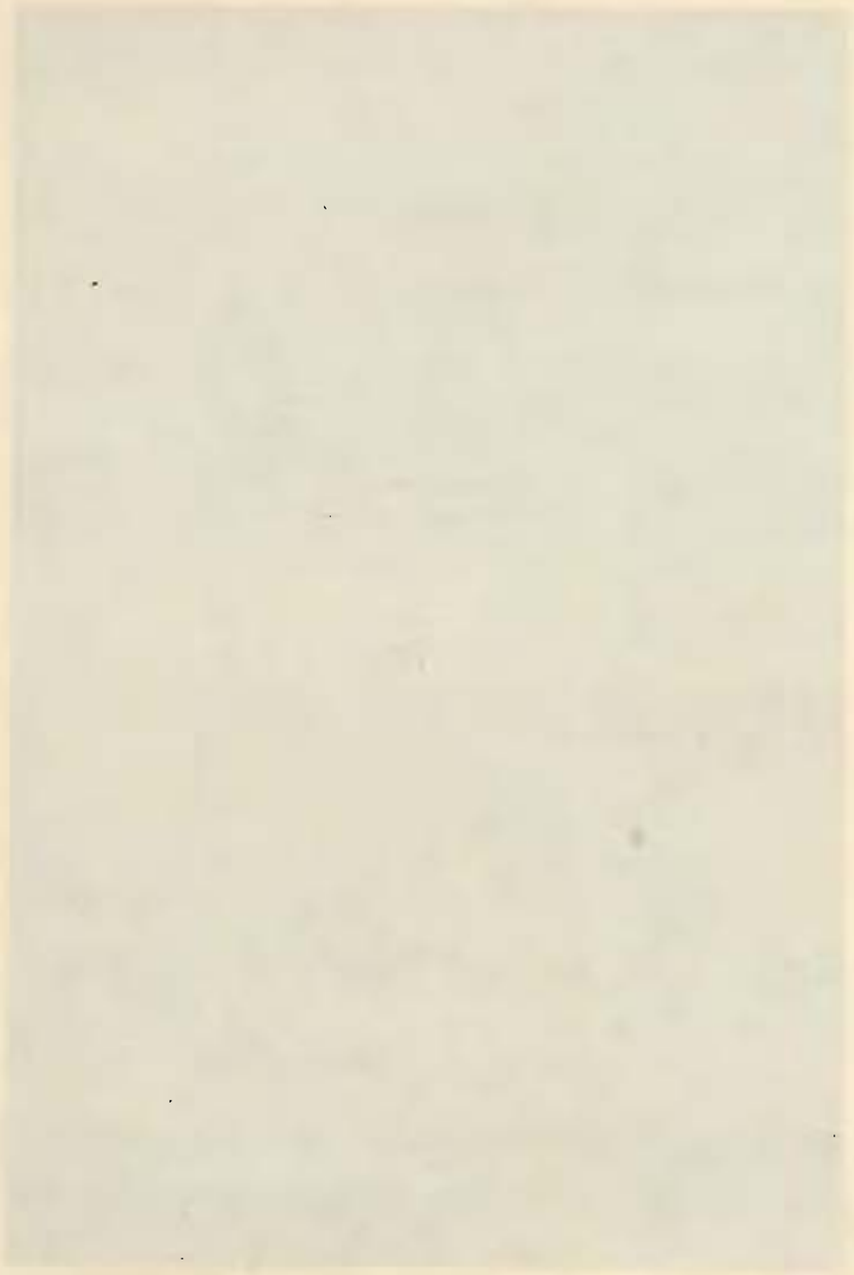
From a painting by the author.



THE ERUPTION OF PELÉE

I.

THE GEOGRAPHY OF PELÉE.

MONT PELÉE (frequently transcribed *la Montagne Pelée*, the "bald mountain") which, prior to the eruption of May 8, 1902, was barely known beyond its own little territory, occupies with its contreforts nearly the whole northern section of the island of Martinique. Its humble height, hardly equalling that of the famous Ben Nevis of the Scottish Highlands, does not permit it to loom up lofty, but it holds its crown veiled in mist during the greater part of the day.* The appellation of "bald mountain" is usually associated with a bare spot which it is thought the volcano carried about its crown at the time when it was first described by Dutertre, about 1640; and inferentially this characteristic is noticed by Father Labat, who in his "Nouveau Voyage aux Isles de l'Amérique" (The Hague, about 1724) refers to himself as the "*père* (or *mont*) *pelé*" (bald father). Just where or how this assumed bald spot on the volcano was located cannot at this time be determined, for it is certain that in the past, as well as in the recent present, the mountain was covered with a luxuriant vegetation quite to its summit; and I am informed that even the precipitous face of the Morne de La Croix was similarly garnished. Félix Lombard, in his paper "La Martinique et les Erreurs des Géographes," † dwells emphatically upon this characteristic of the mountain, and asserts that at the time of his writing the volcano was visible in its full extent and that it was entirely covered with most luxuriant green (*vert le plus vigoureux*). It should be said that there are those who believe that the word *pelée* is of Carib origin and that it bears no relation to the French word, which has given the modernized meaning of "bald."

The "*grands bois*," or what has frequently been referred to by writers as the forest primeval, with all the wealth and luxuriance of vegetation that a tropical nature can supply, were the glory of the mountain. MM. Leprieur, Peyraud and Rufz, who composed the scientific commission that investigated the eruption of August, 1851, speak in their report of the magnificent woodlands of bromelia, melastome and gaylussacia that they were obliged to traverse, and which only thinned off to lighter woods near the summit. Hearn describes

*The approximate geographical position of Pelée is given by Sapper as: lat. 14° 48′ 50″ N.; lon. 61° 10′ 12″ W. ("In den Vulkangebieten Mittelamerikas und Westindiens," 1905, p. 205).

†*Revue Scientifique*, August 9, 1884.

the same forest forty years later, and refers rapturously to the beauties and fascination of the tangled mazes which held one at almost every step. Even so late as the closing days of April of the year of the great cataclysm (1902) the woodland was in nearly its full magnificence. Little or nothing remains of all this on the sides where the outflows took place, and it is astonishing how completely the traces of the once noble vegetation have been extinguished. For the better part of a year after the May eruption Pelée showed up from the west and southwest naked as though it had never known a cover. And far beyond the line of absolute destruction the tree-growth had been crippled, grayed and laid low by the ash that had fallen upon it. On the eastern face of the mountain the zone of destruction previous to the great eruption of August 30, 1902, covered only the middle and upper slopes; and the forest, though battered and burned, remained standing in part. Three days before the August eruption I noted the cindered forest of the Falaise gorge, at an elevation of from seventeen hundred to eighteen hundred feet, returning to life, with brilliant greens decking the new crowns. The revivifying tree-ferns were especially beautiful. New life was also beginning to clothe the ridge-sands of the Rivière des Pères and the Rivière Sèche on the southwest. All of this disappeared with the August eruption. But once again the force of life is beginning to assert itself, and the spectator, who from the commanding eminence of the Morne des Cadets looks over to the unobstructed slopes of the still gently steaming volcano, sees these slopes illumined in part by a rapidly developing vegetation. Saint-Pierre is already overgrown by low jungle, and even the summit dome of the mountain has given root to diminutive tree-ferns. Of the growth of palms at the summit of the mountain and the clumps of fern and lobelia that in past years delighted the visitor to the Lac des Palmistes, naturally not a vestige remains.

The summit of Pelée, which commands a superb view of the island and of its surrounding ocean, was prior to the May eruption constructed in greater part of a small lake-basin and of a line of bounding heights lying on its western and northern sides. The highest of these, which bore the cross * that was placed upon it by the late Père Mary, was the Morne de La Croix, whose height is roughly assumed to have been two hundred and fifty or three hundred feet. Its elevation above the sea is generally stated to have been four thousand four hundred and twenty-eight feet, which is the measurement of Dupuget† in 1796; but the determinations of the scientific commission of 1851 give for the full height of the volcano only four thousand one hundred and ninety feet (twelve hundred and seventy-seven metres), which conforms closely to my own barometric values, and, I believe, more nearly represents the true altitude.

The Lac des Palmistes was a shallow pan of water whose surface lay but little below the bounding lip of the basin on the eastern side. Leprieur, Peyraud

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*Replacing a more ancient one.

†*Journal des Mines*, Paris, 1796, 3 (part xviii), p. 58.

and Rufz, who visited it in 1851, immediately after the eruption of that year, describe it as being about three hundred paces in circumference, and resting on a floor of mud and pumice fragments. Their estimate is, I believe, an approximately correct one, although the lake is sometimes described as having been very much larger. Beyond the position that it occupied, there was nothing to suggest for it the nature of a crater-lake, which the Martiniquians generally thought it to be. Labat refers to this summit lake in his work, published about 1724, but it would seem that its crateral origin was assumed only after the publication by Jonnès of his paper "Explorations Géologiques et Minéralogiques du Volcan éteint de la Montagne Pelée."* The reference to the lake is, however, not very clear; and the statement that the "great crater is now converted into a lake" (translation) may very properly refer to the crater on the southwest side and to the Étang Sec. Jonnès could hardly have referred to the summit lake as occupying a large crater.†

At the time of my earliest visits to the summit of the volcano this attractive mountain tarn, which for many years had been the central point for picnicking parties of an extensive region around, had disappeared, and no trace of the waters remained. The basin itself had been largely filled in with matter ejected from the volcano, so that the floor lay only from two to three feet below the rim on the eastern side. The floor was still steaming over most of its part, and it gave out a peculiar "steamed" odor of mineral oil. My thermometer, thrust two and three inches beneath the surface, gave a temperature of from one hundred and twenty-four to one hundred and thirty-two degrees, and at a somewhat deeper point, one hundred and sixty-three degrees. In just what manner the lake-water was thrown off as the result of the first eruption cannot be known; but it is reasonable to assume that the greater part of it may have been steamed off by the heated ejecta that were thrown into it. There is nothing to support the view that it was in any way sucked into the crater and became a determining factor in the explosion. The lake-basin remains intact, and has undergone no changes beyond that of infilling and contraction of its area.

The plateau-summit of the volcano, which was thus partly occupied by the basin of the Lac des Palmistes, slopes off southward in the direction of Morne Rouge, and "spills" off on the east and southeast in a gradual coalescence with the outer slopes of the mountain. On the southwest it ends abruptly with the wall of the crater. The westerly (or crater) wall of the butte that still represents the Morne de La Croix drops into the basin of the Étang Sec with a practically vertical face—*à pic,* to use the expression of French investigators. How much of the Morne de La Croix fell with the first disruption it is impossible to say; but it is certain, as could easily be determined by a comparison

**Bulletin Société Philomatique de Paris,* 1820, p. 8. Pelée was ascended by La Condamine, who also made a measurement of the mountain, but I have been unable to obtain the record of observations made on this visit.

†The map accompanying Labat's "Nouveau Voyage aux Isles de l'Amérique" locates a lake (Lac des Palmistes?) on the mountain.

of contours, that not nearly so much of it disappeared in the early weeks following the eruption of May 8 as was generally supposed. I should rather believe that its height was lessened only by from fifty to seventy feet, instead of the one hundred and fifty as claimed. The fall of the *piton* itself—*i.e.*, of the pinnacle surmounting the Morne—seems to have been finally accomplished on May 24, as is published in *L'Opinion* of Fort-de-France, in despatches from Morne Capot, as follows: one-twenty P.M., "*Autre fragment Piton s'est écroulé*"; and eight P.M., "*Piton disparu complètement.*"

Pelée has not the conical outline of the typical volcano, but is elongated on a northwest and southeast axis, with the highest point lying in the northwest. It is plain to see in this direction that it is only part of a former larger mountain, whose buttressed masses lie still farther to the north, and of which the Morne Sibérie, the Pain du Sucre, and the Piton Pierreux, the last-named nearly two thousand feet in elevation, are still prominent relics. The sea face is on this side abrupt and precipitous, presenting ragged bluffs and promontories, with some detached islands and island points. Standing off some little distance from this side of the coast, the spectator obtains the only symmetrically contoured outline of the volcano, and notes the majestic extent of its great flanks as they sweep over the whole forefoot of the island. The gently falling slopes toward the interior, being usually free of complication and rising with low gradients of from fifteen to twenty-five degrees, are exceedingly pleasing to the eye, and conform to the picture of many of the other volcanic mountains of the Lesser Antilles. Towards the southeast Pelée sends out a long ridge to unite with the mass of the Pitons de Carbet, the point of second elevation in the island (3960 feet), and thus builds out, with the peaks of Carbet and their long slopes, nearly the whole mountain relief of two-thirds of the surface of Martinique. The volcano itself covers an area of about fifty square miles.

The singular manner in which the mountain has been cut up into ridge-backs and deeply separating water-ways, all radiating from almost the exact centre of the volcano, may liken it to a many-rayed elevated star. Some of these ridge-backs are sharp enough to permit them to be called *arêtes*, and they fall off rapidly into the troughs that lie on either side. Each of these troughs is the bed of a stream, whose course in nearly every case is directed to the sea. On the east side alone are these streams tributary to a major water, the Rivière Capot, which rises in a fairly deep basin several miles to the eastward of Saint-Pierre, and defines approximately the eastern boundary of the region that is dominated by the volcano. None of them has a course of more than four or five miles in a direct line, but despite this many have proved wildly destructive during periods of heavy rains. More than one settlement keeps in sad memory the picture of ruin which water and rock have wrought. Basse-Pointe and Prêcheur, with their acres of giant rocks, their cañoned streets and battered walls, read impressively this side chapter from the history of Pelée. In June, 1902, I determined the height of the flood-water of the Falaise, at

its confluence with the Capot, to have been at least thirty-five feet above the normal level of the two streams. The extended flood-plain at this point was covered with giant boulders, many of them five feet and more in diameter, and all of them rounded as though they had travelled for many miles. I measured some exceptional blocks that were from eight to twelve feet in length. All the masses were volcanic,—basalts, andesites, trachytes, pumice, etc.,—and represented the old stock of the volcano or of its predecessor.

Not less than twenty-five streams, about one-half of which have been dignified with the name of Rivière, radiate from the slopes of Pelée, and the greater number of these occupy deep ravines or well-defined *Thalwege*. The most important of those flowing to the northern side of the island are the Grande Rivière, the Rivière Macouba, and the Falaise. The Prêcheur, on the west, is responsible for the destruction, on the 6th and 7th of May, 1902, of the village of the same name, situated near its mouth. Farther south are the Blanche, Sèche, and Rivière des Pères, the last-named limiting Saint-Pierre on its northern side, and separating it from the faubourg of Fonds-Coré. The Roxelane alone of Pelée's waters entered Saint-Pierre. Having its bed built up in part with walls, and surmounted by attractive gardens and villas, it formed perhaps the most picturesque feature of the city.

Of all these various waters, the Rivière Blanche, by reason of its close association with the crater of the volcano, has become the most noted in the later history of Pelée. It was into the channel of this stream that the boiling mud from the Étang Sec, which wrecked the Usine Guérin on May 5, and brought the first casualties of the eruption, was precipitated. In its upper part, and just below the crater-basin, its course prior to the late activities was directed through a narrow and deeply incised ravine, with steeply sloping walls, the abrupt contours of which, noted by nearly all observers, were fashioned subsequent to the events of early May. The whole slope of the volcano on this side, the surface of which in the valley region has been raised by 200 feet or more as the result of the accumulation of volcanic ejecta, is wildly terrifying in aspect, and much of it is sprinkled with boulders which have been shot out from the forming cone, or rolled down on its outer face.

The great feature of Pelée that has been accentuated as the result of its late activities is the crater, whose caldron, or what remains of it, lies southwest and west of the summit of the mountain, directly under the lee of the Morne de La Croix. The steep face of the Morne plunges into it *à pic*. The feature is not an entirely new one, as it is clear from the topographic description of the region given by the commission of 1851, and from observations made just before the main cataclysm of 1902, that a soufrière or crater-basin existed on the site of the present one already at the time of its earlier eruption. This was the basin of the Étang Sec, whose floor, at its outlet in the V-shaped cleft, and before the great dome was constructed over it, was as nearly as I could determine from an eye-measurement taken at an elevation of 1600 feet, and from the observations of others, about 2400 to 2600 feet high on the south-

western slope of the mountain, and consequently from 1500 to 1600 feet below the lowest part of the rim of the crater-wall on the east side (the plateau surface of the Lac des Palmistes). The altered condition of the mountain, combined with the vagueness of past descriptions, has made it difficult to recognize the exact topographic features as they had been previously determined, and which appear to have been known to the inhabitants of Saint-Pierre and of its surroundings almost alone.* Hence many errors have crept into the descriptions that have been given. It was my good fortune to have with me during one of my excursions one who was thoroughly familiar with the old mountain, and who could readily locate the main features in a comparison with the old topography.

The earliest accurate description of the crater that was published after the May cataclysm is that of Dr. E. O. Hovey, contained in his "Preliminary Report on the Martinique and St. Vincent Eruptions," and which appears in the *Bulletin of the American Museum of Natural History* (October 11, 1902). The author there correctly recognized a circumvalent rising valley partially surrounding a central or subcentral constructing cone, and bounded on all sides from the southeast to the northwest by high and precipitous walls, composed of ancient tuff-agglomerates and lava-beds, which culminated in the impending andesitic mass of the Morne de La Croix. This great encircling wall, which falls on the southwest side to an elevation of about thirty-two hundred feet, and in some parts is retained as an acutely narrow ridge, reminding me forcibly of the encircling wall of the Nevado de Toluca, in Mexico, is perhaps a little more than a mile in length. Dr. Hovey estimated the width of the entire basin at its summit to be about half a mile, a determination which agrees closely with my own observations and with the earlier measurements that had been made for the *cuvette* of the Étang Sec.

Over the floor of this crater-basin has been built up the great dome, now considerably overtopping the highest part of the surrounding wall, whose later stages of construction have compelled a comparison with the Giorgios dome (*cumulo-volcano*) of Santorin, and through whose summit was forced that most unique of volcanic structures—the obelisk of Pelée. This structure, the denticulated base of which still remains, is, together with the dome, described at length elsewhere. At the present time the depth of the crater-basin, which has been reduced to hardly more than a *rainure* surrounding on its inner sides the central dome, is in many or most parts less than 200 feet (even considerably less). Opposite the Petit-Bonhomme, where a coalescence has been effected between that ancient buttress and the dome, it has been completely obliterated.

The wholly accordant observations of Landes, Roux and others, leave no room for doubt that the seat of activity and destructivity on the 8th of May,

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*The lack of precise knowledge regarding the points of Mont Pelée is well shown by the narrative of the "guide," Julien Romain, contained in *Les Colonies* in the issue of May 5, 1902, which places the Morne de La Croix on the *western* side of the crater-basin, and the Étang Plein (Lac des Palmistes) still *farther west* of the Morne de La Croix!

1902, and during previous days, was the basin of the Étang Sec; therefore the caldron on whose base is now implanted the great dome. It is also equally certain that the real opening of this basin was on April 25, when a heavy ash- and steam-cloud was seen to issue from it; but it can hardly be doubted that a minor eruptivity, beyond the simple emission of sulphurous and aqueous vapors, may have existed before this time. Nothing is known of the size or characteristics of the constructing cone—the predecessor of the later dome—when the eruption took place; and therefore the allocation of the destroying blast to a definite point in the basin, whether to its absolute floor or to the opening in a rising cone, remains speculative in value.

In associating the later activity of Pelée with parts of the volcano that were concerned in the eruption fifty-one years earlier, we have as a basis for study and comparison only the report of the Scientific Commission of 1851, MM. Leprieur, Peyraud and Rufz. From this report it is made clear that none of the vents of the later eruption had part in the earlier one, which in itself appears to have been hardly more than a warning, with a localized area of destruction immediately about the explosive points. There were at the time of the investigation of the commission three active craterlets, two situated at an elevation, as determined barometrically, of 883 metres, and the third, which was seemingly the largest, although measuring only one and a half metres across, situated some distance farther down the slope. This is thought to have been the seat of the ancient Soufrière.* The position bore directly east of Prêcheur, from which it was distant seven kilometres in a direct line. The vent nearest to Saint-Pierre was distant ten kilometres from that city. These several openings, which were found in a condition of semi-activity on August 9, were located in a ravine of the Rivière Claire, a northwestern or right-hand tributary of the Rivière Blanche, and at positions which can probably no longer be identified. The commission did not consider them to be active points of the main eruption, but assumed for these a considerable number of other craterlets lying in an adjacent valley, and at positions whose general or medial elevation above the sea is placed at 816 metres. These were found to be all dormant.

That none of the several points of activity or past-activity that are here referred to are in any way identifiable with the Étang Sec (the focus of the recent outburst)—a correspondence which has generally and not unnaturally been assumed—is thus plainly indicated by the geographical position *outside* of the actual basin of the Rivière Blanche, and in the further narrative of Leprieur and Peyraud (p. 16), which states that these investigators visited the old lake-basin for the purpose of making additional observations on what was assumed to be another and still more ancient crater of the volcano (*"Sans visiter l'Étang Sec qui passe pour un autre cratère plus ancien du volcan"*). This is,

*"*Mais nous voulions visiter encore un troisième cratère que nous voyions fumer aussi à quelques centaines de mètres plus bas dans la même ravine, et qu'on nous disait avoir pour siège l'ancienne Soufrière.*" "Éruption du Volcan de la Montagne Pelée," p. 9.

indeed, a very important statement, for it shows the eruptive point or points of the volcano to have shifted their positions since 1851 towards the side of Saint-Pierre. The lake, instead of being dry (as its name signifies—dry tarn), was found to contain considerable water, the quantity of which was estimated to be about five times that contained in the summit lake (the Lac des Palmistes: "*remplie au jour où ils le visitaient par une masse d'eau considérable et à leur estime cinq fois plus grande que dans le lac supérieur*," p. 16), an overcharge which the guides attributed to an unusual fall of rain during the past winter season. The elevation of the lake was determined barometrically to be 921 metres (3025 feet), corresponding closely with the level of the most elevated of the craterlets which had been located in the more distant ravine ("*Ainsi cet étang-sec se trouve presque à la même élevation que les bouches supérieures du volcan placées dans une ravine plus éloignée. Rien d'ailleurs n'était changé dans ces lieux au dire des guides, on ne remarqua ni fente, ni éboulement*").

The belief that Pelée had but a single eruption recorded in its history prior to the one of May, 1902, a supposition that is almost universally held in Martinique, is erroneous, the volcano having passed through a moderate paroxysm on January 22, 1762. A fairly extended account of this eruption is published in the *Journal des Mines*, of Paris (Vol. III, 1796, pp. 58–59 of Part xviii), as an annotation of Dupuget's paper: "Coup d'œil rapide sur la Physique générale et la Minéralogie des Antilles," and appears from the notes of an eye-witness, Aquart, communicated to M. Dupuget. Earthquakes and the emission of sulphurous odors and vapors in considerable quantity were an accompaniment of this eruption, whose disturbing seat was in a number of craterlets situated at an elevation of about 500 toises (3000 feet — consequently closely corresponding with the altitudinal position of some of the vents of the later eruptions). Much vegetation was burned or singed, and a number of opossums were killed. It is said that the earth was riddled with holes, and many sulphur aspirators were opened. At a lower level of some five hundred to six hundred paces distance there was a flow of hot black water (mud?). The account concludes with the significant statement: "This ancient eruption of Mont Pelée seems to have had its entire effect on the western side [of the volcano]. That quarter is completely overturned [wrecked] . . . whereas on the side opposite the surface is less torn."*

There can be little doubt that this earliest recorded eruption of Pelée was from a part of the mountain not far removed from the position of the 1851 eruption, if, indeed, it was not absolutely coincident with it. The general characteristics of the two eruptions appear to have been identical.

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*"*L'explosion ancienne de la Montagne Pelée paraît avoir porté tout son effort du côté de l'ouest. Cette partie est entièrement bouleversée. . . . tandis que du côté opposé le terrain est moins brisé*," p. 59. The year of this eruption is more generally given as 1792, but there can be no question that the event took place at an earlier day, as the facts were communicated to Dupuget while he was on the island, and his voyage was made in 1784–1786. This relation is well set forth by Mercalli in the *Atti della Società Italiana di Scienze Naturali* of Milan, XLI, p. 313, 1902.

II.

THE OBELISK OF PELÉE.

No feature connected with the eruptions of Pelée has so largely attracted the attention of geologists as the giant core of rock, 1000 feet or more in height at the time of its greatest development (June–July, 1903) and 350–500 feet thick at the base, which as the result of volcanic stress had been bodily lifted and pushed out from the summit of the volcano during a period of a full year and more. This extraordinary obelisk of lava, like a veritable "Tower of Babel," transfixed the newly formed cone of the basin of the Étang Sec, and rose vertically above it, the two structures, products of the eruptions beginning in April, 1902, having a full height of approximately 2300–2400 feet. As observed from the east-northeast, or the quarter of Assier and Vivé, it presented the aspect of an acute pyramid; from the south or southwest it gave the appearance of a conical spire, complicated by secondary spires, needles, or fingers, and showing a split or indented apical summit; while from the northeast and north it rose up a gigantic and nearly parallel-sided tower or fortress. From whichever side seen, it was an object of sublime magnificence; and in the condition of vapor-clouds blowing out from its base and from the cone that supported it, with blue sulphur-smoke curling its way along with these, it presented a spectacle of overwhelming grandeur and of terrifying effect. Nature's monument dedicated to the 30,000 dead who lay in the silent city below, it rose up a huge monolith of sheer and almost vertical face—a unique and incomparable type in our planet's wonderland. To-day nearly all that was of this giant obelisk lies in shattered fragments, covering up much of what before was the ancient crater basin of the Étang Sec and of the domed mass which has been constructed nearly centrally over the floor of this basin. The fragments of disruption occur in many sizes, from boulders of two to three feet diameter or less to others having the more respectable measure of ten, twenty, or even thirty feet. Their numbers make up a veritable wilderness of débris, from among which fumarolic vents are still at intervals forcing vapor, and in which at favored spots the eye detects small growths of fern and other lowly types of vegetation.

The obelisk as I saw it in the middle of June, 1903, was arched slightly in the direction of Saint-Pierre,—*i.e.*, towards the southwest, where the surface was scraggy, the result, doubtless, of the numerous basal eruptions which took place at or near the point of contact with the supporting dome. The surface on the opposite side—that turned towards Assier—was, on the other hand, smooth, almost polished in places, and longitudinally grooved from base nearly to summit. This smoothness and graving of the surface were certainly due to attrition against the encasing rock or "mould" which formed the wall to the

channel of exit, and the curving over of the mass to one side would seem to point to extrusion from beneath a somewhat vaulted or curved casing. One could well compare the structure and its method of escape to a core of paint issuing by pressure from an oil-tube. The general surface-covering was in color ruddy gray, brown and purplish in part, but on the smooth face it was nearly white, a condition probably in some way associated with the rubbing on that side and with the presence of sublimation products on the surface.

As to the fundamental and inner construction of this remarkable volcanic appendage, our knowledge until the beginning of 1906 was largely conjectural. Seen with a powerful glass from a point of nearest approach, perhaps 700 feet, the rock appeared "burnt-out," like a furnace-product; and the noise given out by the falling particles and boulders was generally like that of falling clinkers, which led to the supposition that the mass might on the whole be cavernous. But its rigid adherence and resistance to a prodigious crushing strain lent little countenance to this view. The noise from the more imposing discharges of dejecta was like that of rolling thunder, at times barely distinguishable from the roar of the volcano itself, and could only have been produced by the avalanching of compact rock.

In a fifth ascent of the volcano, which I made on Feb. 17, 1906,* when, by reason of the dying down of the activities of the mountain, it was made possible to descend into the crater and reach the wilderness of boulder-débris which resulted from the breaking apart of the obelisk, I determined the constituent rock of the obelisk to be a wholly compact, fine-grained hypersthene-andesite, wholly free from either a vesicular (or scoriaceous) or obsidian-like structure, and giving no indication of having undergone recent fusion, and there was nothing in this examination to give countenance to the surmise that the interior of the obelisk might possibly have been hollow, with fluidal lava, hidden from view by the massive outer walls, contained within. Had such an enclosed flowing magma really existed, there would certainly have been lava overflows at one time or another. On the other hand, that the obelisk was rifted and had irregular passages through it or through parts of it, into which lava was at times injected, is certain; and the members of the Lacroix mission on more than one occasion noticed areas and lines of incandescence in the basal portion of the core, which they associated with flowing lava-masses. Indeed, it can hardly be doubted that the fall or disruption of the giant monolith was brought about in great or greater part as a result of steam expansions in the interior. On the night preceding my fourth ascent of the volcano, June 12, 1903, the southwest base of the rock-core was resplendently luminous, made so either by actually rising lava or by a partial remelting of that portion of the structure. From a distance of a few miles, whence this magnificent spectacle was seen,

* An account of this ascent is published in the *National Geographic Magazine*, for August, 1906.

my powerful glass failed to determine which of the two conditions existed,—a matter of little consequence, as in either event molten lava was in close association.

That some of the rifts completely traversed the obelisk from base to summit, I had the opportunity to fully satisfy myself, for on the morning of June 15, when skirting the northern and western shores of the island, a thin steam-pennant could be seen to be continuously issuing from the apical summit; in other words, the volcano was gently "smoking" at the top. The issuing vapor was perfectly white, and it seemed to carry little or no ash with it. From the same apical summit a number of incandescent balls are reported to have been shot out on the night of March 26, 1903, but I believe this assertion has not found justification in the facts.

The ascent of this remarkable core of rock was due to processes similar to those which produce the outwelling of lava in the ordinary form of volcanoes, —*i.e.*, to interior volcanic stress. Despite its colossal dimensions, it was heaved bodily upward, receiving new accretions of matter almost entirely from below. The most cursory examination of the relations existing would immediately point to this form of growth and development, but the carefully conducted angle-measurements and observations of contour made by the representatives at two stations of the French Scientific Commission leave no possible doubt in this matter, and they further furnish us with data touching the rate of growth. The consideration of the depth to which this giant monument descended solid into the volcano would be interesting were there any way of reaching the problem, but for the present there would seem to be none such. It is perhaps enough to say that this depth must have been considerable, otherwise the column could not have stood through the exploding condition of the mountain; it may, indeed, have been very great. On the other hand, the problem cannot be divested of the fact that molten or incandescent lava did at times rise quite to the level of the insertion of the monument in its base.

It is a matter of some importance geographically to know when this great mass of rock first appeared and to ascertain through this fact its relation to the great eruptions of May, June, July, and August, 1902. Lacroix, in an article published in the *Dépêche Coloniale* (April 30, 1903), states that the basal dome of the volcano had terminated in a needle since the middle of October, 1902, and presumably this is about the period when it was first seen by him.* But there can hardly be a doubt that its formation or first appearance was of much earlier date, for on August 24, 1902, almost a week before the second death-dealing eruption, a vertical (although comparatively short) needle was distinctly seen by me from the southwest side, and it appears in my photographs taken on that day. Indeed, I remark in my report,† that it seemed to me likely

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* In Lacroix's "La Montagne Pelée et ses Éruptions" (p. 118) the first appearance of the *grosse aiguille* is stated to have been in the night of Nov. 4. At that time the volcano had an elevation of 4428 feet (1350 metres).

† "Mont Pelée and the Tragedy of Martinique," p. 163.

that the two glowing masses of fire which shone down from the summit, like red beacon-lights, on the morning of August 22, emanated from the two (incandescent) horns that capped the summit of the mountain. One of these protruding masses, or "horns," as I have called them, was seemingly set at a broad angle to the other.

In an earlier report on my observations and experiences,* published shortly after my return from my first visit to Martinique, use is made of a drawing of the crater by Mr. George Varian, an artist associate who was with me when we first reached the rim of the still very active crater, and whose extreme faithfulness in the delineation of nature I frequently had occasion to admire. In this drawing a great core of rock is made to appear centrally in the crater, rising somewhat above the crater's rim. In my own description I refer to these points in the crateral structure as "the central core of burnt-out cinder masses, topped by enormous white rocks, whose brilliant incandescence flashed out the beacon-lights which were observed from the sea some days after the fatal 8th, and even at our later day illumined the night crown of the volcano with a glow of fire." When at that early day we stood on the crater's edge, the activity of the volcano was still such that we could obtain but momentary glimpses of the interior of the crater and of the crater-walls, and it was impossible to shape constructively the relations of the parts as they passed before us in fleeting shadows. After seeing one of my own photographs and the photographs of investigators who were on the volcano after I had left it, I became doubtful as to the accuracy of Mr. Varian's drawing, the more so as it depicted a structure that could not be brought into relation with any known volcanic feature, and in my later publication I thought fit to omit the illustration. There is at this time no doubt in my mind that the sketch of my artist associate was an accurate one, and that "the central mass of jagged white rocks" was already as early as May 31, 1902, the embryo of the great Pelée tower. That it did not survive to the later day is certain, for on June 20, when Dr. E. O. Hovey took his photograph of the central cone, it no longer appeared.† It was probably overthrown in the violent eruption of June 6. On the other hand, it is not unlikely that it reappeared within the period of a few weeks, for a prominence suspiciously like a protruding spine is distinctly shown in a photograph taken on July 6, which is published by Dr. Jaggar.‡ It should be said that on May 31, 1902, the sound of falling "clinkers" (rocks, etc.) was precisely that which we heard on June 13, 1903, emanating from the falling and exploded débris of the obelisk.

The giant tower at the time of my visit reached an absolute elevation above

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* *McClure's Magazine*, August, 1902.

† *Bulletin Amer. Mus. Nat. His.*, xvi., pl. 44, Fig. 2. See also a more recent paper by Dr. Hovey in the *Amer. Journ. Science*, Oct., 1903, p. 271.

‡ *Amer. Journ. Science*, Jan., 1904. Lacroix holds to the belief that the Jaggar spine was more likely to have been merely a projecting serration of the constructing dome-surface.

sea-level of 5020 feet,* the determination made by M. Guinoiseau from Assier, with which a less accurate Abney-level measurement made by me from Morne Rouge closely agrees. Its height was on May 31, 1903, 5248 feet, but it seems to have lost on that day through breakage 180 feet of its summit. It frequently underwent partial decapitation, and the form was thus largely disturbed, the summit or apex particularly suffering. During the four days preceding June 15—within the period of my visit to the volcano—the ascent, as determined by angle measurements made by M. Guinoiseau at Assier, was six metres; in the eight days preceding June 7, ten metres.† However incredible such a rapid rise may appear, the facts that are presented in the first period of the obelisk's history are still far more imposing, and of a kind to impress upon the observer in a wholly exceptional way the sense of the sovereign grandeur of nature. Were it not for the immediate object placed in full view, there would be few, even among extreme cataclysmists, who would be prepared to believe that for a period of a month or more so gigantic a structure as the Pelée core could have been heaved up at an average daily rate of from 20 to 25 or even 25 to 30 feet. As has already been stated, the first appearance of this extraordinary structure as noted by the French Scientific Commission was on or about October 15 (or the beginning of November), 1902, but by November 24, despite partial breakages of the summit, it had already risen to 1575 metres (5166 feet) above sea-level.‡ Of this total height upwards of 800 feet belonged to the obelisk alone, a rise, therefore, of this amount, with breakages, in from 35 to 40 days. The rise during the four days of Nov. 9–12, inclusive, was 196 feet (60 metres), or an average of nearly 50 feet per day. The maximum elevation attained by the obelisk was in the period of June 25–July 6, 1903, 5274 feet (1608 metres) above sea-level ("La Montagne Pelée et ses Éruptions," p. 123).

The history of the rock-core following the early days of December, 1902, was one of frequent breakages and of successive repairs, so far as mere elevation is concerned, resulting from progressive and virtually continuous upheaval. Marked changes of outline, particularly as seen from the east and the southeast, followed the major disruptions, and to such an extent that it was made difficult to harmonize photographic views taken at different times from nearly identical positions. In the first week of December the height of the obelisk was lessened by 60–70 metres, but this loss was made good in a very few days, and despite successive losses the structure on December 16 rose to within 70 metres

* Lacroix gives for the absolute elevation of the obelisk on June 13 (the day of my ascent), as determined by measurements made at the observatory of the Morne des Cadets, 1582 metres (5189 feet), which is nearly 170 feet higher than is given by the Assier measurement. It seems that in nearly all cases the values obtained at the observatory—and perhaps with more accurate methods of observation—were higher than those of Assier.

† M. Giraud, in *L'Opinion*, of Martinique, June, 1903.

‡ Lacroix, "La Montagne Pelée et ses Éruptions," p. 123. In the *Comptes Rendus* of Dec. 1 and Dec. 29, 1902, the height at the close of November is given as approximately 1500 metres.

of its greatest height. Through, or accompanying, the rather severe eruption of January 25, 1903, there was a further loss of 30 metres (at first reported to be 250 metres), and at this time it was observed that the volcano was capped by two needles.* This interesting fact is significant in its relation to my own observation that two "horns" or needles projected from the newly formed cone on August 24 of the previous year. On March 13, the date of Lacroix's departure from the island, the obelisk had risen to 1568 metres (5143 feet), overtopping the remains of the Morne de La Croix by 1009 feet;† but at the end of two weeks, in the eruption of March 26, it again lost 25 metres (82 feet).‡ Seemingly the extreme height that was reached by this extraordinary volcanic structure, as has already been said, was almost exactly 5274 feet (June 25–July 6, 1903). There can be no doubt that had there been no apical disruptions it would have reached a full thousand or fifteen hundred feet higher.

On comparing my photographs taken from the crater-rim on June 13, 1903, with those of the French Commission and others, especially the very beautiful ones of Dr. Hovey, one is struck with the remarkable changes of outline which the obelisk had undergone,—changes that could have resulted from breakage alone, except perhaps at the immediate base. From no point of view on the old basin of the Lac des Palmistes could I obtain a picture that was more than suggestive of what appears in the photographs of Hovey taken eleven weeks before (on March 26) and illustrating his article on "The New Cone of Mont Pelée."§ Equally "irreconcilable" are still earlier pictures which I found in possession of local photographers in Fort-de-France. It is a suggestive fact that almost every moderately severe eruption threw down a portion of the summit, besides at different times opening great longitudinal fissures. Such a cleft was opened by the eruption of November 18, 1902, and through it a slice of the core measuring nearly 300 feet in height (90 metres) was removed. Other fissures followed rapidly in the early part of 1903, producing those modifications of contour which Major Hodder has likened to the change from a "huge lighthouse" to the form of a church-steeple.

In considering the question of the disruptions and summit-falls or decapitations of the core, the fact must not be lost sight of that the entire height was at times penetrated by steam, which rose not through a central or permanent chimney, but along one or more rift-passages. As I have elsewhere noted, the ascending steam was observed by me, during two hours or more, to pass out distinctly from the actual apical summit in a delicate line of pennant.** It

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* *Comptes Rendus*, Feb. 16, 1903.

† *Dépêche Coloniale*, April 30, 1903.

‡ The elevation of 5143 feet is almost exactly that which was found by Hovey on March 25: height above crater-rim, point of observation, 1174 feet; height of crater-rim, 3969 feet above sea-level.

§ *Amer. Journ. Science*, Oct., 1903, cuts facing p. 276.

** Dr. Hovey appears to have been less fortunate in his observation, for he remarks that no steam was ever blown out from the top.

seems very probable, as I have already stated, that it was precisely this rock-contained steam which, with additional force given to it at times of special eruptions, was responsible for the lofty disruptions, as well as for the dislocations on the upper flanks.

It will naturally appear to all who have reflected upon this new manifestation of volcanic activity that the power to lift or even sustain so gigantic a structure as this obelisk, with a cubical content (even if less in weight) equal to that of the Great Pyramid of Egypt, must have been prodigious. But the problem from the purely geological side is merely that of the normal volcano pushing up its great core of molten lava, with this difference, that in the Pelée uplift the element of friction enters as an important factor in the calculation of the dynamics of the lifting force. What may have been the value of the differential, unfortunately, in the absence of knowledge regarding the fixation of the obelisk, cannot be stated, nor even approximately surmised. Our present knowledge of volcanic phenomena, indeed, does not even permit us to make a comparison between the lifting force of the low volcano and that of the lofty cone, two or more miles in height.

The dome that supported the obelisk, or rather through which the latter passed, and which remains to-day, has been built up entirely since April 23, 1902. At the time of my third visit to the island (June, 1903) it overtopped the general summit of Pelée by about 200 feet, and had therefore an absolute height of some 1600–1800 feet. Much the same relation held in the month of Feb., 1906, when the jagged tooth-marks of the disrupted obelisk still protruded through it. It is to this structure, implanted upon the basin of the Étang Sec, that I refer in my earlier reports as the "new fragmental cone." Dr. Hovey refers to it in the same relation. The exterior seems to me to have always been in great part a mass of débris, volcanic ejecta of all sizes, through which steam was puffed at numerous points. Solid lava ridges protruded through it, and gave to it, especially in the southeast, a ribbed structure, which is in a measure still visible through the débris that covers the surface. The base occupies almost the entire floor of the former tarn-basin. Lacroix, who enjoyed unusual advantages for the study of this seemingly normal volcanic structure, asserts that it never was a true fragmental cone, but a dome or monticule of lava without permanent crateral opening, formed (in part through natural overflows of viscous lava and in part through endogenous intrusion) in the manner of the famous pre-crateral dome of Giorgios, in Santorin, of 1866.* It will be recalled that in the formation of that interesting structure there was an upwelling of highly viscous lava, which simply accumulated in an irregular bouldery mass about the opening of the volcanic chimney. At a somewhat later, although still early, day a crater opened in this monticule or dome, and from it flowed out streams

* Lacroix, in his "La Montagne Pelée et ses Éruptions" (p. 139), concedes that the dome or cone may have had an opening at the time of my own observation, and, indeed, believes that this opening may have been a necessary condition to the later phenomena which he describes.

of molten lava. I am not convinced that the early stage of the Pelée dome, however it may have become modified later on, was of this structure. The photographs that were taken prior to August 30, 1902, show, nearly all of them, where the summit is at all visible, a truncated top, a form absolutely like that of the normal crater-cone and as much unlike the monticule of the Giorgios (or Puy) type. This is beautifully shown in the photograph taken by Dr. Hovey on June 20, 1902; and equally so in my own photographs taken from the west side on August 24, which depict the volcano "smoking" directly from this summit chimney. It seems to me more likely that the conditions of Santorin had been simply reversed in the case of Pelée: a fragmental cone was opened first, and only later became plugged by the rise in it of what ultimately appeared the obelisk. Indeed, it would appear that the plugging went on as a process continuously with the making of the dome, troubling the volcano in its workings, but yet not so far obliterating the structure that held it as to obscure its relations. The fact that the obelisk passed bodily through the dome is in itself evidence of a kind supporting the view of a crateral cone. That the cone or dome at a *later* period acquired more or less of the structure that Lacroix ascribes to it, there can be little question.

In their local setting the obelisk and its supporting cone occupied in June, 1903, the virtual centre of the basin of the Étang Sec (the erupting crater of 1902), the floor of which had been brought up by infilling to within 300–350 feet of the summit of the surrounding wall of the caldera, a distance reduced by Feb., 1906, to perhaps one-half. The width of the space separating the top of the dome from this wall was roughly estimated to be 200–250 yards, excepting in the west, where it had coalesced with the slope of the Petit-Bonhomme (Ti-Bonhomme). At the time of my 1903 visit the dome was in a fairly active condition, blowing out steam at numerous points; and there could be no question that these issuing steam-puffs came directly from the interior, and were not secondary explosions emanating from the covering débris. According to M. Guinoiseau, one of the observers of the French Scientific Commission, the activity at this time was particularly accentuated, greater than it had been at any time since the month of January preceding. In Feb., 1906, fairly large volumes of steam were quietly issuing from the upper portion and summit of the still smoldering mass, to whose lower slopes, especially in the immediate vicinity of feeble fumaroles, a scattered vegetation of diminutive tree-ferns was beginning to attach itself.

In the chapter on "The Geography of Pelée" I have given a fairly extended survey of the Pelée crater, to which, and to the account of my fifth ascent of the volcano (Feb. 17, 1906) published in the *National Geographic Magazine* for August, 1906,* there is little to add beyond what is contained in the

* A portion of this account is here reproduced: "Following the rim of the crater along its northern face, or in the direction of the Petit-Bonhomme, we found a spot where it seemed that a descent might be made over the very sharp knife-edge, and where, indeed, an earlier

preceding pages. It might be noted that it was (and is) of the caldera type,—*i.e.*, with its partially encircling walls trenchantly steep, almost or quite vertical in places,—and clearly showing the lines of stratification of the superimposed fragmental materials (pumice, ash, etc.). These are traversed by the base or "dike" of what remains of the Morne de La Croix, whose andesitic mass could at one time be followed by the eye virtually through the entire height of the wall (300 feet high). Into this caldera, the basin of the former Étang Sec, was implanted the new cone, with its great transfixing obelisk. It has been remarked that on the western side the cone had united with the basal processes of the Petit-Bonhomme; elsewhere it was surrounded by a V-shaped valley (*rainure*), the top-width of which was roundly 600–800 feet.

There is nothing in the configuration of the mountain to give countenance to the extended caldera-form, with the mass of Pelée as a centrally rising polygenetic cone, which Stübel has fancifully constructed from the large French map of the island of Martinique, the contours of which have only distantly approximate relations to the actual relief of the land. There are on the north side of the crater, but absolutely on the summit of the mountain, the remains of an ancient crateral wall, which Dr. Hovey has already likened to the Somma wall of the Atrio del Cavallo, but it bears no relation to the contours shown on the French map. It is a short way back from the edge of the present crater, and its rocks show a partially columnar structure.

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descent had already been made by my associate, together with two companions, MM. Salet and Beaufranc. A very stiff wind was unfortunately blowing over this crest, and for a time it seemed that its persistence would thwart our effort to gain the rim. My own affairs were not particularly encouraging either, for I had but one good foot, and dragged another as a reminiscence of a mishap on board the steamer during our voyage. Once over the rim, however, we were on fairly easy ground, and the scramble to the bottom was quickly made. Here we were immediately brought into contact with the parts of the obelisk, which were lying about everywhere, almost completely cloaking the body of the dome itself and measurably filling in the horseshoe-shaped area of the old crater basin. Close to the point of our descent the depth of the crateral cavity could hardly have reached a hundred feet. Westward of our position it was still less, while directly under the old Morne de La Croix it may have more nearly measured 150 to 200 feet. The dense vapors (in the absence of an aneroid) did not permit of any accurate determinations of depth at this time. The width of the hollow at its base had been reduced to hardly more than a rock-space in some places; elsewhere it widened out to a number of yards, and from its boulder-strewn surface steam was issuing in scattered jets."

III.

THE AFTER-HISTORY AND NATURE OF THE OBELISK.

In the destruction of Pelée's giant obelisk one of the most remarkable features of the earth's surface has disappeared, and its removal takes from the eye of the geologist an object illustrating an almost unique phase in the history of volcanic phenomena. The systematic destruction of this great core of rock began in the early days of July, 1903, and was accomplished with rapidity, so that by the middle of that month there was a loss to the summit of nearly 400 feet, and before the close of the second week in August of a further 100 feet. During this period of destruction, and for weeks afterwards, the activity of the volcano was very pronounced, and discharges of the *nuées denses* (the name given by the French Scientific Commission to the descending black clouds which were thought to be similar to the blast that destroyed Saint-Pierre) were frequent, not only along the valley of the Rivière Blanche, but also directly towards Prêcheur (August 20–21, 27–28, September 4–6, etc.) and across the former basin of the Lac des Palmistes (August 20–21, 28–30, September 11–12, 13–14, etc.). The greater number of the discharges continued (Nov. 2–3, 3–4, etc., and at various times in 1904) along the valley of the Rivière Blanche, taking the course of the hurricane-blast of May 8, 1902.

Coincidently with this destruction of the obelisk and the return of Pelée to a condition of fairly violent activity, it was observed by the French Scientific Commission that the conical base upon which the obelisk was implanted—or, rather, through which it passed—was itself undergoing marked modification, being forced up in the manner of a dome. Effusions of viscous lava were adding to its mass, breaking through the confines here and there, and solidifying before there was an opportunity for a free flow. At other times the growth of the "dome" was seemingly merely an outward-swelling or expansion (intumescence), an ebullition, resulting from steam-pressure and the accretion of lava rising from below. Whether thus formed by exogenous additions or as the result of endogenous accretions, the growth of the dome, despite the not insignificant and sometimes very pronounced losses to its mass following upon almost every larger explosion, was remarkably rapid. During the ten days preceding August 17, 1903, as we are informed by Prof. Giraud, the dome had gained in height 88 feet (27 metres).* During somewhat less than eight days, immediately preceding August 27–28, the gain in height was 164 feet (50 metres); and between August 26 and August 30, 98 feet (30 metres);† showing an average daily increment of 24½ feet, closely corresponding to the rate of growth of the obe-

* E. O. Hovey, *Science*, Nov. 13, 1903, p. 633.

† Giraud, *L'Opinion*, Martinique.

lisk in its earlier period. The phenomena attending the growth of the dome were those of the general eruptions: the evolution of the great volcanic steam-ash cloud, rising at times to 2000, 3000, and 4000 metres above the summit of the volcano; loud detonations, frequent discharges of dust and boulders, and the more violent explosions of the "black cloud." During the eruption of September 9, which lowered the dome 15 metres, the *nuée dense*, following the course of the Rivière Blanche, reached the sea in five minutes, thus repeating the history of the early period of Pelée's activity. In an earlier eruption, September 3, when the dome lost 30 metres, a similar cloud reached the sea in seven minutes. It is significant that at about the middle of September these clouds, instead of following the usual downward course, now in the main ascended vertically.* On September 15–16 such a cloud rose to the extraordinary height of 7000 metres.

During much of the period here noted parts of the dome appeared brilliantly incandescent, some of the luminous points being fixed for a number of consecutive days. On a few nights when observations were permitted, nearly the entire surface of the dome appeared as if in a glow of fire, and brilliant reflections were thrown upon the clouds overhead. The trains of boulders discharged from the dome with almost every violent eruption were also frequently incandescently luminous. It would seem that by the first of October the new dome had actually been constructed to a height slightly exceeding 500 feet, doubtless enclosing within itself a considerable portion of the lower moiety of the destroyed obelisk, if, indeed, it did not again bring it to a condition of molten fluidity. The most rapid development of this extraordinary structure appears to have been on August 30–31, when, as reported by M. Giraud, the rise in a single day was 78 feet (24 metres).†

It is interesting to note in connection with the construction of this remarkable crateral dome that it was accompanied by new extrusions of solid "turreted" matter, acicular processes or obelisks appearing at different times in two or more parts of its summit. Thus, in the early days of September, 1903, the observers of the French Scientific Commission noted that the dome terminated in an aiguille rising from its northwest part, which needle on September 7 rose nearly 10 feet. On September 9 this new growth acquired an additional 6 metres, and between September 10 and 12 further 8 metres. A second process was at a later day extruded through the southeast portion of the dome, and its fortune, as well as that of the earlier one, partook of the same vicissitudes of construction and destruction which marked the history of the original great obelisk. On October 20 it lost 5 metres. There seems to be at this time no way of ascertaining the precise relations existing between these newer structures and the basal portion of the first formed and partially buried obelisk; nor can

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* Giraud, "La Colonie." See also the numerous data given in Lacroix's final report, "La Montagne Pelée et ses Éruptions," 1904, pp. 138–150.

† *La Colonie.*

it be told if any structural relation in fact existed, although I strongly suspect that it did. But that the more newly appearing structures were in themselves of no mean significance is proved by the observation that on November 25 one of the needles lost 30 metres of its height as the result of the eruption of that day.* At that time the greater part of the dome was incandescent.

In comparing the Pelée dome (not the obelisks, spires, or processes) with resembling structures elsewhere, the geologist naturally turns to the two or three anomalous types of cone or summit that have become known for their departure from the form of the normal volcano. These are the domed cone of Giorgios, already referred to, which appeared on the island of Santorin in 1866; some of the Puys, as the Puy Chopine, of the Auvergne region of France; and (perhaps most remotely) the pyramidated tops of volcanoes which Stübel has described from among the equatorial Andes. The last-named structures, however, so far as I am able to comprehend Stübel's work, are seemingly only physiographic monuments associated with the original making of the volcanoes, and have nothing in common with a later crateral discharge.† They belong to the type of Stübel's monogenetic and not polygenetic volcano. A closer approximation to the Pelée dome is probably to be found in the dome-structure, first noticed in 1895, and more fully developed in the spring of 1898, which Matteucci has described in connection with late outbreaks of Vesuvius (preceding the great eruption of 1906). Matteucci's studies are recorded in a number of very carefully prepared papers,‡ which leave little room to doubt the substantial accuracy of the observations presented. We learn from these reports that the dome (or *cupola lavica*) gained in one month (February 14 to March 15, 1898) 15 metres in altitude, the floor of the crater swelling up (intumescing) at the same time to 50 metres. The total height of the dome was represented to be 163 metres. Matteucci sees in this upheaval the combined action of a deeply planted mechanical force and of a superficial intumescence, and he does not fail to recognize the conditions which are thought to be associated with the making of laccolites.§ There would probably be no impropriety in designating the Vesuvian structure "laccolitic," even if it represents no true laccolite.

That the Giorgios dome, the type of the cumulo-volcano, is essentially representative of the structure seen in the later stage of the Pelée dome, as

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* *L'Opinion.*

† This seems also to be the view held by Hans Meyer: "In den Hoch-Anden von Ecuador," 1907, pp. 286–287. The pyramid of Quillinada, in Ecuador, is thought by Meyer to give evidence of solidification and extrusion suggestive of the crateral parts of Pelée (pp. 276, 286).

‡ "Sur les Particularités de l'Éruption du Vésuve," *Comptes Rendus*, 1899, vol. 129, pp. 65, 66; "Sul Sollevamento endogeno di una Cupola lavica al Vesuvio," *Rendicont. Accad. Scienze Fisiche e Matemat. Napoli*, 1898, xxxvii., pp. 285 et seq.; "Se al Sollevamento endogeno di una Cupola lavica al Vesuvio possa aver contributo la sol indicazione del Magma," *Bollet. Soc. Geol. Roma*, 1902, xxi., pp. 413 et seq.

§ "Si tratta di uno Sforzo mecanico profundo e di una Intumescenza superficiale," *Rendicont., Nap.*, p. 299.

Lacroix has urged, seems undeniable; indeed, the question of differences would seem to resolve itself, so far as a direct comparison is made possible, almost entirely into one of not very important details. The greater or lesser activities of the two volcanoes may account fully for these differences.

In my work "The Tower of Pelée" (p. 32) I have remarked: "Until the activity of Pelée will have so far lessened as to permit of a closer study of the dome its full nature cannot be determined, perhaps not even to the extent of allowing us to say in how far, if at all, it is related to the hollow, oven-like forms which Dana and others have described from the Hawaiian Islands under the name of "driblet" cones, and of which Israel C. Russell has more recently given us exaggerated types from among the Jordan Craters of Oregon. One of these "ovens" measures 20 feet in height and 40–50 feet in basal diameter.* That the intumescing Pelée dome is at times largely hollow seems sufficiently established by the markedly diminished height which follows or accompanies eruptions of only moderate intensity. In many cases of such eruption there would appear to be a general collapse."† Unfortunately, at this later day (1907) the dome is so completely buried beneath the débris from the fallen obelisk that its accessibility for study is, if anything, less than it was before. The actual summit, which bears the craggy serrations of the base of the obelisk, was still unattainable at the time of my visit in Feb., 1906.

However closely we may approximate the structure of the Pelée dome to other domes, the problem of the obelisk remains apart by itself. The geologist, failing to note any similar structure among recent volcanoes, is tempted to make comparisons with those giant stocks of lava which have long been recognized as " volcanic necks " and "laccolitic cores," and which are presumed to owe their prominent forms in the landscape to differential erosion of the land-surface. That some or many of these cores are only such resisting blocks overlooking an eroded land-surface cannot be questioned, but it is not so certain that all are of this nature, and some may well be of the type of structure which Pelée has presented in its extraordinary obelisk. One cannot resist the conclusion, even without the direct support of facts, that there must have been other protrusions before the one of 1902, and some of these ought to be preserved somewhere; but where?

Sir Richard Strachey‡ calls attention to "plugs" of trap, said not to be uncommon, rising out of the Dekkan plateau, which he believes to be the analogues of the Pelée core. A sketch of one of these, made as early as 1839, is in its form certainly very suggestive. Another structure might, perhaps, also

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*"Geol. Southwestern Idaho and Southeastern Oregon," *Bull. U. S. Geol. Survey*, 1902, No. 217, p. 52.

† Professor Russell, in the report referred to, presents an exceedingly suggestive illustration of a (pressure) "dome in recent lava," also among the Jordan lavas of Oregon; but it is held that the lava of this and similar domes was antecedently horizontal, and was forced up as the result of later pressure (p. 54, pl. xv., Fig. A).

‡ *Nature*, October 15, 1903, p. 574.

be brought up for comparison in this connection. I refer to the giant Devil's Thumb,* on the northwest coast of Greenland, marking the entrance to Melville Bay. As I recall it from a distant view of two or three miles, after a lapse of many years, and as it appears in the sketch on the border of the Admiralty Charts, it has almost exactly the outline of the Pelée obelisk, rising up in supreme and almost isolated majesty to a height of 2350 feet. Unfortunately, however, we are not in a position to state if this prominent feature in the landscape is volcanic, or even if one of the vast basaltic areas of Greenland absolutely surrounds its base. The relief and conditions of the land would seem to argue against any form of erosional construction.

I have little doubt that the obelisk of Pelée was merely an ancient core of the volcano that had been forced from the position of rest in which solidification had left it. The generally accepted view regarding its construction is that which was advanced by Lacroix, and which holds that the giant block was an active acidic (andesitic) lava whose viscosity was such as to permit of solidification (under the pressure of a first-formed dome) while still within the chimney of the volcano, and whose movement posterior to extrusion was, by reason of this solidification, necessarily made a vertical one. There could be no free flow. This explanation appeals in its simplicity, and it is one to which I confess myself having been at first committed. There are objections to it, however, and I have stated these in my work "The Tower of Pelée" (1904, pp. 33–34) and more recently in the *National Geographic Magazine*.† My principal argument is given as follows in the latter publication:

1. The hypothesis of M. Lacroix compels a belief in the rapidity of the cooling and solidification of large lava masses which is seemingly at variance with all knowledge that we possess regarding the behavior of rock masses in fusion. The Pelée obelisk, although rifted much in the manner of the jointing of other rocks, was virtually solid to the core, and none of its decapitations disclosed moving fluid lava in the interior. We should be forced to believe that a full cooling and solidification of the constructing lava mass had in an almost incredibly short space of time extended completely through the substance of the extruding part. At the time of its final disruption, in the early autumn of 1903, it is true that the basal scar was described as being a vast glowing brazier; but I should say that this condition was brought about by the forcing into the base of the monolith of some of the same lava which elsewhere was oozing out, and constructing, or helping to form, the supporting dome. Indeed, it may well be that the destruction of the obelisk was brought about largely by an "eating" into the mass of burning lava.

2. The hypothesis involves the assumption that the tower or obelisk was one of the later constructions associated with the awakening of the volcano, having been *preceded* in time by the construction of the dome, and its rise is

* Not the more southerly one bearing the same name.

† "The Shattered Obelisk of Mont Pelée," Aug., 1906, pp. 473–474.

dated back only to the middle of October (or November) of the year 1902. But, as has already been intimated, there are good grounds for believing that it existed within the chimney of the volcano as early as the fatal 8th of May, and its presence there as an obstructing "plug" may well have been responsible for the force and downward stroke of the destroying cloud that annihilated Saint-Pierre. There can hardly be a question that the scraggy and apparently cindery mass which I described in my earlier reports as defining a wall in the crater, and which is so well illustrated by Mr. George Varian in the paper (*McClure's Magazine*, August, 1902) detailing our ascent of the mountain on June 1, 1902, was the identical rock. While at Morne Rouge on the day following (June 2), Père Marie assured me that three distinct tooth-like structures were plainly visible from the belfry of his cathedral, "looming up" above the crater's rim.

3. Professor Lacroix has pointed out, what seems to me to be in opposition to his own views, that the volcano had for several weeks maintained a condition of parallel (opposed) activity at the summit: the construction of a fluidal dome and the simultaneous erection of a rigid spine or tower. It would be difficult to explain this divergent condition on any theory of almost instantaneous cooling of outwelling lavas. One could hardly expect to find an outwelling mass so behaving as to lend itself to the formation, at or near the same place and under very nearly similar conditions, of two structures which were so largely dissimilar in habit as the fluidal dome and the rigid spine. If the substance of the dome was able to maintain its fluidity, it might reasonably be argued that the mass of the obelisk would have been able to do the same. On the other hand, the divergent condition is entirely consonant with any theory which holds that the extruded rock was an ancient rock-core that had been bodily lifted from its moorings, and that it bore no relation in its making to the newer activities of Pelée. This is the view that I myself hold and is that which I have enunciated elsewhere. M. Lacroix has in many places pointed out that the mechanics of the two structures were independent of one another.*

4. On the theory of a rapidly solidifying lava, one would naturally expect to find the surface of the cooling body giving out vapors from its inner parts, but the Pelée obelisk, except perhaps along lines of rifting or near its base, never, so far as I am aware, exhibited this peculiarity, the tower of rock looming up at all times grimly cold and dry, and with much the appearance of steam having acted upon its surface. This condition of dryness, contrasted with the

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* "*Pour bien comprendre le mécanisme de la formation de l'amas de lave il faut distinguer très nettement:* 1, *la masse principale du dôme, qui n'a subi que des modifications lentes et peu considérables d'octobre* 1902 *à mars* 1903: 2, *l'aiguille qui la surmontait et qui elle, au contraire, était en voie de continuelle modification*": " La Montagne Pelée et ses Éruptions," p. 118; and again p. 142: . . . "*elles ont montré que la masse même de celui-ci* (*dôme*) *ne participait pas au mouvement d'ascension comme je l'avais pensé tout d'abord, qu'elle restait immobile, tandis que l'aiguille, au contraire, était dans un état de perpétuel changement.*"

steaming appearance of the supporting dome, I consider in itself as almost fatal to any theory of a rapidly cooling lava mass.

To the objections that have here been stated others perhaps less direct—such as the form of the rock-core, the hard attrition and polishing that it exhibited, etc.—might also be urged, and none perhaps more forcibly than the character of the rock-mass itself. This I have already stated* to be a light-grey, fine-grained hypersthene andesite, of almost holocrystalline texture and differing but little from some of the older rocks of the volcano. It is thoroughly compact, and so far as my examinations in the wilderness of débris revealed, seems to be wholly destitute of gaseous cavities, and nowhere even approximates obsidian in aspect and composition; nor does it exhibit evidences (if, indeed, such can be determined) of having passed through a recent fused stage. Of course, it might be going too far to say that scoriaceous or vesicular masses may not exist buried up in some part or another of the material which is everywhere heaped up. The rock apparently belongs to type IV. of Lacroix's classification of the ejected products of Pelée (quartzitic andesites), although some specimens give a faint indication of looser aggregation (approximating the rocks of type III.?), perhaps resulting from weathering, or, what seems to me more likely, the action upon the surface of superheated steam or other gases.

In assuming the Pelée obelisk to have been an ancient neck-core which under enormous pressure had been lifted from its moorings, we at least require no condition that is not generally provided for by volcanoes. There can be no objection to postulating the existence of such a core here, as in other volcanoes; and if existing, there would seem to be no reason why, under the gigantic force of Pelée's activity, it should not have been dislodged and pushed bodily outward.† This view of the nature and extrusion of the giant monolith would at the same time satisfactorily explain its isostatic condition and do away with the necessity of formulating new laws or conditions governing the rapid cooling of lavas. In assuming the presence of this huge core in the throat of the volcano, blocking it and preventing the free escape of the impounded gases, it becomes much easier to understand the violence of the explosions which have marked so many of the Pelée eruptions and the disruptions that so repeatedly wrecked (more particularly) the southwestern base of the tower,—the side directed to Saint-Pierre or the valley of the Rivière Blanche.

To the objection that might be made that no similar extrusions have characterized the outbreaks of other volcanoes, it is not difficult to furnish the answer that they have not provided an obelisk of any kind either. The fact is that violent volcanic eruptions have been only sparingly studied, and few observers have been sufficiently fortunate to be on the field of activity at times

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* *National Geographic Magazine*, Aug., 1906, p. 474.

† It is but proper to add that several geologists had suggested, in conversation with the author, the broad possibility of the Pelée tower having had this origin or pointed out the difficulties that lay in the way of accepting the more general view.

when the earlier phenomena of an eruption could be profitably noted. There are, doubtless, many facts connected with the physics of the opening of a volcanic mountain which have heretofore escaped notice, and some of these may have been directly allied to the greater facts which Pelée itself has presented. The extrusion or lifting of giant solid masses by volcanoes is not, however, an absolutely unknown fact. Abich, as far back as 1882,* described the cliffs of limestone and marble which form an essential part of the centre of the crater of the ancient volcano of Palandokän, and which he unhesitatingly assumed to have been lifted to their positions as the result of the volcano's elevatory force. A somewhat similar or identical relation is presented by the Puy Chopine, in Auvergne, where, as we are informed by Scrope and others, great blocks of elevated granite, sandwiched between trachyte, and constituting a portion of the basal rock of the volcano, now form part of the upper moiety of the dome and point unequivocally to elevation at a time or times of eruption. Other examples of this kind in the past histories of volcanoes could be cited, and, doubtless, many more than are at present known will be found when the craters of volcanoes, active and non-active, will have been more accurately investigated than has been the case until now.†

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* "Geologische Forschungen in den kaukasischen Ländern," ii., pp. 67–78.

† For individual views on the structure and nature of the Pelée obelisk see: Israel C. Russell, "The Pelée Obelisk," *Science*, Dec. 18, 1903; Jaggar, "The Initial Stages of the Spine on Pelée," *Amer. Journ. Science*, Jan., 1904; Prof. N. H. Winchell, *Amer. Geologist*, 1904; Gilbert, *Science*, June, 1904. Also, Branner, on the "Peak of Fernando de Noronha," *Amer. Journ. Science*, Dec., 1903. In a paper on the "Criteria Relating to Massive Solid Volcanic Eruptions" (*Amer. Journ. Science*, April, 1904), Prof. Russell cites a number of instances from among the American volcanic fields—Panum Crater, in the Mono Lake region, California; the tower-rock of the Bogoslov eruption of 1883; Pauline Lake Crater, Oregon—where structures thought to be analogous to the Pelée rock have been developed. These are all explained on the hypothesis of a rapidly solidifying viscous lava, thrust out in the manner that has generally been assumed for the Martinique monolith; but to whatever extent these may share the Pelée type of structure, it seems to me that they receive an at least as acceptable interpretation in assuming that they are merely extruded ancient cores (necks). One may reasonably hold that such extruded cores must exist somewhere, and it seems to me that careful search will reveal many among structures which have hitherto received wholly erroneous interpretations.

IV.

THE PHENOMENA OF THE ERUPTIONS.

THE general characteristics of the great eruption of May 8, 1902, may be briefly summed up as follows: For two weeks and more prior to the event Pelée had been in rapidly increasing activity, emitting clouds of ashes and sulphurous vapors, and opening its crater on the southwestern flank of the mountain (in the ancient basin of the Étang Sec) on April 25. At this time the sulphur vapors had accumulated in such quantity in Saint-Pierre that respiration was made difficult, and animals dropped dead in the streets of the city. On May 2 the ashes had so far covered the roads as to compel a cessation of traffic, and three days later, shortly after noon on May 5, occurred the discharge of the avalanche of boiling mud which overwhelmed the Usine Guérin. This stream, travelling with wholly exceptional velocity, issued from the basin of the Étang Sec, and followed down the course of the Rivière Blanche. From this time up to the 8th, during which interval torrents of volcanic water were deluging and destroying towns and villages,—Prêcheur, Basse-Pointe, etc.,—the unrest of the volcano was rapidly travelling to a climax, and on the morning of the fatal day, without particularly active symptoms presaging the storm, the blow fell with almost lightning-like swiftness. The issuing explosive and exploded cloud left the crater at almost exactly eight o'clock (time of Fort-de-France; approximately, 7.50 local time of Saint-Pierre), and at two minutes after eight (or before) the destruction of the greater part of the city had been accomplished. Saint-Pierre fell before a hot tornadic blast, whose sweep could not have been less than from one to two miles a minute, (and was perhaps vastly swifter,) was tumbled into ruins, and in greater part consumed by an immediately following conflagration. A not particularly heavy fall of ashes and lapilli came close upon the wake of the destroying blast, and almost at the same time a fall of rain, whose duration appears to have been less than an hour.*

In this destruction, with few exceptions, the entire population was annihilated, and all the evidence points to the conclusion that in by far the greater number of cases death was very swift, almost instantaneous. Some few lingered on, and two individuals appear to have survived. Death may have been due to a number of causes, directly related to the crushing of a city under the force of a violent hot tornadic blast, but primarily it appears to have been the result

*On an exceptionally sharp photograph taken on May 10, the privilege to examine which I owed to the kindness of the late Signor Parravicino, Italian Consul at Barbados, the minute-hand of the large clock of the Military Hospital clearly indicated the time of stoppage to have been 7 h. 52 m. On most of the later photographs (taken prior to May 20) this time appears more nearly 7 h. 50 m. I suspect that the hand of the clock must have fallen back two minute spaces as the result of one of the volcanic jars.

of scorching and asphyxiation (the inhalation of an extremely heated vaporous [or gaseous] atmosphere). The measure of the work done by electric discharges has not been determined. Seemingly not less than thirty thousand lives were lost in this catastrophe, representing the entire population of Saint-Pierre and the people of a number of adjoining faubourgs and settlements, the zone of most destructive devastation being measured on the ocean front by the interval which separates the *anse* immediately north of Carbet and Sainte-Philomène. In the middle line or zone of the sector of devastation the destruction, following the area of concentrated force, was necessarily most complete. In it the houses were most thoroughly wrecked and few of the corpses showed any vestige of clothing covering the body; and it appears that there were no persons directly within this zone, excepting the prisoner Ciparis and a certain Léandre, so little burned as to be able to survive their injuries. Laterally to this zone of greatest destruction the force of annihilation was a gradually decreasing one, so as to permit houses to stand and the corpses to retain their covering; and in the further exterior, to inflict wounds of a purely scorching nature which were not necessarily fatal or even of consequence.

The zone of absolute destruction was a comparatively small one, and probably did not much exceed eight or nine square miles; but considerably beyond it extends a region of minor devastation, over which the vegetation was in great measure destroyed, temporarily at least, by singeing, cindering, and the weight of fallen ashes. The explosion of May 8, while being responsible for the destruction of the life of Saint-Pierre and of its associated settlements, was only in part responsible for the appearance of the city as we now see it; the eruption of May 20, which was perhaps as violent as the one that preceded it by twelve days, gave new characteristics to the ruins.

Whatever seismic movements may have accompanied or preceded the great catastrophe, it is certain that, if they existed at all, they must have been of very minor consequence, otherwise some record beyond a passing notice would have been made of them in the Saint-Pierre journals.* And it is a fact that no earthquake shock was noted at Fort-de-France on the morning of the 8th, nor, indeed, at any time previous to August 24, six days before the second death-dealing eruption of Mont Pelée. In this negative aspect the eruptions of Pelée seem to differ from those of the Soufrière of St. Vincent. The barometric records kept at Saint-Pierre indicate a remarkable atmospheric stability during several days preceding the storm, the mercury column registering regularly, up to and inclusive of the 7th of May, seven hundred and sixty-two millimetres, only once falling to seven hundred and sixty-one; it may be that early on the 8th, as the sudden movement of the needle in M. Clerc's aneroid *possibly* indicates, there was a sudden or marked fall, but of this we have no record; nor is any abrupt change, except that represented by a momentary depression of three millimetres, indicated in the registry of the Meteorological Observatory of

*Some slight shocks are noted in *Les Colonies* of May 1 as having been felt on April 29.

Fort-de-France. It is certain that a heavy counter-gust swept to the volcano immediately after the outburst, probably drawn to the mountain by a condition of partial vacuum which followed the displacements in the atmosphere due to the successive explosions—the condition that in St. Vincent, during the Soufrière eruption, permitted windows to be smashed in by boulders and lapilli on the side turned *away* from the volcano.

As a marked negative feature of the Pelée eruptions was the absence of a free lava-flow, a characteristic which also marked the earlier eruptions of 1851 and 1762. Yet the early history of the volcano plainly shows that the prehistoric eruptions were largely accompanied by extravasation of flowing magma, which in their later stages or periods was mainly andesitic in character. That a molten magma rose well into the throat of the volcano or supplied its base is indisputably proven by the ribbing of lava which was thrust into the mass of the crateral dome and to an extent by the ejecta of a fragmental character. Much of the ejected pumiceous particles, on the other hand, as well as the lavæform boulders that lie about in fairly large numbers must be considered as ancient parts of the volcano. The fact that this contained lava was not thrust out as a flowing sheet from the mouth of Pelée can hardly be taken, in a comparative study, as a measure of the force of the volcano, as manifestly the power to lift will be largely determined by the weight or height of the column to be lifted; and our present geological knowledge does not permit us to state this for Pelée or for any other volcano.

It hardly admits of doubt that several of the later paroxysmal eruptions, those of May 20, June 6, and August 30, 1902, for example, shared the general characteristics of the one of May 8. The main phenomena were either in whole or in part the same. My investigations and inquiries made on August 30 and September 1, immediately before and after the outburst of the tornadic blast which annihilated or invaded Morne Rouge, Ajoupa-Bouillon, Morne Capot, Morne Balai and the heights of Bourdon, and swept another fifteen hundred or two thousand of Martinique's inhabitants from existence, confirm me in the belief that the principal agent in this later eruption, and not unlikely also in the earlier ones, was superheated exploded steam, charged in part with particles of incandescent or glowing matter. To the showering of the latter upon the combustible substances of Morne Rouge was due the partial destruction by conflagration of that town. Whatever accessory gases, besides sulphurous (sulphuretted-hydrogen?), may have assisted in the work of asphyxiation or other mode of killing, has not been ascertained, nor is it known that there were any such. The simple condition of superheating and steaming can probably sufficiently explain all the cases of asphyxiation and scorching, or of death where it was not brought about through contact with burning or incandescent particles, electric strokes, crumbling walls, and the violence of a sweeping tornado. The inhaling of an atmosphere of the intense heat of many hundreds of degrees, in places with a temperature possibly much exceeding one thousand degrees, means practically almost instantaneous death, and its effects

could be seen in that heating of the air-passages and excoriation of the lining membrane of the throat and bronchial tubes which were associated with the pitiful cries for water and the sensation of being deprived of air. At the same time, one would hardly be justified in positively denying the assistance in the work of destruction of some toxic gas, as carbon oxyd, whose presence in minor quantity could not readily be detected by later observations.

The geologist will never be wholly certain as regards the precipitating cause of the catastrophe—or more broadly, of the series of catastrophic events of which the eruptions of Mont Pelée formed only a part. In my work "Mont Pelée and the Tragedy of Martinique" (chapter on "The Volcanic Relations of the Caribbean Basin"), I have attempted, following Suess and others, to point out the genetic connection of the different island groups of that region, and their relation to a past orographic unit and continental disruption. The numerous disturbing incidents, whether volcanic or seismic, that have latterly crowded themselves into the history of this zone or region—as, indeed, they had already done two or three times before in a period of a hundred years—together with the unquestionably inter-related manifestations that developed as a part of the synchronic movement, lead one to believe that all of these disturbances had a common origin, whose initiative was to be found in a readjustment of the floor of the Caribbean Basin. This broad zone of weakness, developed along the northern confines of the South American continent and between the fragmented parts of the ancient Andes (Lesser Antilles) on the east and the Pacific coast of southern Mexico on the west, including within its area the greater part of Central America and the tracts of Mexico lying south of the plateau (whose permanency as a "region of concussion" has latterly been indicated by Deckert in his paper: "Die Erdbebenherde und Schüttergebiete von Nord-Amerika"),* is seemingly still in a condition of continuous oscillation, and doubtless of much fracturing and reacting subsidence. Along its edges of greatest weakness, and where relief from strain might most easily be had, do we necessarily seek for the greatest development of volcanic activities. It is also there that, on any theory that associates volcanic phenomena with the accession of oceanic waters to seats of potential magmatic force within the earth's interior, we should expect to meet with violent or paroxysmal outbursts.

The principal features and effects of the Pelean eruptions may be paragraphically summarized as follows:

A. A disturbance in the electro-magnetic field of our planet which in magnitude surpassed all hitherto recorded disturbances of this nature, the almost immediate effects being registered at the widely removed magnetic observatories of Cheltenham (in Maryland), Baldwin (Kansas), Toronto, Stoneyhurst, Val Joyeux (France), Paris, Potsdam, Pola, Athens, Honolulu, Zi-ka-Wei, in China, and elsewhere, the traverse of the disturbance being in all cases about two minutes of time. No previous volcanic eruption, not even the paroxysmal

* *Zeitschrift der Gesellschaft für Erdkunde,* Berlin, 1902, pp. 367–389.

destruction of Krakatao in 1883, is known to have produced any magnetic disturbance other than of a local character.

B. The production of electric or pyro-electric illuminations in the volcanic cloud seemingly far surpassing those that had ever before been noted, and presenting features that had not hitherto been recorded.

C. The propagation of sound-waves to distances of 800 (and probably 1000 or more) miles, the explosion of May 8 having been heard with terrific intensity at Maracaibo, the sound, as likewise that accompanying the eruption of August 30, seeming to come from above.

D. The transmission of a shock-wave, or earth tremor, as would appear from the single observation made at Zi-ka-Wei, in China, passing completely through the earth,—a condition that had only once before been noted (in connection with the Krakatao eruption).

E. The formation of a remarkable series of "after-glows," or brilliant red skies, which doubtless made the passage over the entire earth, and were observed off the Venezuelan coast, at Los Angeles (California), Honolulu, Bombay, Funchal (Madeira), in most parts of Europe, from Italy to England, and along nearly the entire Atlantic border and over the central portion of the United States. These skies, with the attendant Bishop's ring, were less brilliant than those which followed the Krakatao eruption, occupied a position much nearer to the earth's surface, and travelled with somewhat less than half the velocity.

F. The emission of prodigious quantities of steam and ash, the steam-column passing at times vertically through the zones of both the trade and anti-trade winds and to heights above the summit of the volcano estimated to be from four to six miles. The furthest distance at which the falling ash was noted on the surface of the sea appears to have been about 700 (900?) miles.

G. The bursting forth of an explosive tornadic blast, of a nature perhaps not yet entirely understood, whose death-dealing and destroying effects have had no parallel in the earth's history. The event of August 30 was a repetition of that of May 8.

H. The extrusion from the crater-summit of the volcano of a giant core of solid lava, a veritable tower or obelisk, which at its most lofty period (June–July, 1903) rose to about 1020 feet, with a thickness at the base of 350–500 feet (shortest and longest diameter).

I. The eruptions of Pelée took place in times of atmospheric stability, were unaccompanied by earthquake movements, and had no relation to distinctive phases either of the moon or of the sun.

J. The ejected products, exclusive of the tower and its immediate base, were of a fragmental,* aqueous, and gaseous nature, there having been no true lava-flows (at least, not beyond the crater-limits).

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*The fragmental products of the Pelée eruptions are essentially a highly acidic hypersthene-andesite, whose general composition, as determined by the analyses of Hildebrand, Mirville, Pollard, and others, may be stated to be SiO_2, 53–62 per cent.; Al_2O_3 (and Fe_2O_3),

K. No marked alteration in the coast-line or in the height of the land has thus far been noted in the region of the disturbance. There is, on the other hand, strong reason to believe that violent disturbances took place along the oceanic floor near by, even if not necessarily disturbing in marked degree the position of that floor.

L. Each violent eruption was accompanied by a vertical displacement, of short duration and with infrequent oscillations, of the sea-level, the surface rising on both the east and the west side of the island about three feet.

M. There can be no doubt as to a chorologic relationship existing between the activities of Pelée and the Soufrière of St. Vincent.

The Force of the Explosion.—It is hardly possible, except in a very indeterminate way, to establish a comparison between the explosive force which marked the eruption of May 8, 1902, and that of other great eruptions whose histories are fairly well known to us. If the measure of this force is to be read merely from the mechanical work of volcanic decapitation and evisceration, in the amount of solid material that was thrown out, in the height of projection of some of this material, and the concussions to which these projections gave rise, then the eruption of Pelée may be thought to stand far down in the scale of volcanic catastrophism, having been surpassed by Papandayang (1772), Asama-Yama (1783), Skaptar Jökull (1783), Temboro (1815), Coseguina (1835), Krakatao (1883), Tarawera (1886), Bandai-San (1888), and perhaps even by many of the eruptions of Vesuvius, Etna, and Mauna Loa. The erupted material of Pelée was not particularly large, and probably even considerably less than that thrown out by the Soufrière on the day preceding. The volcano had been well opened nearly two weeks in advance of the cataclysm, on April 25, and the crater had been throwing out great quantities of ash and lapilli almost unremittingly since that date. At the moment of the

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20–30 per cent.; CaO, 6–10 per cent.; MgO, 2–4 per cent., + $N_2O_1K_2O$, and H_2O. This does not differ essentially in composition from the andesitic rocks which form the old stock of the volcano, and which are so largely distributed over the island of Martinique. A true cyclic succession of the volcanic rocks, following the Richthofen view, would seem not to have been here realized, although it is true that a large part of the ejected material was in all likelihood from the old stock of the volcano. To this class belong, doubtless, a large part, if not practically the whole, of the ejected ash, many (if not most) of the cracked blocks (certainly ejected in solid form) that have been designated bread-crust bombs, and much of the scoriaceous products. The notion that volcanic ash is a product, through finer and finer trituration, of a fresh or new lava—lava of the period of eruption—seems to find no support from the facts presented by Pelée. Giraud, from a determination of a few fossil remains found in the tuffs of Trinité and Marin (*Turritella tornata*, also found in the Miocene of Panama—*Pecten* (*Amussium*) *subpleuronectes*, and *Aturia aturi*) and on other grounds, assumes the earlier volcanic outflows to have begun in the Oligocene, and to have been carried through the Miocene period (Bull. Soc. Géol. de France, Nov. 17, 1902, p. 395; *ibid.*, Feb. 16, 1903, p. 130). In a fairly extensive collection of fossils that I obtained at Bassignac, near Trinité, at an elevation of some 70–80 feet above the sea, the Miocene facies is well apparent, many of the types being those that are representative of the Jamaican and Floridian deposits.

catastrophe, it would seem that no very great part of the mountain was raised or hurled into the air. A comparison of ancient and modern landmarks shows unmistakably that whatever change was imposed upon the summit or general contours of the mountain, this change did not affect the broad aspect either of the slopes or of the former crest-line, nearly all the old topographic features having been retained, although emphasized in part. It is not unlikely that in this eruption some considerable portion of the periphery or floor of the crater was actually blown out, the fragments coming from the destruction of which may have constituted the *gerbe de rochers* which has been described by M. Thierry (*Comptes Rendus*, July 7, 1902, p. 71) and others as having been projected several hundred feet above the crest of the volcano.

However easily one may force a comparison between the energies expended in different eruptions, based upon the value of their mechanical effects, a study of correlative results shows that this form of comparison is not wholly free from error, and may lead to serious misconceptions. Thus, comparing the eruption of Pelée with that of Bandai-San, in 1888, we know that the amount of solid matter thrown out by the former was comparatively small. The discharge of the latter, on the other hand, has been assumed by Professors Sekiya and Kikuchi in their official report to have been one billion five hundred and eighty-seven million cubic yards, distributed over twenty-seven square miles of surface (*Journal College of Science*, Imperial University of Japan, III, 1890, pp. 91 *et seq.*).* Yet despite this vast dislocation and the great tornadic tempest to which it gave rise—a tornado moving with a velocity assumed to have been not less than ninety miles an hour—the damage wrought, estimated by the Pelée standard, was (although very great in itself) fairly insignificant. Only one hundred and sixty-six houses were destroyed, completely or partially, and less than five hundred (four hundred and sixty-one) lives lost. Nor, indeed, were the "frightful" detonations that accompanied the explosion heard at any great distance,—to windward, not more than thirty miles.

The force of a blast such as that which, in the case of Pelée, annihilated a compactly built city along a direct line of nearly or quite two miles can hardly be estimated. Its measure can well be taken from the excess or non-development of the ordinarily associated volcanic phenomena, as these seemingly gave way to a form of eruptivity whose force-centre lay in a different path. It is reasonable to assume that had Pelée been a sealed mountain up to the time of

*This quantity (1.20 cubic kilometres) is just one-fifteenth of that which has been assumed to represent the outthrow of Krakatao in 1883 (4.3 cubic miles), and hardly more than one-hundredth (!) of what (28.6 cubic miles) Verbeek believes must have been blown out by Temboro in 1815.—Royal Society Report on Krakatao Eruption, p. 439. It seems to me that Verbeek, and geologists after him, have exaggerated the extent of the Temboro eruption; at least the account of the cataclysm as it appears in Sir Stamford Raffles's Memoirs (pp. 241–246), while manifestly dealing with an unusual event, would hardly convey to the mind a stress of nature greater than that which is painted by Caldcleugh (*Philos. Trans.*, vol. 36) and other writers (*Am. Journ. Science*, 1835, pp. 332 *et seq.*) of the eruption of Coseguina.

its first great eruption, the mechanical effects of disruption might have presented themselves on a scale vastly more imposing than that on which they were actually found. Professor Judd, reviewing the characteristics of the Krakatao eruption,—which he assumes to have been developed on a "much smaller scale than several other outbursts which have occurred in historic times,"—asserts that "in the terrible character of the sudden explosions which gave rise to such vast sea- and air-waves on the morning of the 27th of August, the eruption of Krakatao appears to have no parallel among the records of volcanic activity." We may say in the same way of Pelée that in the intensity and swiftness of the death-dealing blast, the vast disturbance caused in the magnetic field, and the extraordinary brilliancy and remarkable character of the electric phenomena, the eruptions of May 8 and of later date stand unique in the records of volcanic manifestations.

Distribution of the Products of Eruption.—It has already been stated that the eruption of May 8, as well as the eruptions of later date, were entirely free from open lava-flows, and that the solid products of eruption consisted exclusively of mud-materials, lava-bombs, boulders, lapilli, pumice and ash. None of the more massive ejecta were thrown to any great distance from the volcano's mouth. Their location, except where subsequently disturbed, is almost exclusively on the upper slopes of the mountain, at distances usually within close range of the summit; and those of larger size, measuring several feet in diameter or very much more, where occupying a more distant position, have in most cases undergone secondary transportation by rolling down the nearly unobstructed slopes. When nearly opposite the lower lip of the crater on August 24, 1902, just in advance of a fairly powerful eruption, I was witness to giant boulders or rock-masses sweeping down the exterior slope of the great fragmental cone. Some of these, I believe, could not have been less than twenty or thirty feet across—perhaps they were even considerably more. Where rolling over an open or unobstructed course the distance covered was great, perhaps reaching to two or three miles. The rising plane that forms the parting between the Rivières Blanche and Sèche, and over which swept the mud-flow of May 5, was, when I passed it on September 6, a week after the eruption of August 30, checkered with great boulder-masses, some of them of very large size. Doubtless, some of these ejected rock-boulders were merely fragments of the united or fused cindered masses that in part construct the summit of the eruptive cone; but others were almost certainly true ejected masses that had been hurled into the air, just as had been the case in the eruption of May 8. Of the ejected material of the volcano that was thrown to a greater distance than five or ten miles there do not appear to have been many fragments that were larger than an egg; nearly everything was, indeed, very much smaller—particles measuring an inch or less. The finer ash was, of course, drifted off to great distances. Practically the whole of Martinique received some sort of a deposit. Perhaps the farthest distance at which the drifting ash of Mont Pelée has been *noted* in the lower regions is six hundred to seven hundred miles, although there can hardly

be a doubt that the areal distribution is much more extensive than would seem to be indicated by these limits. The inquiry in this field is necessarily complicated by the discharges from the Soufrière of St. Vincent, whose driftage preceded that of the main eruption of Pelée by one day, and by the number of discharges which preceded the main incident. Whether the phenomenon be referable to Pelée or to the Soufrière, it is interesting to note that on May 8, six hundred and sixty miles east by south of Pelée, in latitude 13° 22′ N., and longitude 49° 50′ W., a falling dust was recorded by the bark *Beechwood*, bound from Salaverry for New York.

On May 8, two-thirty A.M., the bark *Jupiter*, from Cape Town, reported receiving dust at a distance of nine hundred and thirty miles east-southeast of St. Vincent (Meteorological Office Pilot Chart). This seems to be the farthest distance of driftage on the sea which has been observed, and if the materials are referable to the great eruptions, then manifestly they are part of the eruptions of the Soufrière and not of Pelée. The time period would then indicate a velocity of travel of nearly sixty miles an hour, nearly treble that which (as will be seen farther on) may be assumed for the passage of the upper dust-strata which carried with them the phenomena of the afterglows.

Other observations on falling dust are contained in the logs of the steamship *Coya*, bound from Montevideo for New York (fall noted in the evening of May 7, ten-thirty o'clock—latitude 11° 23′ N., longitude 57° 52′ W., two hundred and fifty miles east-southeast of St. Vincent); the bark *Eleanor M. Williams*, from Conetable Island for New York (fall, May 8, three to eight P.M., in latitude 14° N., longitude 57° W., two hundred and fifty miles east of Martinique); the steamer *Porto Rico*, on June 7, lying at anchor near Ponce; the ship *Monrovia*, from Rio de Janeiro (at four P.M. of May 8, two hundred and forty miles southeast of Barbados); the ship *Kaiser* (May 20) in latitude 19° N., longitude 54° 11′ W., about 500 nautical miles N. E. of Martinique (Häpke, "Vulk. Asche auf Bremer und Hamburger Seeschiffen," *Abhandl. d. naturw. Ver. Bremen*, 1903, pp. 542–548); and the bark *Capella* (July 9), in latitude 14° 20′ N., longitude 62° 45′ W., about 90 miles S. W. of Pelée. The particles that fell on the *Kaiser* measured, according to Häpke, 0.01 to 0.05 mm. Those falling on the *Capella* were about twice this size, and contained much magnetic iron, as in the Vesuvian and Krakatao ash. It is interesting to note that nearly all the long-distance observations were made on the windward side of the islands, which would seem to show that the greater part of the dust was projected through the zone of the trade-winds, and carried eastwardly in the path of the alternating (or "anti-trade") winds. The royal mail steamer *La Plata* (*Nature*, June 26, 1902, p. 203) notes falling dust on May 9, six P.M., one hundred miles west of St. Lucia.

The Steam- (Ash-) Cloud.—This appeared white, gray, yellow, reddish, brown and almost black, depending upon the quantity of ash with which it was encumbered, the pure white indicating a nearly pure steam-cloud. When

the volcano was in moderate activity the *panache* or pennant rose in gentle outflowing sweeps, little different from the curling smoke of high chimneys. Even in this condition the visible part rose to a mile or two above the crest of the volcano. In more violent or paroxysmal stages the emitted vapor boiled up or out with great force, disengaging itself in rapidly enveloping puffs and rolls, and constructing the well-known cauliflower form of clouds. These either rose straight up, looking as though they had been shot out of a cannon's mouth, or spiralled about in corkscrew fashion, giving the appearance of being sucked into a central vortex.* It is in this stage that the volcano appeared in all its majesty—sublime and terrifying. I did not see anything that could properly be said to represent the "pine-cloud" of Vesuvius. The ascensive force of the steam-column was very great, and from a number of eye-measurements that were made at different points I should say that it frequently mounted up to three or four and five miles. On our descent from the mountain in the afternoon of August 30, 1902, about four and a half hours before the explosion of that date, there was a burst which seemed to me to carry the steam-column, narrowed somewhat like a Lombardy poplar, to a height of not less than six or seven miles. Prodigious though this may appear, it is still very much less than the ascent of the steam-cloud which issued from Krakatao at the time of its eruption in August, 1883. That was assumed to rise to nearly nineteen miles.† On the same August 30, when the crater was boiling from all its parts, and the roar from the ascending straight column was appalling, I timed the velocity of the issuing stream with my watch, and found it to be from one and a half to two miles per minute, and at intervals even greater. Only when coming near to this column did one appreciate the violence of its outpour, the force that projected it into the air and kept it there, ploughing through the other clouds that had preceded.

It is an interesting question to ascertain to what extent this high flight was dependent upon the propelling power that shot out the vapor, or was merely a measure of the vapor's low gravity and expansive power. We may, perhaps, readily admit that the far upper zone of this pennant was "floating" of its own accord, and only through consecutive concussions from below felt the true projecting force of the volcano; but this admission does not materially affect the problem, since we have to consider in this connection not only the outer column of steam but also that which was contained in the throat of the volcano, and which may even have risen from very considerable depths. The fact that

*Mack ("Über Wirbelbewegungen in vulkanischen Rauchwolken"—*Meteor. Zeitschrift*, Vienna, 1901, pp. 250–256) refers the spiralling of volcanic clouds to the condition which determines the similar movement in liquids when they are forcibly ejected from round tubings. Seebach has described a volcanic vortex spiralling vertically instead of horizontally (*Abhandl. Königl. Gesell. d. Wissenschaften*, Göttingen, 13, p. 57).

†One of the artillery officers stationed at Fort-de-France determined by instrumental measurement the elevation of the steam-column to have been five thousand metres, or almost exactly three miles.

so frequently the lofty pennant was shot in a straight line entirely through the zone of the trade-winds, as many of my photographs show, and perhaps even through the zone of the anti-trades, naturally proves that, at certain times at least, the propelling power was responsible for the full or nearly full height that the cloud attained.

In the chapter on "The Geography of Mont Pelée" of my work "Mont Pelée and the Tragedy of Martinique" I have stated that it appeared to me that not only were the eruptions taking place from the summit of the new cone that had been erected over the floor of the basin of the Étang Sec, but also from still-existing parts of this ancient floor, and I ventured the assertion that the destructive blast of August 30 may have had its origin here, rather than in the chimney-pot. I was led to this conclusion by the violence of the steam eruptions coming from the great depths of the crater, and their gradual crowding over to the side turned to Morne Rouge—the location whence seems to have issued the explosive tornado of May 8. This view seems also to have been shared by Professor Lacroix, who observes (*Comptes Rendus*, October 27, 1902, p. 673): "It would appear that it is from the interval between the walls of the crater and the base of the cone, as well as from the flanks of the cone itself, that the columns of gas and vapors, at times of calm, ascend vertically to prodigious heights ("*Il semble que c'est de l'intervalle situé entre les parois du cratère et la base de ce cône, ainsi que des flancs de celui-ci que sortent actuellement les colonnes de gaz et de vapeurs qui, les jours de calme, montent verticalement à une hauteur prodigieuse*"). The plate (decimaprima, 28*a*) illustrating the eruption of Vesuvius in 1767, and contained in the "*Gabinetto Vesuviano*" of Della Torre (1797), perhaps represents the same form of double synchronic activity.

Quantity of Ash-Sediment Discharged.—No determination of the quantity of ash thrown out by Pelée during its various eruptions can have more than a speculative, or at best, a roughly approximative value. Much the greater part of it was distributed over the sea, and at times, for days in succession, this quantity was prodigious. The near-by localities during this period may, on the other hand, have received but little of the ejected material. The late Professor Israel C. Russell, in a paper on the "Volcanic Eruptions on Martinique and St. Vincent" (*National Geographic Magazine*, December, 1902), attempts to give mathematical expression to this quantity by assuming that the contents of an energetic Pelée steam-cloud rising to three or four miles was about 4,000,000,000 cubic feet, and that such a cloud was charged at its minimum with one per cent., or 40,000,000 cubic feet, of solid matter. It was further assumed that every such cloud was regularly replaced at intervals of five minutes by another cloud (the rate of ascent here considered being about three-quarters of a mile per minute, which is very much less than I found it to be on August 30, 1902). Hence, the discharge of solid matter from the crater would have been in every five minutes 40,000,000 cubic feet. In all of these data I believe that Professor Russell has understated, rather than overstated, the conditions as they existed, and perhaps very much so, but they serve as an

interesting basis for further analysis and comparison.* The discharge of 40,000,000 cubic feet of solid sediment every five minutes means 480,000,000 cubic feet per hour, and 11,520,000,000 cubic feet per day of twenty-four hours, which is *one and a half times the quantity (of sediment) that is discharged by the Mississippi River in the course of a whole year!* In other words, if these figures are in any way approximative, the sedimental discharge from the crater of Pelée, taken at a minimum estimate, was in any period of time during a condition of moderate eruption more than five hundred times that of the Mississippi River, and consequently considerably greater than that of all the rivers of the world combined. This daily discharge from Pelée of 11,520,000,000 cubic feet of sediment would, if evenly deposited, have raised the level of a region having the area of Martinique by almost exactly one foot. Mont Pelée was in a condition of violent and almost continuous activity for upwards of two hundred days; can we assume that during this time it may have thrown out a mass of material whose cubical contents were hardly less than a quarter of the volume of Martinique as the island appears above the water? One is, indeed, almost appalled by the magnitude of this work, and yet it may even have been very much greater than is here represented. Geologists must take account of this force as being one of great potential energy, whose relation to the modelling and the shaping of the destinies of the globe is of far greater significance than has generally been conceived.

Flaming Gases.—I do not think that we are quite justified in denying the presence of flames in the visible phenomena of Pelée. Burning gases and issuing flames having been observed in some volcanoes, there is no particular reason, so far as I can see, why they might not also have been here. The fact that most of the supra-crateral illumination, so often described as flame, is merely a reflex from the glowing, incandescent matter *below*, is in no way an answer to positive statements, coming from seemingly careful, even if non-scientific, observers, which assert that flames were unmistakably distinguishable in more than one eruption. Such statements should naturally be received with caution, but not necessarily immediately denied. If it may be true that a part of the extraordinary electric illumination which we witnessed on the night of August 30, 1902, at the time of the destructive eruption, and which others witnessed on the 25th of the same month, on August 9, and on May 26 and 28, besides other times, was of a gaseous nature, as some investigators pretend, then it becomes easy to believe that flames may have been seen shooting out from or burning around the crown of the volcano. M. Roger Arnoux, a member of the Société Astronomique de France, in his report to Camille Flammarion, claims to have seen fixed flames (*"des feux fixes d'une flamme très blanche"*). I saw nothing that was even remotely suggestive of flame.

Electric Illumination in the Volcanic Cloud.—The cloud illumination which

*Russell himself seemed to incline to the opinion that ten per cent. would more nearly represent the proportion of solid matter contained in the cloud.

I have elsewhere described as accompanying the eruption of August 30, 1902 ("Mont Pelée and the Tragedy of Martinique," Chapter XVI), the kind which had been observed several times before as part of the eruptive activity of Pelée,* certainly constitutes one of the most interesting, and perhaps least understood, phenomena associated with volcanic discharges. Indeed, we are still hardly in a position to assert that the phenomena are wholly electric, or whether they may not be in considerable part gaseous; or, again, whether they may not represent a form of electric manifestation whose peculiarities have been induced by development in a complex gas-cloud in place of the ordinary atmospheric one. On the night of August 30 the heavens were simply aglow with fire, electric flashes of blinding intensity traversing the recesses of black and purple clouds, while scintillating stars burst forth like crackling fire-works, and serpent lines wound themselves in and out like traveling wave-crests. The number of forms in which the illumination appeared was bewildering, but only a few of these—short, straight, rod-like lines, wave-lines, spirals, long-armed stars, and circles with star-arms hanging off from the border like so many tails —could be fastened with precision by the eye. None of the irregular figures— circles, circles with undulating streamers, serpent-lines, straight lines, etc.— had the full dazzling quality of the zig-zag lightning that at times flashed through their field, but appeared extremely brilliant, yellowish in color, varying at times to purple. Possibly, this was an indication of the great height of the clouds and the tenuity of the atmosphere in which they were developed, a condition which is well known to influence the character, as regards color, of ordinary lightning flashes. Again, the particular gaseous constitution of the clouds may have influenced the color effects. The flashes and serpent-lines that appeared to take horizontal courses through the clouds, or across spaces uniting individual fields of cloud, manifestly marked a successive development in a progressive field. I did not myself observe any of these "bars" terminating or exploding in an end-flash or star, as some others have stated, but the condition might well have existed, seeing how many rocket-like bursts appeared in some parts of the cloud. The normal flashes were bewilderingly numerous, and of course not localized. The scintillant stars alone appeared to have a place of their own, which was nearest to the border of the great cloud, and perhaps in the highest parts of it. The display lasted nearly an hour, almost exactly the duration of the discharge of lapilli and ash on the Habitation Leyritz where we were staying, and during this time there was a continuous, but not loud, roaring—perhaps, it would be better to say, rolling —of thunder, which in regular crescendos and diminuendos seemed to traverse the entire field of the volcanic cloud. Some pretended to have heard a feeble crackling associated with the electric display, but I am not sure that I myself

* See August F. Jaccaci, "Pelée the Destroyer," *McClure's Magazine*, September, 1902; Robert T. Hill, *National Geographic Magazine*, July, 1902; Kennan, "The Tragedy of Pelée," 1902.

was made aware of this condition. On the other hand, an uninterrupted crepitation was noted at the Observatory of Fort-de-France.

Whatever may be the precise nature of these extraordinary displays—and only after careful spectroscopic analysis of similar displays will it be possible to arrive at a positive conclusion as to their character—it is certain that something similar has been observed in the eruptions of some (perhaps many) other volcanoes. The balls of electric fire that in different eruptions have been described in connection with the ascending steam-column of Vesuvius are almost certainly a part of the same phenomenon, although sometimes they are referred to as actually falling incandescent boulders, the same as in the Soufrière eruption of 1812. Sekiya and Kikuchi, in their report upon the Bandai-San eruption (1888), speak of innumerable sparks of fire being seen through the densely falling ashes, with characters quite different from lightning; but these investigators refer to them as being produced "by stones and rocks striking against each other in the air or falling on a rocky bed. . . . We could discover nothing to lead us to believe that there had been combustion or any other heat manifestations."* It is singular that at the time of our own observations all of the phenomena were overhead, nothing appearing in the region immediately about or directly over the crateral opening.

Seemingly the counterpart of what we observed on the night of Aug. 30 was noted during the eruption of Santorin in 1650, for Pègues, in his description of this event, says: . . . "*l'air paraissait tout en feu . . . Vous eussiez vu comme des serpents voler, des épées briller, des lances traverser le ciel, des torches ardentes voltiger de toutes parts*" ("Histoire et Phénomènes du Volcan et des Iles Volcaniques de Santorin," 1842, p. 152).

Nothing exactly of the nature here referred to seems to have been remarked as an accompaniment of the Krakatao eruption (Captain Wooldridge speaks of serpent-like flashes of forked lightning), but the report of Pond and Percy Smith on the great eruption of Tarawera, in New Zealand, in June, 1886, leaves no doubt that the phenomena witnessed there were identical with those of Pelée. "The electrical phenomena accompanying the outburst," we are told, "must have been on the grandest scale. The vast cloud appears to have been highly charged with lightning, which was flashing and darting across and through it, sometimes shooting upward in long, curved streamers, at others following horizontal or downward directions, the flashes frequently ending in balls of fire, which as often burst into thousands of rocket-like stars."† It should be noted that some of the electric display of Tarawera was "accompanied by a rustling or crackling noise . . . probably the same [noise] as is heard sometimes at great auroral displays." It would seem that Flett and Anderson observed a minor exhibition of this form of electric discharge in the low-rolling black cloud of July 9.

**Journal College of Science*, Tokyo, III, 1890, p. 129.

†*Transactions New Zealand Institute*, 1886 (1887), p. 352.

A note communicated by Mr. Powell, Curator of the St. Vincent Botanic Gardens,* on the great eruption of the Soufrière of September 3, 1902, refers to serpent electric flashes in the sky at that time. Doubtless, these were of an identical nature with those observed in the Pelée cloud, although no reference is made to the lines occurring in parallel associations. The parallel banding or composite structure of the lightning flash may be frequently seen in good photographs.

Atmospheric Stability.—It is a noteworthy fact, and one that is wholly opposed to the view that violent volcanic eruptions are necessarily indicated by precedent atmospheric disturbances, that none of the great eruptions of Pelée followed any marked barometric fluctuation. For several days preceding the May 8 eruption, including May 7, as the Saint-Pierre records show, the atmosphere was singularly impassive, the barometer registering at noon seven hundred and sixty-two millimetres, and only on one day dropping to seven hundred and sixty-one millimetres. Much the same condition of stability was recorded by the barometer of the Meteorological Observatory of Fort-de-France during several days preceding the explosion of August 30. Immediately preceding the event of May 8, and also that of June 6, as the observations of M. Fernand Clerc and the registry of the *Pouyer-Quertier* indicate, there was a rapid fluctuation with sudden fall (and equally rapid recovery),—the depression of June 6 amounting to four millimetres, which, I understand, is quite significant in the island of Martinique,—but this movement may have been induced as the result of a terrestrial (seismic) concussion rather than of a true currental displacement in the atmosphere.† The eruptions of Tarawera and Bandai-San likewise took place at times of atmospheric calm, or when the barometer indicated no abnormal depression, "either shortly before or during the catastrophe" (Pond and Percy Smith). The great cataclysm of Krakatao was preceded by a night of raging storm, but as the volcano had really been very active already before that date this fact loses all significance. Breislak, describing the great eruption of Vesuvius in June, 1794, remarks upon the stability of the barometer: "*Le tableau des observations météorologiques . . . prouve que le baromètre n'a éprouvé aucun changement sensible*" ("*Voyages dans la Campanie*," 1801, p. 216). I think that it would not be difficult to show from the records of many eruptions that the state of the atmosphere has little to do with the development of phenomena of this class.

Counter Atmospheric Current.—The existence of such a return current, or of a wind directed to the volcano, following immediately upon the explosion of

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* *Journ. Geol. Soc.*, London, Feb. 10, 1903.

†The almost instantaneous barometric fluctuation noted at the Meteorological Observatory at Fort-de-France on the evening of August 30, and at the immediate time of the eruption, was from three to four millimetres,—fall of 3 mm., and rise of 4 mm. in the space of ten minutes (Report of M. Mirville). There was a distinct odor of ozone noticeable at this time.

May 8, is substantially vouched for in the published observations of MM. Arnoux and Célestin, members of the Société Astronomique de France, and of others who witnessed the catastrophe at close range. Some of these describe the wind as being of almost hurricane force, sweeping off the branches and twigs of the trees that stood in its course, and overthrowing or sweeping off other objects. On June 6, when the great ash-cloud swept over Fort-de-France, and announced the very severe eruption that had just taken place, I particularly noted the extreme velocity with which the normal clouds of the atmosphere were sailing in a lower zone directly to the volcano, the appearance being very much as though they had been forcibly drawn to it. There was, I believe, no particular movement where I was standing. At the time of the Bandai-San eruption these counter-currents appear to have been particularly strong, and perhaps even did much of the wrecking. Professors Sekiya and Kikuchi state that the "fearful blasts that wrought such havoc on the forests and villages on the 15th of July certainly were not counter-currents of this class, however strong these may have been," but "gusts *from* the volcano." Yet it appears in the testimony and report of T. Uda, of Kokaï village, Yama-Kori, who was the nearest reliable witness to the catastrophe, and only 3.2 miles east-southeast of Bandai-San, that: "Soon after the eruption a great whirling wind suddenly swept over the eastern part of the mountain with great violence, destroying Shibutani, Shirokijo, Ojigakura, etc." These villages are part of the seven that are indicated in the official report as having been destroyed. This statement, therefore, seems to stand directly opposed to that of Sekiya and Kikuchi.

Pond and Percy Smith in their report on the Tarawera eruption note the creation of a similar wind: "Soon after the first outburst, and before the fall of the first stones, a great wind arose, which rushed in the direction of the point of eruption with great force, and was most bitterly cold" (p. 351). The reference to the lowering of the temperature is very interesting. On June 6, in Fort-de-France, immediately on the coming of the ash-cloud and of the counter-current there was a perceptible cooling of the atmosphere, perhaps by fully ten degrees, and this condition remained for two or three hours. How much of this may have been a direct result of the developed counter-wind, or how much may have been due to the cutting off of the sun's rays by the interposed cloud, I do not profess to be able to say; but the suddenness of the lowering of the temperature makes it almost certain that the phenomenon was intimately bound up with the coming of the wind. In tropical regions the blanketing of the sun's rays more generally brings about a sultry atmosphere; in this instance, it was one of refreshing coolness, following closely upon previous hot air. As regards the nature of this counter-current I do not think it can be questioned that the explanation given by Sekiya and Kikuchi is approximately the correct one. The immense volumes of steam that issue from the volcano suddenly expand, and in doing so necessarily lower the temperature of the surrounding atmosphere, and also diminish its pressure. "To fill the partial vacuum thus produced and to equilibrate the reduced pressure, there follows

an inward rush of air towards the crater. The strong winds commonly described as a feature of volcanic eruptions are probably due to this cause."

Magnetic Disturbances.—The May eruption of Pelée seemingly stands apart from all other volcanic eruptions in the magnitude of the magnetic disturbance which it occasioned, the electro-magnetic waves that were shot out causing many hours' disturbance to the magnetic needle at nearly all points of the earth's surface where magnetic observations were recorded; and it has perhaps been justly claimed that this was "the first instance that magnetic effects caused by eruptions of distant volcanoes have ever been recorded at magnetic observatories."* The disturbances were recorded at the United States Coast and Geodetic Survey magnetic observatories located at Cheltenham, Maryland, and at Baldwin, Kansas, at practically the same instant of time—corresponding to 7 h. 54 m. local time of Saint-Pierre. A second disturbance was noted on May 20, conformably with the second great eruption of Pelée. Corresponding disturbances were noted at Toronto, Stoneyhurst, Greenwich, Val Joyeux, Hamburg, Paris, Potsdam, Pola, Pulkova, Athens, Honolulu, etc., and it is remarkable that all of these were noted at almost precisely the same moment of time, corresponding to 7 h. 54.1 m. local time of Saint-Pierre. Bauer has fixed the time from data obtained from twenty-six observatories encircling the globe.†

The striking fact obtained from these records is that the major disturbance was registered primarily upon the horizontal component of the earth's magnetic force. At the Cheltenham observatory, as stated by Bauer (*Science*, May 30, 1902), the disturbance appears to have amounted at times to about $\frac{1}{350}$ of the value of the horizontal intensity (.00050—.00060 c. g. s. units) and to from 10′ to 15′ in declination. At Pola the increase in the horizontal intensity was .00023 c. g. s. units; vertical component, .00005 c. g. s.; declination, 1.5 (Kesslitz, *Meteor. Zeitschrift*, Vienna, 1902, pp. 316–317). At Athens,‡ as at most of the other stations, no seismic disturbance of any kind was noted

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**National Geographic Magazine*, June, 1902, p. 209. It may be that some minor magnetic disturbances which were noted (at Melbourne, for example) at about the time of the Krakatao eruptions are referable to that outbreak.

†L. A. Bauer, "Magnetic Disturbances during the Eruption of Mont Pelée on May 8, 1902." Paper read before the International Geographic Congress, Washington, September, 1904. A slight variation in the time-period is reported by Messerschmidt for Berlin (*Annalen der Hydrographie*, 1903, p. 152): horizontal, 7 h. 52 m.; declination, 7 h. 55 m.; and by Kesslitz for Pola (*Meteor. Zeitschrift*, Vienna, 1902, p. 316): 7 h. 55 m.

‡The Athens record was reported to the Académie des Sciences of Paris as: "*Une perturbation magnétique, très sensible, affectant principalement la composante horizontale, un peu moins la déclinaison et excessivement peu la composante verticale*" (Engivitis, *Comptes Rendus*, 134, 1902, pp. 1425–1426). The first fluctuation was noted at 1 h. 25 m. mean Athens time. The Val Joyeux record notes the earliest perturbation, also affecting almost wholly the horizontal component, at 12 h. 6m., mean Paris time (Moureaux, *Comptes Rendus*, 134, 1902, p. 1107). The duration of the disturbance was both at Val Joyeux and Athens almost exactly eight hours.

at this time; on the other hand, the great earthquake of Guatemala, on April 18, was impressively registered by the seismographs at nearly all, or all, of the observatories. The most interesting magnetic notation is that of Zi-ka-Wei, China, the observations pertaining to which were made by M. de Moidrey, and are published in the *Comptes Rendus* for August 11, 1902: "*Ce jour-lá, à 7 h. 58 m.* [Martinique time], *après une longue période de calme magnétique, notre bifilaire indique un accroissement brusque de la composante horizontale, qui reste agitée pendant huit heures environ*" (p. 322). The duration and the great distance at which the disturbance was felt are alike noteworthy. Zi-ka-Wei is situated almost exactly on the meridian opposed to Saint-Pierre—*i.e.*, half round the world in distance from it. This record is specially significant as during the Krakatao eruption it was considered doubtful if the instruments of this station recorded any disturbance that could be correlated with the cataclysmic occurrences in the Sunda Straits.*

The replies to the official inquiries sent out by the Krakatao Committee of the Royal Society would seem to indicate that no particular magnetic disturbances were noted in Bombay, Melbourne or Toronto, and the perturbation was so slight and of so doubtful a nature in the European cities that it may be questioned if they were in any way related to the eruption; at all events, there was nothing that was at all comparable with the magnitude of the disturbance registered at the American stations. On the other hand, it seems that some slight magnetic variation was noted at Pará, Brazil, on the day of the Krakatao eruption. Dr. Van der Stok, the Director of the Batavia Observatory, noted at the time of the Krakatao eruption a marked magnetic oscillation, which he attributed to the influence of the magnetic iron contained in the falling ashes. Probably this disturbance was of the same nature as that which I noted on the rim of the ancient basin of the Lac des Palmistes at the time of my first ascent to the summit of Pelée (May 31), when the compass-needle was deflected forty degrees or more to the eastward. The basin was still steaming extensively, and was largely filled up with ejected material from the volcano, recently cast out.†

In discussing the problems that are associated with this new form of magnetic disturbance, Bauer expresses himself as follows:‡

"The coincidence of the magnetic disturbance with the Mt. Pelée eruption was such a striking one as to suggest, as already stated, some physical connection. And the first thought might naturally be that the displacement of masses in the earth's interior produced a redistribution of the electric currents inside

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*Marc Dechevrens: "*Je ne sais si les irregularit·s magnétiques que j'envoie ont eu aussi une relation avec le bouleversement de Krakatao; les magnétogrammes ne montrent rien le 28.*"—Royal Society Report, 1888, p. 473.

†See in this connection the suggestive paper by David: "La stabilité de la direction d'aimantation de quelques roches volcaniques." *Comptes Rendus*, 1904 (138), pp. 41–42.

‡"The Present Problems of Terrestrial Magnetism."

the earth, which in turn gave rise to the magnetic disturbance observed on the earth's surface. We have had, namely, repeated instances in which seismic disturbances, known to have occurred, were recorded not on seismographs, but on *magnetographs*. This might occur if, for example, the mechanical displacement of masses below the surface resulted in either the formation, destruction, or redistribution of the electric currents, which in turn produced the magnetic effect. This magnetic effect would then propagate itself more rapidly to the surface of the earth than the mechanical vibration, and hence might be recorded first or even give a record when the mechanical vibrations by the time they reached the earth's surface would be too feeble to leave their trace on seismographs.

"However, in the case of the magnetic disturbance before us no such simple explanation is possible. While the mathematical analysis has not yet been completed, it has progressed sufficiently far to show that the cause of the magnetic disturbance cannot be referred to any distribution of electric currents *below* the earth's surface, but that, on the other hand, the observed phenomena are better satisfied by assuming a distribution of electric currents in the regions *above* us. As is known, it is with the aid of the changes in the vertical component of the earth's magnetism that we can decide whether the forces producing the observed disturbance have their seat in the earth's interior or in the regions outside. The question now is, was the coincidence between the magnetic disturbance and the Mt. Pelée eruption a mere chance connection? If not, then the further analysis of the magnetic disturbance is going to be of the greatest interest.

"The production of static electric charges by the rapid ejection of particles of steam or vapor is well known. It may thus be possible that the violent and tremendous ejection of vaporous particles from within the volcanic cone produced such a high electrification of the regions above the volcano as to have sufficiently altered the potential of the semi-permanent electrification of the upper regions to have immediately produced an inflow or outflow from outside space of electric charges so as to make the resultant effect comparable to that associated with a magnetic storm coming from without. It will be recalled that the products ejected by the eruption were described to be principally of a vaporous or gaseous character and finely powdered ash. All reports dwell especially upon the electric flashes over the mountain during the eruptions.

"If it is possible, therefore, to disturb the entire earth's magnetism by an explosion on the earth, our conceptions as to the manner of the connection of magnetic disturbances and solar eruptions have had some light shed upon them."

The suggestion of Bauer, based upon the preponderating change in the horizontal component of the earth's magnetism, that the seat of the magnetic disturbance was more likely to have been exterior to the earth than interior, is interesting, and leads to the inquiry as to what possible condition could have been so abruptly imposed upon the outer shell of our planet as to permit of a universal magnetic disturbance being brought about in an almost identical instant of time. Dr. Bauer, as the quotation from his writings shows, sees the

possibility of such a condition in the vast volumes of steam that had been ejected by the volcano. The possibility of changing the electric potential of the atmosphere by discharging into it vast quantities of gaseous matter had, indeed, already been advanced by Prof. Arthur W. Wright, the Director of the Sloane Physical Laboratory in New Haven, in an effort to explain certain peculiar electric conditions of the atmosphere in New Haven on the morning of May 9, 1902. At that time a marked negative potential was indicated, whereas for twenty years previous, under like conditions (the day being a perfectly clear one), the atmosphere invariably showed a positive charge. On May 8, the day of the eruption of Pelée, the conditions were normal. The change to the negative potential is thought to have been not unlikely a direct result of the Pelée discharges of gas (*Monthly Weather Review*, June, 1905, pp. 242–243). As bearing further on this interesting problem, should be noted the successional alterations of positive and negative potential in the electrification of the atmosphere which were observed at Madras, India, by Prof. Michie Smith, at about the time of the Krakatao eruption (Royal Society Report, p. 210).

Although there is apparently a relation of cause and effect in occurrences such as have here been cited, it is well to guard against the lurking error that so frequently enters into a seemingly simple explanation. Thus, in the case of the New Haven conditions referred to by Prof. Wright it is not absolutely clear why the change in the electric potential, if it was in any way connected with the Pelée outbreak, should only have been effected on May 9, when for every day in a week's time preceding the main cataclysm the quantity of gaseous matter discharged by the volcano was probably fully equal to that emitted on the 8th. Of course, it might be urged in opposition to this doubt that many days' activity was required to bring about the change noted, but with this explanation the occurrence as a supposed synchronic event largely loses its significance. The condition as it is expressed in Dr. Bauer's explanation is not altogether different, for it is not alone sufficient to explain in general terms the making of the magnetic storms, but we have to explain the instantaneity of the distinctive disturbance as well. What was its particular incident? It may perhaps be assumed that the actual explosion of Pelée, the explosion that annihilated the town of Saint-Pierre, itself furnished the condition that in an atmosphere of changing electric potential developed an instantaneous magnetic derangement. This condition, while it may have few known facts in science to support it, does not seem an entirely impossible one, and indeed the effect of explosions in determining possible magnetic changes has been made a subject of experimental research.*

The uniqueness of the magnetic disturbance of May 8 necessarily compels a doubtful reservation as to the acceptance of any theory that may at this time be

*See a paper by Prof. Nipher on the possible relation existing between violent explosions and magnetic disturbance in *Science*, July 11, 1902 (p. 64), where the author distinctly associates the Pelée explosion with the great magnetic disturbance immediately following.

offered in explanation of the phenomenon. One may, indeed, legitimately doubt whether in the special case that is here presented the differential in the value of the changes in the horizontal and vertical components of the earth's magnetic force affords in itself a sufficiently well-grounded basis for allocating the origin of the disturbance to the exterior of the earth. Certain facts connected with the magnetic disturbances that are associated with seismic movements might by some be considered to argue rather in the opposite direction.

Afterglows.—Among the interesting optical phenomena associated with the Pelée eruptions were the remarkable afterglows which for an extended period were noted in many and widely separated parts of the earth's surface, and presented themselves with an intensity that almost rivalled those which for a period of a year and more followed the Krakatao eruption. I have elsewhere noted these glows as having been observed by me on September 9, 1902, about latitude 26° 30′ N., longitude 68° 30′ W.; on September 10, in latitude 30°, longitude 69° 30′; and on September 11, in latitude 33° 45′, longitude 71°; and again, at a much later period, up to nearly the middle of November, and again in December, and in January, 1903, in New York and Philadelphia. At the latter time, the glows were also observed in Boston, Baltimore, and other American cities. Unfortunately, few observations were made in this section of the United States, and in many parts the bright loom, which appeared usually twenty to twenty-five minutes after the disappearance of the sun, was credited to the smoke which permeated the atmosphere as the result of undue burning of soft coal. In some places the glow was also visible in early morning. The fact that the Soufrière and the volcano of Santa Maria, in Guatemala, were also in eruption during the period of Pelée's activity and throwing out vast quantities of ash, has naturally made it impossible to correlate the afterglows, especially those of the later dates, with the individual eruptions. Mr. Backhouse* notes their occurrence in association with a solar corona (Bishop's ring) at Sunderland, England, at the end of June, on October 30, November 1 (at their full magnificence), 17 and 18; at Torquay, on November 6 and 10; and at Dundee, on December 1. M. Enginitis, the Director of the Athens Observatory, notes the after-glows of October 25 and later, beginning a few minutes after sunset, and rising, like the glow from a conflagration, to a height of 45 degrees. A similar glow is stated to have followed the eruptions of Etna in 1831.†

Brilliant afterglows or modified sunsets whose connection with the Martinique eruption can hardly be questioned were noted, among other localities:

A hundred miles westward of St. Lucia, on May 9 (green sunset, observed by the royal mail steamer *La Plata*).

At Barbados, on May 11 and 14, with brilliant orange skies, beginning at 5.30 P.M.

**Nature*, Dec. 25, 1902, p. 174.

†Communication to the Academy of Sciences of Paris, *Revue Scient.*, Dec. 20, 1902, p. 787.

Honolulu, twelve days after the eruption, with a brilliancy of color about equal to that of the glows which appeared in the first two weeks after the Krakatao eruption. On July 31, as reported by Mr. S. E. Bishop (*Nature*, September 4, 1902, p. 442), the solar corona or "Bishop's ring" was still conspicuous.

Kingston, Jamaica, on May 25–31 and before; with colors reported to have been "extraordinarily rich and beautiful."

St. Kitts, in red color, on May 27—being the earliest distinctive glow noticed on the island.

Off the Venezuelan coast, between Carúpano and La Guayra, noted by H. M. S. *Gazelle*, on May 10.

At Los Angeles, California, on June 22 and 23.

Funchal, Madeira, on June 6, 10 and 11—possibly even at an earlier period—described by F. W. T. Krohn to have been similar to the Krakatao glows; also on or about July 6–7, 12–16, 26–27, and August 1–3.

Slough, England (as observed by Professor A. S. Herschel), on June 17, 21, 26 and later.

Lewisham, South Kensington, and other localities in England during late June and in July.

Bombay, about June 25 (?).

In northern Italy, in early June, with streaked radiations.

At Berlin, in late June or early July, with remarkable coloring.

Hamburg, observed by Stentzel from June 16 to the end of the month ("Vulk. Dämmerungserscheinungen"—*Das Wetter*, XIX, 7, p. 156).

Sunderland, England.—June 26 (Backhouse, *Nature*, 67, p. 174).

Pic du Midi de Bigorre, Pyrenees. Several times during a number of months, beginning about July 31 and culminating in the end of October. The height of the disseminated ash was estimated by Marchand to have been 10–40 kilometres (*Ann. de la Soc. Météor. de France*, Feb. 1905).

Paris.—Oct. 28 to Nov. 18 (Besson, *Ann. de la Soc. Météor. de France*, 1902, 1, p. 220).

Nice.—October 27–30 (Perrotin, *Comptes Rendus*, CXXXV, 1902, pp. 724–726).

Bordeaux.—Oct. 23–Nov. 2 (Esclangon, *Comptes Rendus*, 1902, pp. 846–848).

Morges, Switzerland, as observed by Forel, on July 6–9, 23–28, Aug. 14–22, Sept. 21, Oct. 13–24, Nov. 12–14, Dec. 18–24, and Jan. 6–8, 1903. The illumination, lasting at times for 1½–2 hours after sunset, and beginning in the west, had for its order in the appearance of color yellow, purple and orange. The most intense fiery glow was observed, after sunset, at 5 h. 18 m., on Oct. 29, continuing with diminished intensity until 6 h. 50 m. (*Gazette de Lausanne*). Gruner observes that the really brilliant glows noted in Europe did not as a rule appear until about the end of October; they reappeared periodically toward the close of several succeeding months. See his paper: "Dämmerungserscheinungen im

Jahre 1903," in *Mitteil. d. Naturfor. Gesell. in Bern* (1904) 1905, pp. 7 *et seq.*—(1903) 1904, pp. 1 *et seq.*

Zi-ka-Wei, China. Sept. 15–16 (De Moidrey, *Ann. de la Soc. Météor. de France*, L, 1902, p. 220).

The characteristics of the Pelée (and Soufrière) afterglows were similar to those of the glows of Krakatao, although the intensity of the coloring and illumination was probably at most points of observation less pronounced than in the case of the glows of 1883 and 1884. As I observed the coloring towards the middle of September, at localities north-northwest of Martinique, a few days after the fresh great eruptions of Pelée and the Soufrière, it was very brilliant, the orange and the red being particularly fine. The upper border of the bright illumination faded off into a superb and intense lilac, which, I believe, had not generally been observed as a feature of the Krakatao glows. Bishop noticed this lilac color in 1884 in Honolulu, even in daytime, and it is certainly due to the commingling of the pink or roseate light with the normal blue of the sky. Five great "shadow-beams," with broadening ends directed to the zenith, and of almost exactly the color of the purple-blue in the outlying field of the sky, were a distinctive feature of the area of the glows on September 9 and 10, radiating fan-like from the position of the sun and rising to perhaps forty-five degrees.

The brilliancy of the glows as they were observed in parts of western Switzerland was such as to suggest a conflagration, appearing "as if the whole of the west of Switzerland was on fire and the flames reflected in the sky."* It is singular that Professor Herschel makes the same observation for the appearance at Slough, England, on the night of June 22, which was "an almost terrifying resemblance to reflection in the sky of an immense distant conflagration" (*Nature*, July 24, 1902, p. 294). I have been personally informed that the same aspect of the glows was noted in Honolulu, where many thought that the islands were aflame. The height of the glow-producing matter has been estimated by Herschel to have been at different times from five or eight to thirteen or twenty miles, whereas the atmosphere charged with the volcanic dust of Krakatao was thought to have floated twenty-five or thirty, and even forty and seventy miles high, the uppermost particles of matter being at that time much finer than those emitted by Pelée.

It is interesting to note in connection with the low position of this glow-cloud, as compared with that of the Krakatao eruption, that its velocity of passage was also greatly inferior. Bishop tells us that it arrived in Honolulu ten days after the Pelée outbreak, whereas the Krakatao glows, traversing thrice the distance, arrived at the same spot in only two days' longer time. This would give in the one instance a velocity of about two and a half times that of the other, or of sixty to seventy miles an hour in the case of the Krakatao cloud, and of twenty-three to twenty-five miles for the cloud from Pelée. There is seemingly no reason to doubt that the movement was in both cases from east to west,

* Correspondence in London *Daily Chronicle*, dated Geneva, July 14.

conformably to the determinations that have been made that the high cirrus atmospheric currents take this course in the zone of (approximately) twenty degrees on either side of the equator. Krohn has assumed from the records of Funchal, Madeira, that the rate of travel of the Pelée cloud was on an average thirty miles an hour (*Nature*, September 25, 1902, p. 540). The direction of travel, measured by the time period, would here also appear to have been from east to west.

Bishop's Ring.—Professor Forel has described* the Bishop's ring carefully studied by him at Morges, on Lake Geneva, the identity of which with the ring observed by Bishop in Honolulu, in 1883, is stated to be absolute. The period of visibility of the new ring appears to have extended in different places from the latter days of July, 1902, to near the middle of 1904, and seemingly was a continuous one from favorable points of observation. Forel noted it (practically) every day when he was placed in positions removed beyond the dust-zone of the lowland plains,—from the Rochers de Naye, in Valais, and Pilatus, to the middle and upper slopes of Mont Blanc, where it was also observed (Montanvers) by Laurence Rotch on August 20, 1902.† Among the earliest records of the observation of this new Bishop's ring are Honolulu, July 31, 1902 (Bishop, *Nature*, LXVI, p. 442) and the Pic du Midi de Bigorre, in the Pyrenees, July 26 of the same year (Marchand, *Bull. Soc. Ramond*, IX, 1904, 100). According to Marchand the ring first appeared completely around the sun in December, 1902. This observer also noted an anthelion in the eastern sky, of the same diameter and width as the solar corona, of a purplish pink or copper-red color, which was visible in Jan., Feb. and March, 1903 (*Annuaire de la Soc. Météor. de France*, Feb. 1905, pp. 40–45). Other points of observation recorded are: Zürich—Jan., March 27–28, July 7, 8, 9, and later in the same month, 1903, and again at various times until June, 1904 (observed by Dr. Maurer). Lucerne—July 26, 1903 (observed by Dr. Arnold). Saint-Bernard Hospice—from Sept. 1903 to July 19, 1904. Gorner-Grat—Sept. 5–6, 1903. Grand Combin—Aug. 11, 1903. Stelvio, Col de Sonadon, Matterhorn (base). Morges—appearing continuous on all clear days from Aug. 31, 1903, to end of year; discontinuously visible to July 26, 1904 (observed by Forel). Arnsberg—Nov. 19, 1902, March 21–22, 1903 (Dr. Busch). Heidelberg—Jan., 1903 (Prof. Max Wolf). Hirschberg (Silesia)—from Aug., 1903, to April, 1904 (Reimann). Lemberg (Galicia)—to April, 1904 (Laska). St. Petersburg—Oct. 5 and Nov. 9, 1902; Jan. 21, Feb. 10, 18, 23, March 17, April 5, May 29, July 26, 1903, and as late as Sept. 17, of the same year (Rykatcheff). Philippeville (Algeria)—April 3, 1904 (Duprat, *Bull. Soc. Astron. de France*, 1904, 372). (See the references relating to Forel's investigations already given, and the *Archives des Sciences Physiques et Naturelles* for June, 1905, pp. 611–612, and his "Le Cercle de Bishop de la Montagne Pelée," in *Arch. d. Sciences P. et N.*, March

**Archives des Sciences Physiques et Naturelles*, Oct. 15, 1903; Feb. 15, 1904.

†*Nature*, Oct. 29, 1903.

15, 1905, pp. 230 *et seq.*) A solar corona or Bishop's ring was also observed (by M. R. Fink) on the St. Gotthard on various days between Oct., 1904, and June 30, 1905; on the Tödi (Bosshardt), on Oct. 5 and 15, 1904; Great St. Bernard (Mercanton and F. C. Forel), on Nov. 5, 1904; Col de la Faucille (Sarrasin), Nov. 29, 1904; Zürich (Maurer), Dec. 4, 1904; and Morges (Forel), Dec. 8 and 12, 1904. These later appearances of this interesting phenomenon are, however, associated by Forel rather with the volcanic outbreak in Iceland of April 16, 1904, than with any floating ash of the West Indian volcanoes.

Forel concludes that the virtual continuity in appearance of the Bishop's ring is, at least, presumptive proof that the ash-belt in the *higher* regions of the atmosphere was a continuous one. This is thought not to have been the case with the *lower* belt or zone of ashes which originated the crepuscular glows, for these appeared only at irregular intervals, differing in this respect from the glows following the Krakatao eruption.*

Diminution in the Intensity of Solar Radiation.—A most interesting observation has latterly been made touching the distribution and retention of the volcanic particles in the atmosphere, namely, that they have served as a cushion or screen to reduce the intensity of solar radiation. According to Henri Dufour,† such a diminution in radiation was noted, among other places, at Clarens, Lausanne, Heidelberg, Warsaw, Washington, etc., beginning in December, 1902, and continuing, but steadily diminishing, to March, 1903. This opacity of the atmosphere, which is attributed to the Antillean outpourings, and may be due directly to easier condensation of vapor under the influence of ash-nuclei, is evidenced: 1, by diminution in the intensity of the solar radiation; 2, diminution of the optical transparency of the atmosphere; 3, diminution in the sky's polarization; and 4, displacement of the neutral point of Arago and Babinet. These several conditions had been clearly noted in the atmospheric disturbances following the eruption of Krakatao. Ladislas Gorczynski, who has been following up Dufour's observations and is inclined to accept Dufour's interpretation of the phenomena, notes that the diminution was observed in Warsaw, Poland, as early as May, 1902, and that from that time it increased progressively until the spring of 1903; it had practically disappeared before the close of that year.‡

The same diminution in radiation was noted at Asheville, N. C., by Kimball (*Monthly Weather Review*, May, 1903); at Heidelberg, by Max Wolf (*Astronom. Gesell.* year 38, part 2); at Fribourg, Switzerland, by Gockel (*Meteor. Zeitung*, July, 1903, p. 328), who states that on many days the ultra violet radiation was reduced to one-half its normal value; and at other points in Europe and America. E. Marchand, from observations made at the Pic du Midi de Bigorre in the Pyrenees, notes a diminution in solar radiation beginning

**Archives des Sciences Physiques et Naturelles*, Feb. 15, 1903.

† *Comptes Rendus*, CXXXVI, pp. 713–715; *Archives des Sciences Physiques et Naturelles*, Oct. 15, 1903, pp. 459, 460.

‡ "Sur la Diminution de l'Intensité du Rayonnement solaire en 1902 et 1903." *Comptes Rendus*, Feb. 1, 1904, CXXXVI, p. 255.

with May 27, 1902, and increasing to Jan., 1903. On Feb. 21–22, 1903, the diminution amounted to one-half the normal value of the radiation. It was assumed that at about this time some of the upper dust fell into the lower region of calm. In August, 1903, the diminution still amounted to one-tenth of the normal radiation. Among the associated phenomena noted were: decreased intensity of the sky blue; green color of the moon; pink coloring in high clouds; and a bright illumination on lofty mountain summits (*Annuaire de la Soc. Météor. de France*, Feb., 1905, pp. 40–45; *Monthly Weather Review*, March, 1905, pp. 101–103). C. G. Abbott, of the Astrophysical Observatory of the Smithsonian Institution, has also placed on record the recognition of "an actual decrease in the transparency of the air, beginning somewhere between Nov. 15, 1902 and Feb. 19, 1903" (Smithsonian Misc. Collections, Dec. 9, 1903). It is by no means unlikely that many of the dark days noted toward the latter part of the year 1906 may have been associated with the great outpourings from Vesuvius in April of that year.

The General Optical Phenomena (*Twilight Glows, Bishop's Ring, Anthelia, etc.*), as observed at the Observatory of the Pic du Midi, Pyrenees, and at Bagnères. The record of observations made at these points by E. Marchand and his associates is the most complete that has been made in any locality; indeed, the observations are the only ones touching all the phases of the optical phenomena that have been made by any set of observers. They are here presented in consecutive form as a translation from the *Annuaire de la Société Météorologique de France* in the *Monthly Weather Review* for March, 1905 (pp. 101–103).

"I will summarize here, very briefly, the observations made on these phenomena at Pic du Midi or at Bagnères, by my co-workers, Messrs. Ginet, Latreille, Dort, and myself, since the end of the year 1902; observations which have been communicated at different times to the Société Ramond, principally in the meetings of February 3, and April 7 and 12, 1904.

"Three principal phenomena have been distinguished, which can be attributed, nevertheless, to the same general cause, the presence of dust, or perhaps of extremely fine particles of ice, in the upper regions of the atmosphere, the dust coming probably from the great eruptions of the volcanoes of the Antilles in May, 1902. These three principal phenomena are: (*a*) twilight glows; (*b*) solar or lunar coronas; (*c*) diminution of solar radiation. And we shall have occasion to mention several others of less importance.

(*a*) TWILIGHT GLOWS.

"Two phases of this phenomenon may be distinguished: (1) The appearance, fifteen or sixteen minutes after sunset,* of a first twilight segment, pink, purplish, or copper-red, which lasts from twenty to twenty-five minutes and then

* "We have reference here to the astronomical sunset, which may differ somewhat from the real sunset. At Pic du Midi, the real sunset takes place from eight to thirteen minutes after the astronomical sunset, on account of the large depression, 1° 42′, of the sensible horizon."

disappears below the horizon, leaving but a more or less persistent band of red or orange. The phenomena are naturally reversed when one observes in the morning before sunrise. (2) The appearance, about fifteen minutes after the disappearance of the first segment, of a second segment, pink, or copper-red, occupying about the same position, and disappearing in the same manner, but remaining sometimes much longer than the first.

"The first segment is not peculiar to the period 1902–1904, during which time it only became much more intense and much more brightly colored. It exists at all times, but it was on July 31, 1902, that I found it for the first time at Pic du Midi of an abnormal intensity, an intensity which I observed afterwards at various dates, during August, September, and October; but it was not until the end of October that it attracted the attention of the public.

"By observing carefully the angular maximum height of the summit of this colored segment (due to the reflection of the solar rays, tangential to the earth, on the dust of the upper atmosphere) and the corresponding hour, one may calculate the height of the dust above sea level; allowing for refraction, these calculations have given me rather variable numbers, comprised between 10 and 40 kilometres.

"The second segment, also, usually exists; but it consists ordinarily of a faint white light and therefore generally passes unnoticed; since the month of October, 1902, it has frequently been of a pinkish tint or copper-red, sometimes brilliant and contrasting strikingly with the rest of the sky, which at this time is very dark.

"It is this second segment, when it is colored, that constitutes always, for the public, the twilight glow; it is produced by the solar rays that undergo two reflections on the atmospheric dust.*

"In other words, one may say that the sun itself is the source of light of the first segment, although it has already set at the place where one observes this segment; while the source of light of the second segment is the colored region of the first segment or horizontal band, which latter is in the horizon of that elevated point in the atmosphere where this second segment is produced.

"After August, 1902, the first segment, with its brilliant coloring, was observed several times each month; the second segment was relatively rare and was produced only during groups of two, three, and four days, separated from each other by rather long intervals, sometimes of several months. We must conclude from this that the atmosphere has probably contained a large quantity of dust at a high elevation ever since the latter part of the year 1902, but that it was probably not always abundant enough or elevated enough to be able to produce the second segment.

"However, the second phenomenon demands not only the presence of very elevated dust; it is also necessary that the atmosphere be clear to a great dis-

* "I wish to state, in the beginning, that I describe always the phenomena visible in the evening; that the words first and second segment relate to the sunset; and that in the morning these phenomena occur in inverse order."

tance from the place of observation to the east, for the morning, or to the west, for the evening. This cannot occur frequently; therefore, contrary to what certain authors think, the absence of this second segment does not prove the absence of atmospheric dust.

"Moreover, other related phenomena, which I will briefly enumerate, go to prove, in their turn, that this abnormal dust has never been absent during two years.

(*b*) SOLAR AND LUNAR CORONAS—ANTHELIA.

"After examining carefully the notes that accompany our observations with the dynamic actinometer and which give exactly the condition of the sky about the sun,* I find that the solar corona was clearly perceived for the first time at Bagnères and at Pic du Midi, July 26, 1902, that is, about two months and a half after the great eruptions at Martinique. But it was only beginning with the month of December of the same year that it was seen permanently around the sun, or around the moon during the night. It is still visible whenever the sun shows itself; however, it seemed less luminous in 1904 than during 1903.†

"This corona is composed of a sort of circular white halo, immediately surrounding the sun, and whose exterior contour is slightly tinted with copper-red or purplish pink. The coloration can be seen only by hiding the sun behind an obstacle somewhat distant from the eye, such as a tree, the summit of a house, etc.

"The mean diameter of the colored ring, as measured very frequently at Bagnères or at Pic du Midi,‡ was about 48°, varying from 46° to 50°, at the end of 1903; the width of this ring was at that time about 20°; the outer diameter of the corona was about 70°. At the present time the mean diameter appears to be from 40° to 44°; the measurement is difficult, however, especially at the present time, because the colored ring merges insensibly into the white halo of the interior, and into the blue sky of the exterior.

"At the close of 1903, we frequently saw in the luminous halo some slight striæ, analogous to the filaments of the cirrus, forming a sort of network and showing to the eye the appearance of a very fine dust, irregularly stratified and lighted; sometimes this same appearance of a dusty network was perceived also at the exterior of the corona, which appeared then much larger (its exterior diameter was, on certain days, 130°, while under ordinary conditions it was about 70°). Finally, I saw this dusty network over almost the whole extent of the sky. These phenomena were not produced in 1904.

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* "At Bagnères and at Pic du Midi, we take observations every three hours, daily, with a static actinometer and besides, when the state of the sky will permit, with a dynamic actinometer (of a system intermediate between those of Violle and of Crova)."

† "The name Bishop's Ring is often given to this corona."

‡ "For these measurements and for all those that may have to be made on the phenomena of atmospheric optics, I have devised a special graphometer, very easily used, very convenient, and very easy to construct."

"In considering the corona as a phenomenon of diffraction caused by atmospheric dust, we find easily that the mean diameter of the particles of dust is about 2.6μ, or, in round numbers, three-thousandths of a millimetre.

"But this corona is not the only phenomenon of diffraction produced by the so-called dust. I will mention another, which has not yet been described, and which I observed in 1883 and 1884, at the same time as the Bishop's ring, soon after the terrible eruption of Krakatoa.* This is an anthelion altogether analogous to those which are often produced on fogs or clouds at elevated stations, such as Pic du Midi, and to which the name "Specter of the Brocken" is often given.

"This anthelion appears in the form of a faintly colored purplish pink or copper-red ring of the same diameter and the same width as the colored ring of the solar corona, but visible on the side opposite the sun, or to the east in the evening. I observed it rather frequently during January, February, and March, 1903, very rarely during the following months, and not once during the month of August of the same year.

"Quite often the lower part only of the anthelion was visible. When this was the case, the phenomenon assumed the aspect of two columns of purplish light about 50° apart, slightly curved toward each other (the upper part of the arc being absent) and resting on the pink band which ordinarily surmounts the shadow of the earth.

"Finally, on the same dates, the horizon opposite the setting sun often shows over a large extent a faint purplish tint, which commences some minutes after sunset and continues for a variable length of time.

(*c*) DIMINUTION OF SOLAR RADIATION.

"According to the observations made with the dynamic actinometer as often as possible at the two stations of this observatory, it was on May 27, 1902 (that is to say, 20 days after the great eruptions of Mont Pelée), that the first appreciable diminution of the intensity of radiation was recorded, and that, too, simultaneously at Bagnères and at Pic du Midi, without any other apparent cause than the slightly vaporous (hazy) appearance of the sky in the neighborhood of the sun.†

"But this diminution then ceased. It was observed from time to time during the following months, and became permanent in January, 1903; the diminution then amounted to about one-fifth of the average intensity of insolation that had obtained during preceding years at the same dates and under the same conditions as regards the height of the sun, the temperature, and the humidity.

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* "In the month of December, 1883, I called the attention of the Académie des Sciences to the presence of this diffraction circle [*i.e.*, the Bishop circle] and to its connection with the twilight glows of the preceding month. C. R., 1883, xcvii, p. 1514."

† "Although the observers, Messrs. Ginet and Dort, did not note explicitly on this day the presence of a corona around the sun, but only a light vapor or mist in the neighborhood of the sun, it is probable that the corona already existed."

"On February 21 and 22, 1903, at Bagnères, this diminution attained one-half the normal value of the radiation. The atmosphere was then charged with a dust, hiding objects more than six or seven kilometres distant, and rising not more than 2800 meters on the 21st and 2500 metres on the 22d, according to observations taken at Pic du Midi. The comparison of the actinometric observations made at Bagnères and at Pic du Midi during these and the preceding days appears to indicate that the particles of dust scattered in the higher regions of the atmosphere before February 20 fell little by little into the lower regions from the 20th to the 22d because of an exceptionally calm atmosphere. This dust, however, was visible at Bagnères in the form of light stratified clouds, analogous to the cirrus, on the 21st and 22d; at Pic du Midi the atmosphere was clear above 2500 meters and the solar radiation was less diminished. On the 22d and 23d at Bagnères the fall of this dust on the surface of certain zinc roofs was actually observed.

"There was still considerable diminution of radiation during February, March, April, May, June, and July, 1903; in August the diminution still amounted to about one-tenth of the normal radiation, during the following months it became less without disappearing altogether; there were, however, some fluctuations. During the year 1904 the actinometer has sometimes given almost normal intensities, while on other days, without apparent cause, it has indicated an atmospheric absorption greater than normal by about one-tenth.

(*d*) OTHER PHENOMENA.

"I shall but mention some other phenomena resulting from the presence of dust in the atmosphere.

(1.) *Diminution of the Intensity of the Blue of the Sky.*—This intensity measured five times a day, at our two stations, by means of the Saussure cyanometer (scale of 0, white sky, to 50, black or blue-black sky); the diminution of this blueness was three units of the cyanometric scale at the end of 1902 and at the beginning of 1903.

(2.) *Green Color of the Moon.*—Very often during the same period of 1902–1903 the moon, as seen in a clear sky, had a characteristic greenish tint, and was surrounded by a luminous region of the same color, and outside of that by the halo or corona already described.

(3.) *Pink Color of High Clouds and of Mountain Summits.*—I have often observed that high clouds, whose altitudes are known by processes that we employ for this purpose, when located at the zenith, or even to the east of the zenith, were illuminated by a pinkish light a long time after sunset, as if they still received the rays of the sun; that is, as if they were from fifteen to twenty kilometres above the ground. The mountain summits visible from Bagnères (for example, the Peak of Arbizon, 2830 metres high), have sometimes been illuminated in the same way.* In reality, this phenomenon is quite analogous to

* "I had made the same observations on the Alps (especially on Mont Blanc) and at the Observatory of Lyons in 1883 and 1884."

the second twilight segment; the rays that then reach these clouds have been reflected a first time;* they are, by contrast with a very dark sky, lighted brilliantly by the light coming from the red band or from the first pink segment, which is in their own horizon.

"*General Conclusions.*—One may conclude, it seems, from the whole of our observations, that during two years very fine dust was scattered in the higher regions of our atmosphere; that above the Pyrenees this dust was never absent after the month of June, 1902; that the quantity and the altitude of the particles of dust have undergone rather large variations, but have, however, progressively diminished, and finally, that all the abnormal phenomena above described can be attributed to the presence of this dust.

"As to the dust itself, it appears to have come from the Antilles, as that of 1883 came from the eruption of Krakatao, and that of 1831 from the submarine volcano which produced the temporary island "Julia" in the Mediterranean. . . . I desire now to point out the difference of intensity which exists, according to my observations, between the phenomena of 1883–1884 and those of 1902–1903. In 1883 (I then observed at Lyons), the twilight glows (the second segment) were more luminous and more prolonged, and the diffraction circles, coronæ or anthelia, were much more brilliant and easy to see than in 1903."

The Noise of the Eruption.—Humboldt, in dealing with the volcanic phenomena of the West Indies, makes the interesting observation that the eruption of the Soufrière, in 1812, was not as audible near to the mountain as it was farther out to sea. It is certain that very few of the inhabitants of Fort-de-France heard the explosion of Pelée on May 8 or were made conscious of it through an earth-shock or pulsation. Diligent inquiry among all classes of people leaves me in doubt as to whether anybody really heard it. Yet it is certain that this eruption was unmistakably heard at St. Kitts and St. Thomas, from two hundred and seventy to three hundred miles distant, and in all or nearly all of the islands of the Lesser Antilles. The explosion of May 20 went similarly unnoticed in Fort-de-France, whereas the detonations reported for that event in St. Thomas, St. Kitts, Guadeloupe and Dominica were of marked intensity. On the night of August 30 I was located with my associate at the Habitation Leyritz, at the northeastern foot of the volcano, not more than four miles in a direct line from the crater, and with nothing interposed between it and ourselves except the open, almost directly descending, slope of the mountain. When the death-dealing explosion took place we were either seated in the open dining-hall or were outside remarking upon the magnificence of the electric display. Beyond hearing one or two "thuds," that seemed to rise above the general voice of the volcano, I doubt if any of our party of four could have localized the explosion or series of explosions through any particular sound or detonation. There was surely no detonation that was particularly striking at this time.

* [By the air and vapor and dust.—*C. A.*]

On the other hand, the detonations heard at corresponding times at Port of Spain, Trinidad, at Carúpano, Venezuela, and in the island of St. Kitts—localities removed from two hundred and seventy-five to three hundred and twenty-five miles away in opposite directions—have been likened to the firing of heavy siege-guns. The officers of the *Fontabelle*, among others, assured me that this had been the case in Port of Spain. It seems that the detonations were noted on the Venezuelan coast far beyond Carúpano, where rather severe earthquake shocks were also recorded. The report of United States Consul Plumacher, at Maracaibo, published in the *Monthly Weather Review*, gives the important record that on the morning of the first great eruption of Pelée (May 8) terrific detonations were heard in the region of his post, which was about eight hundred miles from Martinique. These sounds were recognized to be not of "heavy artillery," which they had been thought to be by a servant, for "I knew that . . . if all of the cannons of Venezuela were fired together, they could not produce such sounds. It was not like cannonading with heavy siege-guns; it was neither thunder, nor the strange, unpleasant subterranean sounds of convulsions of the earth; it was as if immense explosions were fired high up in the clouds." This was also remarked at Port of Spain as a feature of the detonations accompanying the eruption of August 30. With the intensity of sound that manifested itself at Maracaibo, it is fair to presume that the detonations were markedly audible two or three hundred miles farther, or perhaps at a full distance from the seat of disturbance of a thousand miles. Humboldt states that "the frightful subterranean noise, like the thundering of cannon, produced by the violent eruption of the latter volcano [the Soufrière of St. Vincent] on the 30th of April, 1812, was heard on the distant grass plains (llanos) of Calabozo, and on the shores of the Rio Apure, one hundred and ninety-two geographical miles farther to the west than its junction with the Orinoco" ("Cosmos," Bohn's edition, V, p. 422)—a point fully eight hundred miles in a direct line from the island of St. Vincent.

It is interesting to note that, while the noise of the Pelée eruptions of May 8 and August 30, as heard at Maracaibo, 800 miles distant, at Carúpano, on the Venezuelan coast, and at Port of Spain, on the island of Trinidad, appears to have come from above, or, as stated by Consul Plumacher, to have originated in the clouds, such detonations have very generally been described as being subterranean, the propagation of the sound-waves being readily facilitated by the solid rock-masses. Thus, Humboldt, referring to the eruption of Cotopaxi in 1744,* states that the propagated noise, which was heard at a distance of at least 436 miles, was surely subterranean; and Scherzer, who received testimony of witnesses of the event,† states that at the time of the great eruption of Coseguina the detonations, which were carried hundreds of miles, appeared subterranean. Probably no exact reason can be assigned for these differences

* "Cosmos," Bohn's edition, I., p. 203.

† "Wanderungen," 1857, pp. 479 *et seq.*

in sound-carriage. It would appear that on the evening of Aug. 30, when Morne Rouge was destroyed, the reports of explosions were distinctly heard on the island of St. Kitts some time in advance of the main cataclysm, or as reported at 8.07 and 8.25 P.M. (*Monthly Weather Review*, October, 1902, p. 487).

The peculiarity of the explosions being heard with terrific intensity at remote points and hardly, if at all, near by, was also exhibited in the Krakatao eruption, the report from which was carried to the island of Rodriguez, three thousand miles away—the farthest distance from a point of origin at which sound has ever been heard, or at least recorded (Royal Society Report). General Strachey (p. 79) believes that "probably this peculiar phenomenon was caused by the large amount of solid matter" which at the time of the eruptions "was ejected into the atmosphere by the volcano, and which formed in the lower strata of the air a screen of sufficient density to prevent the sound-waves from penetrating to those places over which it was more immediately suspended." This explanation, so contrary to the results that have been obtained by Tyndall and others in their experiments upon the transparency and opacity of the atmosphere in relation to the passage of sound-waves—the unexpected determination that the dissemination of solid particles in the air, the presence of fog, rain or snow, etc., has little or no effect upon the transmission of sound—it seems to me can hardly be the correct one; nor, indeed, can it find application to the conditions which existed at the time of the eruption of August 30, when I was located at the Habitation Leyritz. We were then practically under, and not behind, the volcanic cloud, through which came quite distinctly the muffled, but continuous, roar of the volcano. If the obscuration of sound by solid particles was really produced, the phenomenon must have taken place within the body or vent of the volcano itself. I should rather believe that the acoustic interruption was in some way associated with an atmospheric disintegration—the presence within the atmosphere of layers of differing thermal power and differing vaporous constitution producing, to use Tyndall's words, acoustic clouds that are "flocculent to sound" ("Lectures on Sound," 1875, p. 321).* This would, however, still leave unexplained the transmission of the sound to great distances, unless, indeed, we may be permitted to assume that the propagation of the sound-waves has been carried to distant points through the materials of the solid crust. Can it be thought that the sounds coming as if thrown down by the clouds, noted by Mr. Plumacher at Maracaibo and by others in the island of Trinidad, were reflections from lofty "acoustic clouds," to which the sound-waves were transmitted through the central orifice of the volcano? This suggestion is thrown out with much diffidence, and only because no ordinarily

* The remarkable experiments made by the distinguished British physicist in connection with the Trinity House have established the existence of conditions of absolute opacity to sound in an atmosphere that is optically transparent and shown the fallacy of the still commonly accepted notion that a direct relation exists between a clear atmosphere and the transmission of sound.

recognized theory seems to account satisfactorily for the facts as they present themselves.

Atmospheric Perturbations.—The remarkable atmospheric and seismic waves which followed the Krakatao eruption seem in a very minor degree to have been a part of the Pelée or Soufrière phenomena, but the data that appertain to them are only meagrely at hand, so that little can be said regarding the full intensity of the phenomena. Professor Henry Kelm Clayton, of the Blue Hill Observatory, Hyde Park, Massachusetts, has noted "some marked barographic undulations at Blue Hill on the morning of May 7, which," it was thought, were perhaps connected with the eruptions of this period (*Nature*, May 22, 1902, p. 102); but a more recent examination of the facts makes this reference doubtful. No barometric disturbances for this time were recorded at any of the stations in the United States, and seemingly no such record is found among the European observations. (See Moureaux, *Comptes Rendus*, 134 p. 1107; Kesslitz, *Meteor. Zeitschrift*, Vienna, 1902, pp. 316–317; Bauer, etc.) On the other hand, barographic records of the Pelée eruptions of May 8, 20, 26, June 6, July 9, and Aug. 30, are reported from the Weather Service station on the island of Dominica. The form of the wave-tracing is justly compared by Flett and Tempest Anderson to that obtained from a "sudden and violent explosion." At the time of the explosion of August 30 M. Mirville, in Fort-de-France, noted a sudden barometric drop of 3 mm., which was recovered (by a rise of 4 mm.) in about ten minutes' time. At this same time there was a retreat of the sea, followed by a rise above normal of about a metre.*

Seismic Pulsation.—The record for May 8, 1902, of the observatory of Zi-ka-Wei, China, situated almost exactly half around the world from Martinique, notes between 12.25 and 12.35 P.M., Martinique time, two marked tremors or shocks, registered by the mercurial thermometer acting as an accidental seismograph. These, as well as the magnetic perturbations observed earlier in the day, and which so closely correspond in time with the Pelée eruption, are referred by M. de Moidrey to the Martinique disturbance, and it is assumed from the hour at which the phenomena were observed that the time of propagation of the earth-wave was four hours and twenty-seven minutes, giving a velocity of approximately thirty miles per minute (*Comptes Rendus*, August 11, 1902, p. 322). This, barring the Krakatao occurrence, is the only instance that is known to me of an earth-tremor or pulsation having been propagated clean through the centre of the earth to the antipodal surface. The seismographs of Great Britain give no registry for the Pelée eruption, having remained at rest, according to Professor Milne, from the 8th until the 11th of May.

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* Mirville: "Variations de Pression produites par les Éruptions volcaniques," *Ann. Soc. Météor*, Paris, 1903, pp. 16–17; *Meteor. Zeitschrift*, Vienna, 1903, pp. 181–182.

V.

NATURE OF THE DESTROYING BLAST.

THE facts connected with the Pelée eruptions of 1902, whether of May 8, May 20, or August 30, make it all but certain that the engine of destruction was in all cases an explosion (or a series of rapidly following explosions), under enormous pressure, of superheated steam. A titanic blast of high temperature, carrying in its train the fragmented and incandescent particles of lava and the disrupted walls of the old stock of the volcano, swept out of the crater-spot of the Étang Sec, and fell with incredible fury upon the doomed city of Saint-Pierre, annihilating it almost instantly. In how far inflammable or asphyxiating gases may have been associated in the composition of this tornadic steam blast will perhaps never be known; the evidence which assumes their non-presence is in the main of a negative character and hardly conclusive in itself to determine the problem. A large part, or perhaps even the major part, of the destruction wrought seems to have been accomplished in a few seconds. M. Roger Arnoux, of the Société Astronomique de France, apparently a very careful observer, who from the heights of his property at Parnasse closely followed the workings of Pelée at the time of its explosion, asserts that the destroying cloud traversed the city of Saint-Pierre in 2–3 seconds,* an observation that finds confirmation in the accounts of the catastrophe that have been published by Chief Officer Scott of the *Roraima* and other eye-witnesses of the incidents of the fatal May 8. This extraordinary tornadic blast, whose explosive work was registered alike on hillside and in lowland, and whose sector of destruction was measured at the sea-front on a chord of 4–5 miles, was followed at a short interval by the great down-rolling "black cloud," charged with incandescent matter ("fire"), and scintillating with electric flashes, which forms part of the picture of nearly all of the descriptions, and to which is generally attributed the destruction. There is much in the history of this destruction that still remains obscure, but I believe there can no longer be any doubt that the work of the "black cloud" (the *nuée dense, nuée ardente* of Lacroix of later eruptions) was successive to and only secondary to the explosive work of the steam blast. The tornadic force of this explosive blast is attested by the dislodgement from its pedestal of the massive statue of "Our Lady of the Watch" and by the breaking clean across (like clay-pipe stems), near their bases, of the masts of the *Roraima*.

In an article published in *McClure's Magazine* for August, 1902, I expressed the opinion that the destroying element of the blast was seem-

* Letter addressed to Camille Flammarion and published in the *Bulletin de la Société Astronomique de France*, August, 1902.

ingly one of the heavier (carbon?) gases, and that with it the force of the superheated steam was acting only in a minor degree. At that time there appeared to me much to support this view, although I did not hesitate to say that the evidence upon which it was based was far from conclusive. The only gases associated with the eruption whose presence had been remarked with any degree of prominence were the sulphurous and sulphuretted hydrogen, the former much more largely present than the latter.* Sulphur vapors or fumes were oppressively diffused through the atmosphere of Saint-Pierre for the better part of two weeks before the main catastrophe (see "Mont Pelée and the Tragedy of Martinique," Chapter III)—horses and other animals dying from it, and respiration being made difficult for man—and as late as the month of October of the same year, Lacroix, making his observations at the crater border, found them issuing in such quantities in fumarolic blasts from the crevices of the central cone as to make a close approach dangerous. I, myself, several times detected the sulphur vapors five or six miles out at sea, but, singularly enough, failed to note their presence, except to a very minute degree, when standing at the rim of the crater. On the other hand, sulphur in the falling ash of the eruption of August 30 was clearly in evidence at the Habitation Leyritz, and we are informed by Dr. Berté of the *Pouyer-Quertier* (*La Géographie*, September 15, 1902) that the air was densely charged with it when the destroying cloud swept out from Pelée on May 8. From these conditions one has a right to conclude that sulphurous gases *may* have played some, even if not necessarily an important, part in the destruction of life at Saint-Pierre, even though an equally complete annihilation might have been brought about without them.†

The opportunity that presented itself to me at the time of the second death-dealing eruption of Mont Pelée (Aug. 30) of almost immediately visiting the field of destruction, of interrogating a number of the severely wounded, and of examining the bodies and clothing of some of the dead, made clear to me that the real acting force of destruction—to whatever extent it may have been aided by other forces or agents for which testimony does not appear—was superheated steam, or superheated steam charged with hot ashes and lapilli. The evidence proving this, both at Morne Balai and Ajoupa-Bouillon, and, as Lacroix found it later at Morne Rouge, is, it seems to me, conclusive. This

* The absence of chlorine or of chlorine salts distinguishes the Martinique ash. I, however, found some of the ejected boulders or bombs, both in the valley of the Rivières Blanche-Sèche and the basin of the Lac des Palmistes, carrying crusts or patches of greenish-yellow iron-chlorid.

† The instantaneous death which unquestionably was the fate of many, as was attested by the postures in which many of the bodies were found, has by some been thought to bring evidence in favor of asphyxiation through sulphuretted hydrogen gas; but the same condition has frequently resulted from sudden loss of air through overheating or steaming or through an electric stroke. M. Mirville, at Fort-de-France, noted a strong odor of ozone at the time of the explosion of August 30 (*Ann. Soc. Météor*, Paris, 1903, pp. 16–17); this was not apparent to me at the Habitation Leyritz, about four and a half miles eastward of the crater.

steam was shot out as a violent blast, and its mechanical force, withering heat and possible mixture with other gas, shattered, asphyxiated and scorched; and where charged with incandescent particles of solid matter, as in that part of its course which overwhelmed Morne Rouge, also burned. Neither at Morne Balai nor at Ajoupa-Bouillon did I find the faintest indication of anything having burned with a flame, or having been carbonized, not even the dry palm-thatching of the *cases*. The trees that were left standing were dry and largely stripped, and in the zone of lesser destruction the leaves hung to the branches, shrivelled up as though having been rapidly passed through a dry-heat furnace or a scorch-blast. The sap from the twigs was completely gone, and the branches and branchlets broken square across. There was nothing to indicate the passage of combustible gases, and I failed to find—my examination, it is true, was not made with minuteness—evidence of the presence or action of any of the terrestrial gases. A number of inquiries elicited the impression that sulphur was the only gas whose presence was detected in the passing storm, but even its action does not seem to have been severely felt. The scorching, reddening or boiling, and tumefaction of the bodies plainly showed the terribly swift and sure work of the passing steam and hot-air ferment.* The opening of a door or window only for an inch and for an instant was sufficient to invite the work of death. In this second great eruption of Mont Pelée the destroying force, as is shown by the number of frail houses that were left standing in or near the path of the storm, was in any one direction perhaps less powerful than on May 8, but its zone of destruction was far greater, beginning almost immediately in a broad sweep over the crest of the volcano. It may be positively assumed that adjacent to the steam zone on either side was a zone of simple hot air or dry destruction, in which, doubtless, many also perished, for even here the temperature must have ranged well into the hundreds of degrees. Professor Lacroix has, from an inspection of metallic objects that had not been fused or undergone any material alteration, attempted to ascertain in a rough way the degree of heat of the Saint-Pierre blast. The maximum temperature would seem to have been not much over 1900° F.; an approximately indicated minimum was found to be between 800° and 900°. But even with an air-temperature of no more than 700° to 800°, and with the exhaust that would necessarily follow upon the expansion of the steam and the formation of a partial vacuum, one need invoke the aid of no special agent to explain the condition of difficult or impossible respiration which was in so many cases testified to by those who escaped or survived their wounds for a while. Assuredly the sensation must have been one of being deprived of air, and one of the results the burning or even

* Flett and Anderson, in their final report (*Philosophical Transactions*), assume on theoretical grounds that the Pelée blast may "at one stage of its history" have been "entirely deprived of its oxygen and filled with carbon gases"; and they further believe that the destruction of the vegetation on the slopes of the volcano, with the liberation of carbon, may explain the smell of guano and the general odor of organic matter which was noted by some of the earliest investigators. This odor was quite apparent to me on May 31, 1902.

excoriating of the lining of the throat and bronchi and the filling in of the lung-cells. It was like breathing a furnace-fire, especially where the blast was charged with burning matter.

Professor Lacroix accepts the same interpretation of the destroying force that wrecked Morne Rouge as the one to which I have been led as regards Ajoupa-Bouillon, Morne Balai and Morne Capot: "It is not doubtful that the destruction was due to the action of a cloud of aqueous vapor highly charged with hot ashes. There is no reason to seek for a combustible gas; the trees are not burned and the palms from which the leaves have not been forcibly torn show these to be simply dried out" (*Comptes Rendus*, October 27, 1902, p. 672). It is not difficult to apply this lesson of the later eruption of Pelée to the special conditions of the Saint-Pierre catastrophe. With a tornadic blast of the character of, but more powerful than, that which destroyed the five or more towns and villages on August 30, it is easy to assume the destruction of the city, although the swiftness and completeness of this destruction will always appear surprising. We may, perhaps, assume as a factor in this complete destruction the propagation of a number of serially and rapidly following explosions—such as Bunsen, Dixon and others have shown to exist in an ordinarily exploding gas-cloud.* These would surely greatly multiply the force of the exploding or initial cloud. Sekiya and Kikuchi, discussing the Bandai-San eruption (*Journal of the College of Science*, III, 1890) properly remark that "the tremendous explosions of steam at quick intervals, lasting for about a minute, produced violent disturbances of the air, consequent upon the sudden radial expansion of the liberated volumes of steam . . . The eruption of Bandai-San may be aptly compared to the firing of a tremendous gun—such a one, however, as can only be forged by nature." These authors also refer the immediate cause of the eruptions to "the sudden expansion of steam pent up within the mountain." There were no discharges following the first explosion.

While recognizing the efficiency of the hot steam blast in bringing about the destruction of Saint-Pierre and its inhabitants, the absolute annihilation wrought has always appeared to me a puzzling feature as regards the work of steam alone, and while it may be admitted that the overthrow of the city was due virtually to this one cause, it seems not unlikely that the destruction of human life—not considering here the effects of conflagration and of falling walls and boulders—was bound up with accessory conditions, some of which may never be known to us. With regard to the possible coöperation of asphyxiating gases, and as bearing upon my first-expressed view, it is interesting to note that M. Moissan, who has made a close study of the fumarole gases of Pelée, finds the quantity of carbon oxyd so large (1.6 per cent. or more) as to warrant the assumption that it must have been pres-

* See the paper by Harold B. Dixon: "On the Movements of the Flame in the Explosion of Gases." *Proceedings Royal Society of London*, LXX, September 20, 1902, pp. 471 *et seq.*

ent in sufficient measure in the exploding cloud of the main eruption to have caused, through toxic inhalation, the deaths of at least a large portion of the population. Other gases found were nitrogen, oxygen, carbonic acid, hydrogen, methane, and argon, the last two also found among the gases of the waters of Luchon (address to the *Académie des Sciences* of Paris, December 15, 1902; *Revue Scientifique*, January 3, 1903).*

I have always felt that electric discharges must have also been responsible for the destruction of some life; indeed, the case could hardly have been otherwise, for, as we are informed by competent witnesses, the death-dealing cloud was charged with electricity, short flashes passing at rapid intervals from point to point. This same feature was also observed in the descending cloud of June 6, and Flett and Anderson refer to it in their description of the cloud of July 9, 1902. During my second visit to Martinique I was informed, by one who was saved from the destruction of Ajoupa-Bouillon (although losing his family in that terrible disaster of August 30), that the descending cloud that wrought the havoc was flashing with electric lines and sparks, resembling artificial fireworks. M. Lacroix, in his earlier reports and in his concluding work, "La Montagne Pelée et ses Éruptions," finds no evidence of the destroying work of electricity in the eruption of May 8, and concludes that this agent played no appreciable part in the destruction of Saint-Pierre's inhabitants. The arguments and negative evidence of a late day which are brought forward to support his position seem to me wholly inconclusive. (See also Lacroix's article "Pompéi, Saint-Pierre, Ottajano," in the *Revue Scientifique*, Oct. 20, 1906, p. 485.)

I have elsewhere expressed my view that the destruction of Pompeii was in all probability caused by a volcanic discharge similar to that which brought

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* The approximate percentages of some of these gases, obtained from a later analysis, were: nitrogen, 55; carbonic acid, 15; oxygen, 14; hydrogen, 8 (Moissan, in *La Science au XX^e^ Siècle*, March, 1903). The temperature of the issuing gases was about 400° C. Gautier has shown that almost precisely the same gases may be obtained by heating to redness the ordinary crystalline rocks (*Revue Scient.*, Jan. 17; also *Comptes Rendus*, 1901, vol. 132, pp. 58 *et seq.* Moissan has since found the carbon oxyd gas in large proportion among the fumarole products of the Soufrière of Guadeloupe. It is interesting to note that Boussingault, from observations made upon the volcanoes Tolima, Quindi`, Puracé, Pasto, Tuqueres, and Cumbal, of the Equatorial Andes, found that their chief gaseous emanations were water-vapor and carbonic acid, the sulphurous acid present being considered accidental; and it is remarked that even where the odor of sulphur is strongly felt the actual quantity of the gas present is very small when compared with carbonic acid (*Annales de Chimie et de Physique*, vol. LII., p. 23, 1833). Bunsen also found that carbonic acid vastly preponderated among the gaseous exhalations of the Iceland volcanoes. Albert Brun and A. Jaquerad have determined the presence of hydro-carbons in the ash of Vesuvius (Sept. 25, 1904), and they claim that their reaction on silicated carbons (like petroleum), by heating, would sufficiently explain all volcanic phenomena (*Archives des Sciences Physiques et Naturelles*, June, 1905, p. 416). These investigators, singularly enough, as a result of their examination of the products of eruption (the dry ash, scoriæ and lava), assume that steam plays no important part in the agency of volcanoes, and affirm that the familiar white pennant or "steam-cloud" of volcanoes is not steam at all, but a chlorid gas! (*Op. cit.*, pp. 439 *et seq.*; pp. 589 *et seq.*)

about the annihilation of Saint-Pierre, and that the phenomena of the Vesuvian eruption of the year 79 and of Pelée were largely similar. It seems not unlikely that there may have been eruptions from other volcanoes, the conditions of which have not been properly investigated, which had much in common with what are assumed to be the distinctive features of the Pelée explosion. Thus, it is noted by M. Fouqué, in his work on Santorin, that at the time of the eruption of the year 1650 the dead bodies of a number of sailors were found on a drifting vessel several miles from the seat of the eruption, exhibiting abdominal and head inflation, protruding tongues, and inflamed eyes. These features of bodily distortion were a marked characteristic of the killed in both the Pelée eruptions, and have been attributed to special conditions surrounding the death-stroke. It is interesting to note that Dr. von Volpi, describing his own personal observations on the great eruption of Vesuvius in April, 1872, refers to the terrific scalding that was brought about by superheated steam and the resulting scars on the human flesh: "*Man bringt einen Verwundeten, dessen Haut und Fleisch verbrannt sind und krebsroth aussehen. . . . Die Verwundungen rührten nicht etwa von Berührung der feurigen Lava her, sondern von dem glühendheissen Dampfe, der von ihr ausging und bei einer Hitze von 800 Grad alles versengte und verbrannte, was in seiner Nähe war.*" *

The Nuées Ardentes.—Lacroix, it seems to me, has entirely exaggerated the importance and significance of the discharge clouds which he designates by the name of *nuées ardentes* or *denses*. My own observations lead me to believe that their characteristics are bound up almost solely with the mass of disrupted products (rock, lava-fragments, dirt, etc.) which they carry with them, and which necessarily weight them down. As a consequence of this the "cloud" takes a course directly on the slope of the mountain. The *nuée dense* is thus merely the visible part of an overloaded steam-explosion, and it may be said to hold much the same relation to the actual burst that the smoke holds to the true discharge of a cannon. In other words, it is something that follows after. I do not believe that the numerous discharges observed by either the French Scientific Commission or the commission of the Royal Society, any more than the great *nuée dense* which nearly enveloped my party on June 5, were anything more than mere accompaniments of explosions that had preceded—unusually severe explosion clouds, which carried an enormous amount of material in their trains. The term used by Lacroix may, nevertheless, serve a useful purpose in distinguishing these explosive, sedimented clouds from the more ordinary free clouds. The work of actual destruction was determined by the blasts which carried out these trains of disrupted materials and not by the materials themselves; and it is certain that a large or the major part of the wrecking or blowing to pieces of Saint-Pierre was effected in advance of the coming of the "black

* *Unsere Zeit.*, Leipzig, 1872, p. 397. The correspondence assumed to exist between the Pelean eruption of May 8, 1902, and the eruption of Vesuvius of the year 79 has been discussed by Sapper (*Die Umschau*), and Lacroix (*Revue Scientifique*, Oct. 27, Nov. 3, 1906), who arrive at conclusions at variance with those held by the writer.

cloud." The conditions of the topography of the region—its deeply incised cañons, the projecting buttes or promontories (Mont Parnasse, etc.)—are such as to have precluded extensive destruction except as the result of an explosive charge; and, as a fact, the study of the field and of the material overlying Saint-Pierre has shown that no great amount of material, excepting the fine volcanic ash that was deposited in the normal way of ash-falls generally, was showered over the city. Nor, indeed, could such material do extensive damage in the sections of the city which were protected from such storms by the lee-faces of abrupt hills. But the destruction there as elsewhere was virtually complete.

While in a general way attributing the catastrophe of Saint-Pierre to the agency of the visible "black cloud" (*nuée dense* or *ardente*)—a "turbulent mixture of expanding gases and fine dust"—Flett and Anderson, from observations made on the descending cloud of July 12, 1902, and the study of the May 7 cataclysm of the Soufrière of St. Vincent, make clear in their report (*Philosophical Transactions*) that but little of the mechanical destruction could have been effected by the "avalanching" material or by the black and impenetrable cloud which "came clearly out of the avalanche, of which it was clearly only the lighter and cooler surface." It is noted that the radiating "black clouds" of the Soufrière were easily stopped or deflected by surface irregularities, and that their velocity was at times even checked by counter winds (p. 403). Again, many persons struck by this impenetrable wall appear to have escaped with their lives. Mr. Kennan has also expressed the view that the black cloud in itself exerted but little force in the Pelée eruption, whereas the blast that came in advance of the descending black cloud on May 8 is described by Capt. Freeman, of the *Roddam*, to have struck the ship "like a hammer."

The recognition of the nature of the destroying tornadic blasts which in such swift measure swept off upwards of thirty thousand inhabitants from the surface of the earth still leaves untouched some important considerations bearing upon the explosions themselves. What was the exact seat of the explosion or explosions? Was the main explosion in the conduit of the volcano, whence the great internal detonation might have been conceived to pass; or was its *locus* immediately above the crown of the volcano, with its ascensive energy blanketed by some resisting force above? Mr. Kennan, in his work, "The Tragedy of Pelée" (1902), has ably discussed this aspect of the problem, and he compares the explosion to other explosions which have had their directions or intensities determined by the presence of an unyielding wall or barrier on one side of the blast. The "extraordinary violence of the lateral blast caused by the explosion of the Toulon powder-magazine, in March, 1899,"—which, as stated by Colonel J. T. Bucknill (*Engineering*, London, May 26, 1899, pp. 665–666), appears to have exerted its main force in one direction ("something like an accidentally formed fougasse"), and covered the ground for a full kilometre in the path of its course with rock-débris and masonry, while hurling blocks of stone weighing four hundred-weight to a distance of two kilometres,—is justly brought in for comparison, and there is hardly a question that it approximately

supplies the explanation in the case of the Pelée blast. Colonel Bucknill describes the Toulon magazine as being "so solidly built that it practically formed a sort of a cannon or mortar"; and this is virtually what we find or can assume to have been the case with Pelée. Knowing, as we now do, that probably at the time of the eruption of May 8 the chimney of the volcano had already been at least partially plugged—by the ascending tower or obelisk—it is made easier to assume the deflection of the tornadic discharge through cushioning. The condition of explosion may then be stated as follows: A volume of steam with intense explosive energy rising to the crater-mouth, blowing out in its first paroxysm a part of the crater-floor, and then exploding in free air under a heavily depressing cushion of solid rock and ascending steam and ash, and with surrounding walls of rock on three sides and more to form an inner casing to nature's giant mortar. The blast was forced through the open cut, or lower lip of the crater, that was directed to Saint-Pierre. It is interesting to note that the "overflow" eruption of August 30 took place only after the crater-floor had been elevated by perhaps seven hundred to nine hundred feet as the result of the accumulation of volcanic ejecta.

The black appearance and "rolling" of the accompanying clouds were, as most investigators have indicated, due to charging with large quantities of ashes and other solid particles. It is generally conceded that the brilliant red glow which was noted in it by some observers, especially in its advanced position, was merely the loom of the numerous incandescent particles that were contained within the cloud—the cloud appearing as if burning with flame. But may it not be assumed that a part of this red coloring was due to that property in steam under pressure which at times permits it to acquire a red color with transmitted light? This condition was pointed out by Principal J. D. Forbes in the case of escaping steam from a locomotive as far back as 1839 (*Transactions Royal Society of Edinburgh*, xiv., 1839, p. 371). Such a luminous red mass might readily have been taken for a "descending wall of fire," such as some seamen, like Captain Freeman of the *Roddam*, claim to have seen. It is interesting to note that a hot, suffocating blast, evidently of the type of that issuing from Pelée, was noted by Pond and Percy Smith in their investigations of the Tarawera eruption (*Transactions New Zealand Institute*, 1886 [1887], p. 351).

Temperature and Force of the Destroying Cloud.—M. Lacroix has given as the approximate minimum temperature of the destroying cloud, or the ash contained within it, 450° C. (840° F.), and the highest temperature, determined by the fact that copper telephone wires were found not to have been melted, 1050° C. (1920° F.). The criteria assumed for determining these temperatures, especially the upper one, can hardly be regarded as conclusive. Paper can readily be passed several times in succession through a gas flame without igniting, and so a current of almost overwhelming heat could be passed over copper wire without fusing it, were the motion made sufficiently rapid and of brief duration. Packets of matches and other combustible substances were, as a matter of fact, found directly in the path of the greatest storm without indicating any trace of fusion or ignition.

Conditions permitted them to escape, whereas other substances, and much more refractory ones, were completely charred in their immediate vicinity. It can also hardly be assumed that the criteria obtained from the calculated force necessary to overwhelm definite objects, which M. Lacroix uses to determine the velocity of the destroying cloud at the point of contact with the object destroyed, are strictly reliable, since there have been no means of determining to what extent the overwhelming blast was charged with solid, "catapultic" particles. The overthrowing of the statue of "Our Lady of the Watch" has given to Lacroix the "striking" velocity of 130 to 150 metres per second.*

Absence of Free Lava-Flow.—It has been remarked as one of the peculiarities of so violent an eruption as that of Pelée on May 8, as well as those on May 20 and August 30, that there should have been no free flow of lava, a condition that was long ago indicated by Leopold von Buch in the case of the active volcanoes of the Andes generally. Neither in the great eruption of the Soufrière of 1812 nor in the more recent eruptions of that remarkable volcano has there been any lava-flow, that which has been described as lava in 1812 being merely a detrital and mud discharge similar to the discharge of 1902. Some geologists have attempted to measure the explosive force of different eruptions by assuming the quantity of ejected lava as the determinant of this force—the greater the amount of lava emitted, the greater the force of the eruption. It would seem, however, that the opposite conclusion would more nearly represent the truth, for we find that nearly all the great paroxysmal discharges were unaccompanied by lava-flows, or at least by lava-flows of any magnitude. Such was the case, for example, with the eruptions of Galunggung, in Java, of Temboro, in Sumbawa, in 1815, of the Soufrière, in 1812 (and the eruption of later date) of Coseguina, in Nicaragua, in 1835, of Krakatao, in 1883, and the eruption of Pelée, in 1902. To these examples, and many others that might be cited, should be added the first recorded and historic outburst of Vesuvius in the year 79, which presented a condition in marked contrast to subsequent less paroxysmal eruptions, in which the flow of lava had a conspicuous part. It might be assumed, in explanation of this seeming inversion of force and effect, that in the paroxysmal types of eruption the quantity and force of the pent-up steam are more than sufficient simply to lift lava; they blow it to pieces, and produce those enormous volumes of ejected material which have buried or overthrown towns and villages and otherwise defaced the landscape over vast distances. Volcanoes of a less paroxysmal type will pour or "well" out the lava in quiet streams, not necessarily accompanied by any marked form of explosive action.

Oscillation of the Sea-Surface.—The singular oscillation of the sea-surface, the rise of the water by about three feet, which was noted as an accompaniment to several of the more violent eruptions of Pelée, on both the west and east coasts (Fort-de-France, Trinité, etc.),—a phenomenon which I myself witnessed on the morning of June 6—may possibly have been due to direct volcanic shocks

* "La Montagne Pelée et ses Éruptions"; also *Revue Scientifique*, Oct. 20, 1904, p. 483.

impacted upon the floor of the ocean. The existence of oceanic disturbances off the west coast of Martinique at the time of, or preceding, the great eruptions of Pelée can hardly be doubted. The successive breakages of the different cables precedent to the eruptions, and other facts connected with the attempted location of the disrupted ends of the cables, prove this condition almost beyond a doubt. Krebs has latterly called attention, in a paper on tidal fluctuations as related to volcanic phenomena,* to an extended marine disturbance which traversed the entire length of the Guatemalan coast on the 16th and 17th of April, 1902, one and two days in advance of the great earthquake which wrecked a portion of the town of Quetzaltenango and which was almost coincident with the first breaking into activity of Pelée. A similar oceanic disturbance was noted on May 4, the day in advance of the mud discharge from Pelée which overwhelmed the Usine Guérin.

* *Globus*, July 30, 1903.

VI.

THE ANTILLEAN DISTURBANCES AND THE QUESTION OF VOLCANIC AND SEISMIC INTER-RELATIONSHIPS.

ONE of the most significant facts associated with the Antillean upheavals of the year 1902 is the extent of territory over which earthquake and volcanic disturbances of a single or identical period of activity manifested themselves. From southern Mexico in the west to the Lesser Antilles in the east we have an interval in a direct line of not less than 1800–2000 miles, and along or near this line disturbances have been registered in Costa Rica, Nicaragua, Salvador, Guatemala, and Mexico. The remarkable crowding of the phenomena is such that one cannot well resist the conclusion that they are all inter-related or hold a mutual relation to a single inciting cause, and are not coincidental in their occurrence. The more salient facts connected with these disturbances are briefly:

The destructive earthquake of Quetzaltenango, in Guatemala, on April 17–18, 1902, at almost precisely the time when Pelée first seriously manifested its new activity; the renewal of activity, immediately after the earthquake, and at a distance of nearly 200 miles, of Izalco, in Salvador, a volcano whose energies had calmed down for a number of years, but which was in full activity on May 10, two days after the Pelée cataclysm; the eruption on May 7, of the Soufrière, in St. Vincent; the cataclysm on May 8, of Pelée, followed, as in the case of the Soufrière, by violent disturbances extending into September or October; the opening up of the Santiago, or western, crater of Masaya, in Nicaragua, about the middle of July, 1902, with a well pronounced activity continuing into July, 1904; the eruption on October 24 (continuing to Nov. 15) of Santa Maria, in Guatemala, a volcano situated close to the seismic field of Quetzaltenango, and for which there is no recorded previous eruption. The relation of these facts, it seems to me, is so intimate as to force the conclusion that they are directly connected with each other, and one need hardly discuss the probability of another interpretation being found for them; and it was not without reason, therefore, that Milne early advanced the view that the April earthquake of Quetzaltenango was the real initiator of the series of dual disturbances that followed rapidly upon it. Whether or not one should extend the relation of disturbances so as to include the earlier earthquake which in January of the same year wrecked a large part of the town of Chilpancingo, in southern Mexico, and the reawakening of Colima in February and March of the year following (1903), does not materially affect the problem, as the distance separating Martinique from Quetzaltenango is already so great as fully to satisfy the conditions of the broad deduction which it is my aim here to present. Owing to the fact that these disturbances were developed in what

might be termed a single region, and in a region that is not familiar to us in the sense that parts of the world nearer to our homes are, the geologist is not apt to be impressed with the magnitude of the distance that separated them; it is, therefore, proper to state that on the map of the continent of North America it would be measured by the line uniting Galveston with Cape Churchill, on Hudson Bay, or that uniting San Francisco with the volcano of Iliamna, on Cook Inlet, Alaska, or with the volcanic islands of the Aleutian group.

The realization of the important fact that inter-related volcanic and seismic disturbances may manifest their acutest phases of activity over an area of the earth's surface that is measured on a line of 1800–2000 miles naturally opens up a broad perspective of the possibilities in the inner workings of our planet, at the same time that it directs inquiry to the general subject of volcanic and seismic inter-relationships.

I have elsewhere* used the facts, as they appear to me, of the Antillean disturbances, together with others of a like kind drawn from regions remote from the Antilles, as evidence tending to prove that the inciting force of such disturbances may be (and has been) regional rather than local in character and that the generally accepted views of geologists that the far-reaching seismic jars of the earth—the so-called tectonic earthquakes—are independent of volcanic association, might not unreasonably be thought to rest on doubtful premises. At any rate, one may well question whether in the case of some of the seemingly most distinctive tectonic disturbances there is not an absolute association binding them with some form of volcanic activity registered upon possibly a distant quarter of the globe. My own general conclusions as I have stated them are as follows:

1. A broad inter-relationship exists between volcanic and seismic phenomena generally;

2. Inter-related manifestations of volcanic and seismic activity may extend over distances, as measured on the surface of the globe, of hundreds or even thousands of miles;

3. "Tectonic" earthquakes, so-called, are only doubtfully to be distinguished from earthquakes of volcanic association, or those that have been brought about as the result of deep-seated strain;

4. The slipping, upheaval and torsion of terranes as accompaniments of earthquake action are the resultants of impacts or jars already delivered to the earth's crust, and are not the cause of such jars;

5. Earthquake and volcanic disturbances seem to be the expression of one common interior telluric strain or condition, and this condition may in some or many cases be clearly associated with a pronounced magnetic or electromagnetic quality of the planet;

6. There would appear to be a marked synchronism or close following of

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* Paper read before the International Congress of Geologists, held in the city of Mexico, in September, 1906. Paper published in *Science*, Nov. 2, 1906.

major disturbances, whether volcanic or seismic, at distantly removed points of the earth's surface at different periods.

For the facts which have forced these conclusions upon me and inclined me to an acceptance of the Naumann-Humboldt theory of volcanic and seismic relationships in preference to the more modern view of the general independence of the two classes of phenomena, the reader is referred to the article published in *Science* for Nov. 2, 1906.

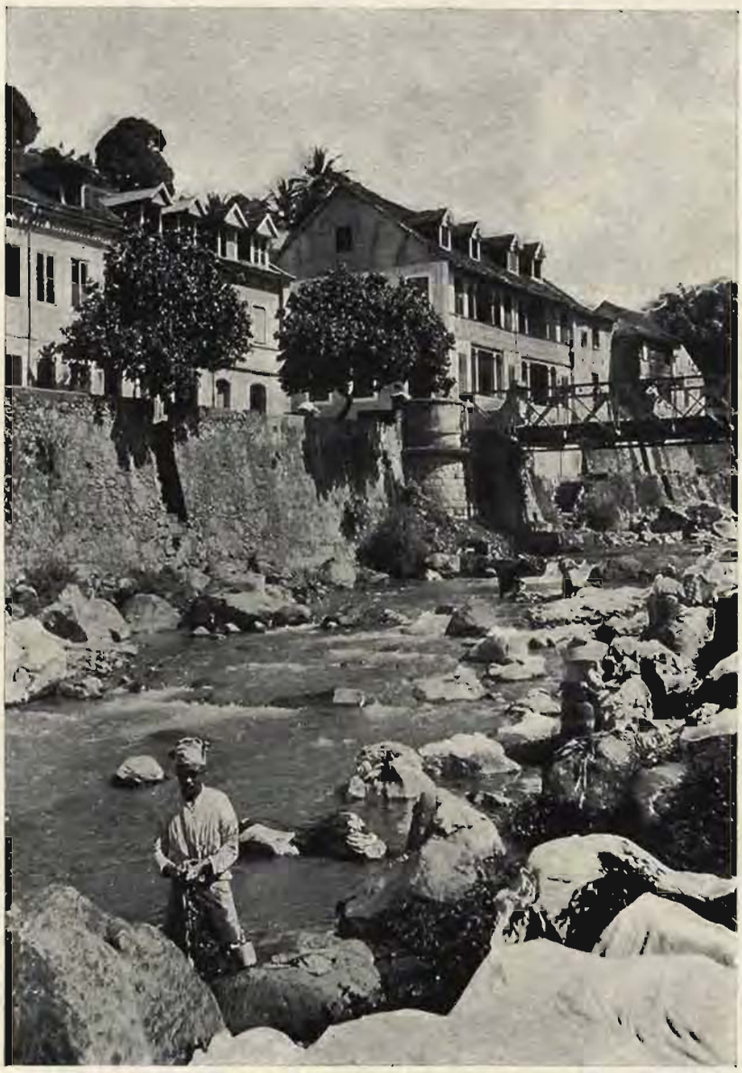
It is an interesting fact, and one seemingly confirmative of the views that I have here expressed, that the four great earthquakes of the most recent time have been found to be synchronously related to volcanic activity: the September, 1905, earthquake of Southern Italy (Monteleone), associated with a recrudescence of activity on the part of Vesuvius and Stromboli (Mercalli: *Comptes Rendus*, Jan. 17, 1907); San Francisco, with the upthrow of Bogoslov Island No. 3; Valparaiso (Chile), with the outbreak of Chillán (Steffen, *Zeitschrift Gesell. für Erdkunde*, Berlin, 1906, p. 638); and Kingston (Jamaica), with outbreaks of the Central American volcanoes (as reported in the logs of the Pacific Mail steamships). The theory of the probable inter-relationship of earthquake and volcanic phenomena has been made the subject of many important papers, from the time of the earliest geologists to the present day, but it nowhere receives more lucid exposition than in a paper (now, as it seems, generally overlooked) published by Charles Darwin in the *Transactions of the Geological Society* of London (2d series, vol. V, 1840). Among the more notable synchronous events there recorded is the simultaneous breaking out into activity, on Jan. 20, 1835—shortly preceding the great earthquake disturbances on the west coast of South America—of the volcanoes of Osaruo, in Chile, and Coseguina, in Nicaragua, separated by an interval of upwards of 3000 miles. In my own paper already referred to I cite among other synchronous happenings in seismo-volcanic activity the cataclysm of Kötlugia (Katla), in Iceland, on the day, Nov. 1, 1755, when Lisbon was destroyed by earthquake, and the combined catastrophic eruptions of Skaptar Jökull, Hecla, and Reykjanes occurring coincidently with the great Calabrian earthquake of 1783. The distance separating Iceland from Lisbon is about 1800 miles—therefore, less than the distance that separates Martinique from Quetzaltenango, in Guatemala.*

* An exhaustive paper, dealing largely with earthquake and volcanic relationships, has latterly been published by Prof. T. J. J. See in the *Proceedings of the American Philosophical Society* (Oct.–Dec., 1906). The author's conclusions regarding tectonic earthquakes are largely identical with those which I have here advanced.

THE END.

II

ALONG THE ROXELANE, SAINT-PIERRE



III

MUD-FLOW OF MAY 5, 1902
Valley of the Rivière Blanche.

III

IV

PELÉE IN THE MAY ERUPTION

Judge Pub. Co., New York

IV

Copyright

V

THE SILENT CITY

From the Morne d'Orange.

Expl. Heilprin

Underwood & Underwood, Stereos. Photo., New York, Copyright, 1902

VI

THE CATHEDRAL OF SAINT-PIERRE IN RUINS

After May 20, 1902.

VI

VII

RUE VICTOR HUGO, SAINT-PIERRE

View taken May 14, 1902.

VII

VIII

THE HEAVENS AGLOW

May 26, 1902.

Painted by George Varian

IX

PELÉE'S GREAT ASH-CLOUD TURNING DAY INTO NIGHT

View taken May 26, 1902, looking from the north.

IX

X

A DELUGE OF BOULDERS

Basse-Pointe, May 30, 1902.

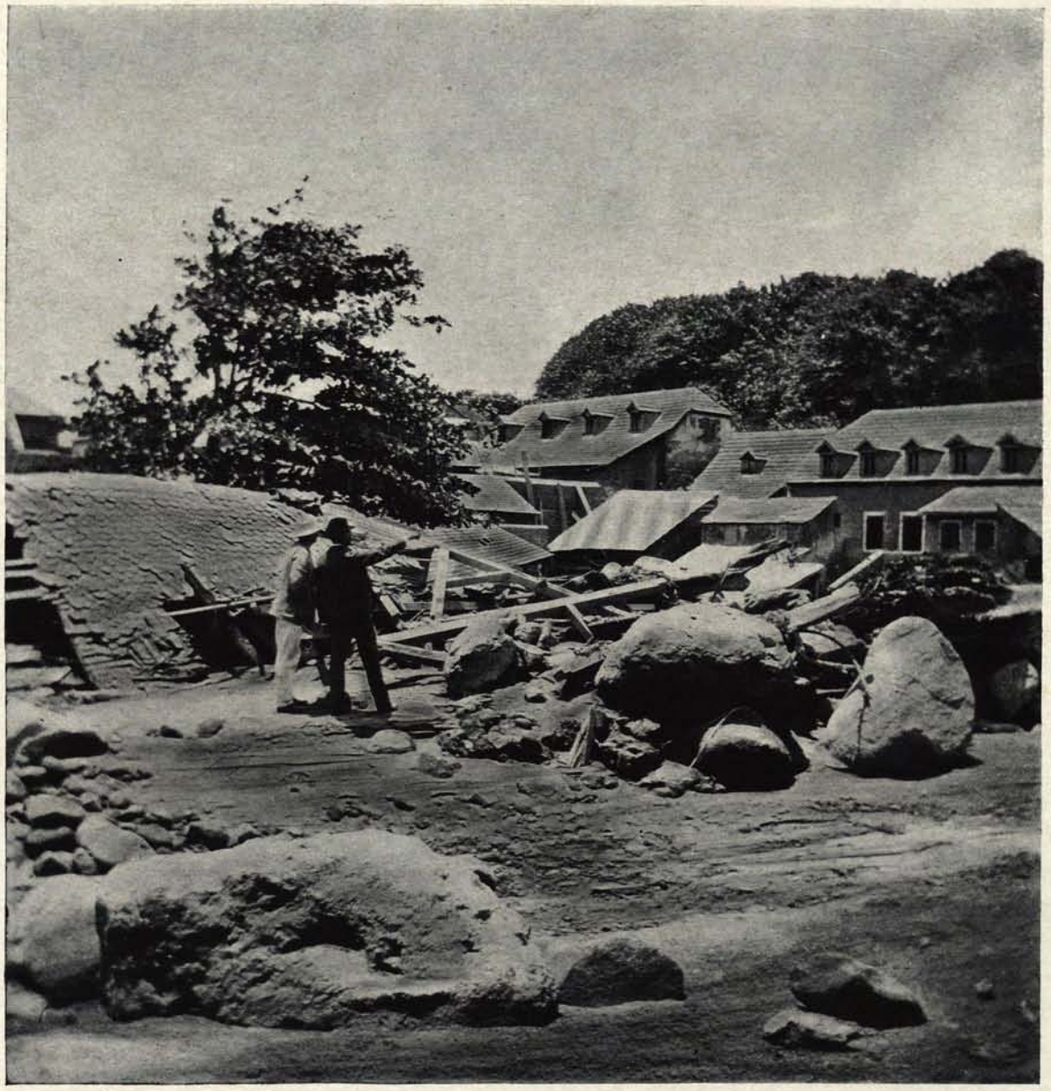


Photo. Heilprin

XI

ASH-CLOUD OF PELÉE

View taken from Assier.

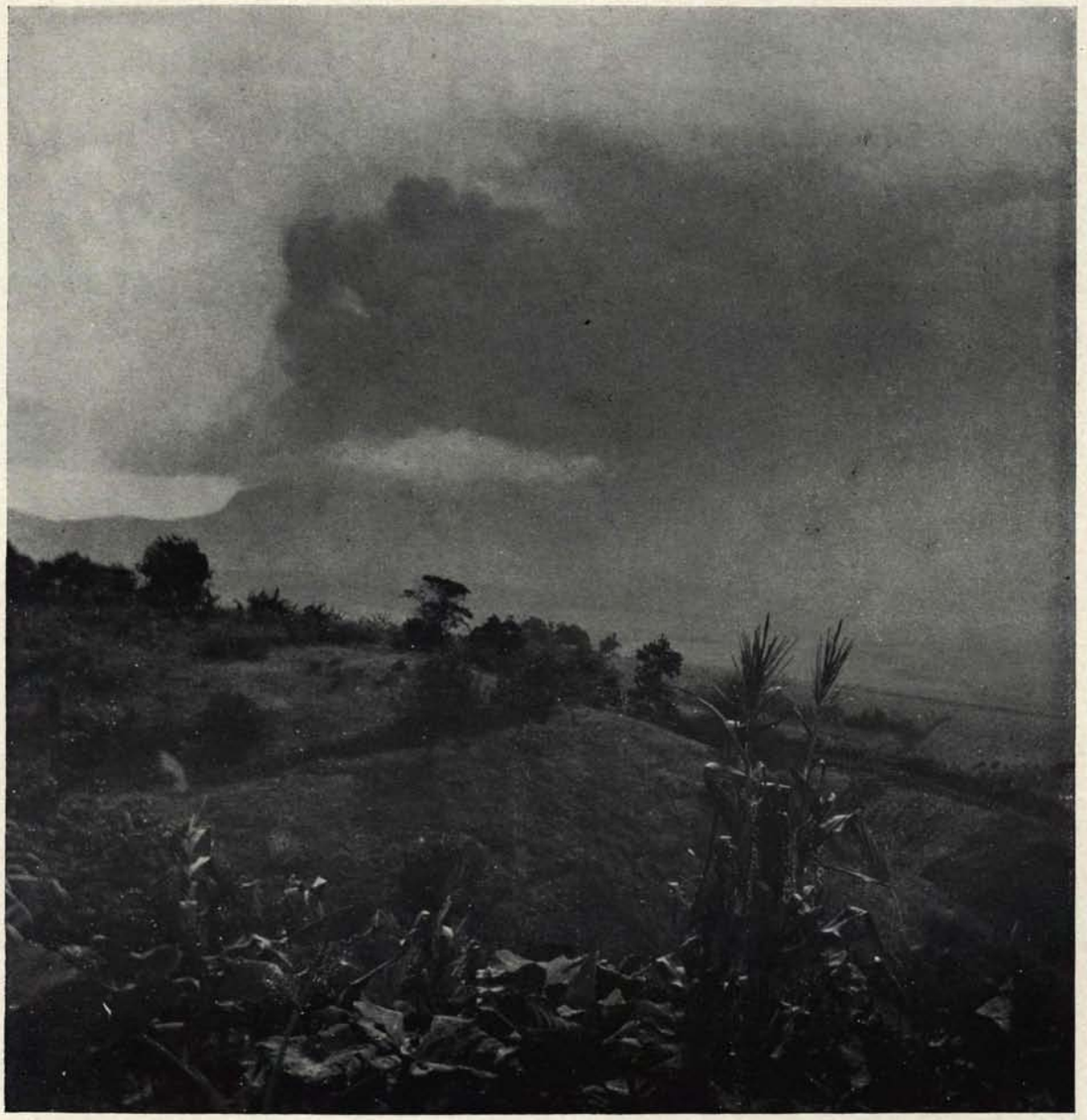


Photo. Heilprin

XI

XII

PELÉE IN A PAROXYSM

June 5, 1902.

Expl. Heilprin

Underwood & Underwood, Stereos. Photo., New York, Copyright, 1902

XII

XIII

TOWERING CLOUDS

Eruption of June 5, 1902.

Expl. Heilprin

Underwood & Underwood, Stereos. Photo., New York, Copyright 1902

XIII

XIV

MUSHROOM-SHAPED CLOUD

Eruption of June 5, 1902.

Expl. Heilprin

Underwood & Underwood, Stereos. Photo., New York, Copyright, 1902

XIV

XV

THE ASH-CLOUD OF JUNE 6, 1902.

Underwood & Underwood, Stereos. Photo., New York, 1902

XVI

PELÉE IN ERUPTION.— AUGUST 24, 1902

The entire crater working.

Photo. Heilprin

XVI

XVII

THE ISSUING BLASTS FROM THE CRATER — AUGUST 24, 1902

Lower white clouds from base of crater.

Photo. Hellprin

XVIII

PELÉE IN ERUPTION, AS SEEN FROM THE GRAVEYARD OF MARIGOT

Early morning of August 26, 1902.

Expl. Heilprin

XIX

PELÉE IN FULL ACTIVITY IN THE AFTERNOON OF AUGUST 30, 1902

Photograph taken about six hours before the cataclysm which overwhelmed Morne Rouge and Ajoupa-Bouillon.

Expl. Heilprin

XX

PELÉE IN THE AFTERNOON OF AUGUST 30, 1902

Photograph taken during a momentary sun-burst.

Expl. Heilprin

Singley, Keystone View Co., Copyright, 1902

XXI

STEAM-ASH CLOUDS IN THE AFTERNOON OF AUGUST 30, 1902

Strongly illumined clouds with rapidly unfolding whorls.

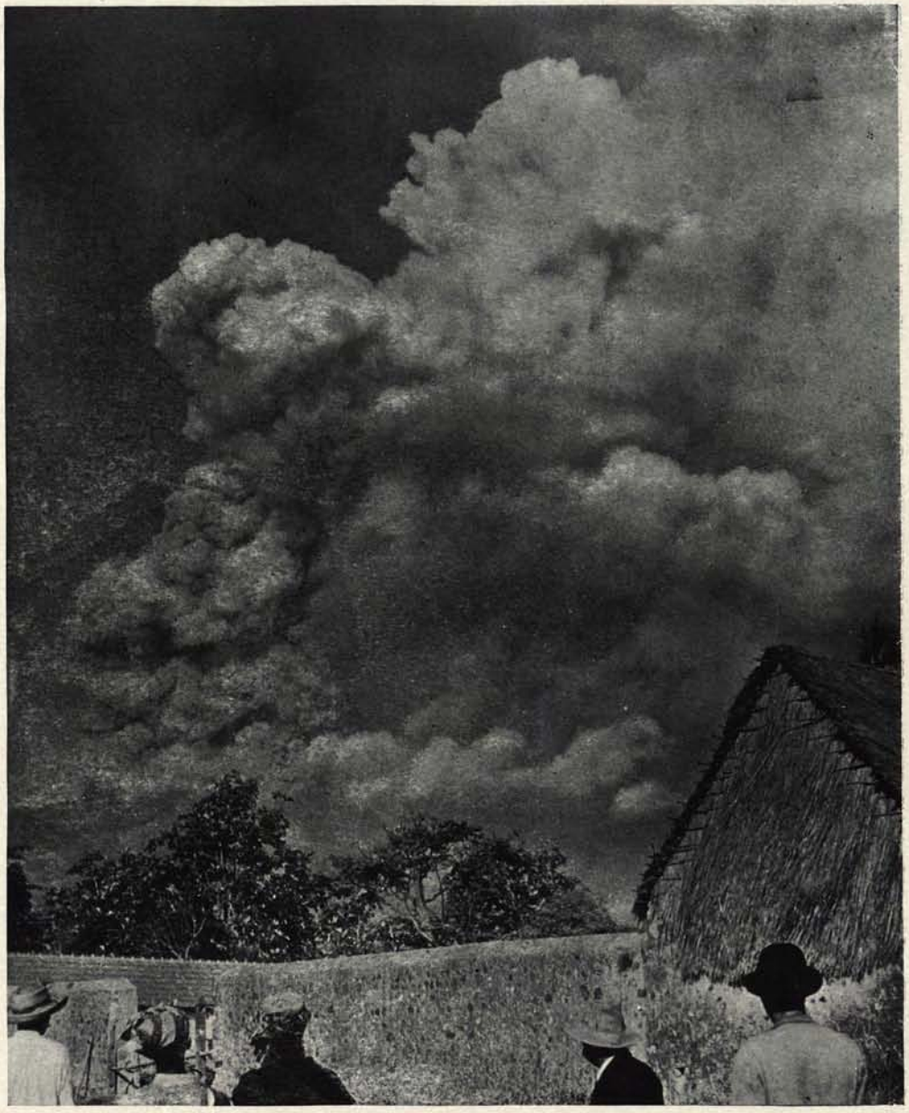
Expl. Heilprin

Singley, Keystone View Co., Copyright, 1902

XXII

PELÉE IN THE EARLY MORNING OF AUGUST 31, 1902

Photograph taken a few hours after the cataclysm which overwhelmed Morne Rouge and Ajoupa Bouillon.



Expl. Heilprin

Singley, Keystone View Co., Copyright, 1902

XXIII

BLOCK OF ANDESITE EJECTED FROM PELÉE

Probably thrown out in the eruption of August 30, 1902; about four-fifths natural size.

Photo. Heilprin

XXIII

XXIV

MORNE ROUGE AFTER THE DESTRUCTIVE BLAST OF AUGUST 30, 1902

Church of Notre Dame de la Délivrance in the centre — one of very few buildings in the town that were left standing. Photograph taken September 7, 1902.

Expl. Heilprin

Singley, Keystone View Co., Copyright, 1902

XXV

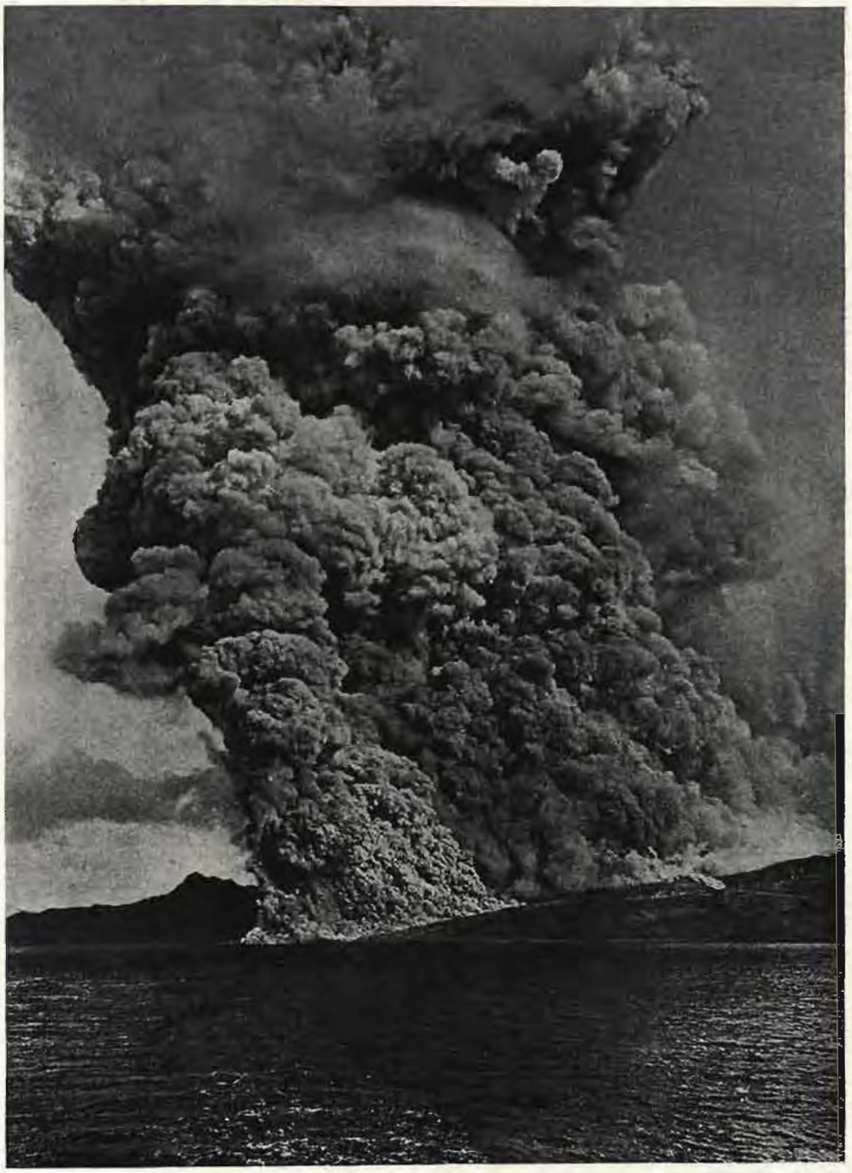
MORNE ROUGE IN RUINS

Destruction wrought by the eruption of August 30, 1902.

Photo. Heilprin

XXVI

THE BLACK CLOUD OF DECEMBER 16, 1902
as it reached the sea.



Heliog. L. Schutzenberger

Photo. A. Lacroix

XXVII

PELÉE AND THE ASH-COVERED VALLEY OF THE RIVIÈRE BLANCHE

In front a huge mud-wall, largely the mud-flow which overwhelmed the Usine Guérin on May 5, 1902.

Photo. Heilprin

XXVIII

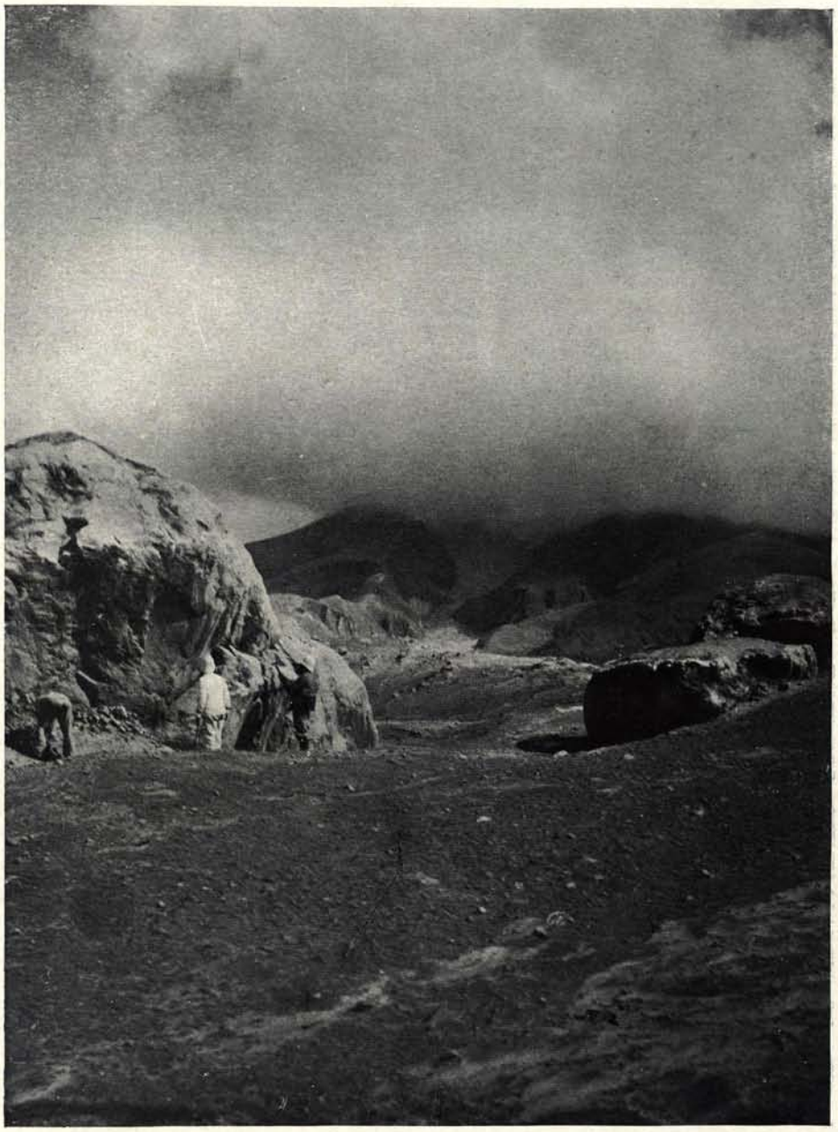
THE VILLAGE OF PRECHEUR BENEATH ITS ASH MANTLE

Expl. Heilprin

XXIX

LOOKING UP THE VALLEY OF THE RIVIÉRE BLANCHE

Giant blocks of rock ejected during the outburst of August 30, 1902.

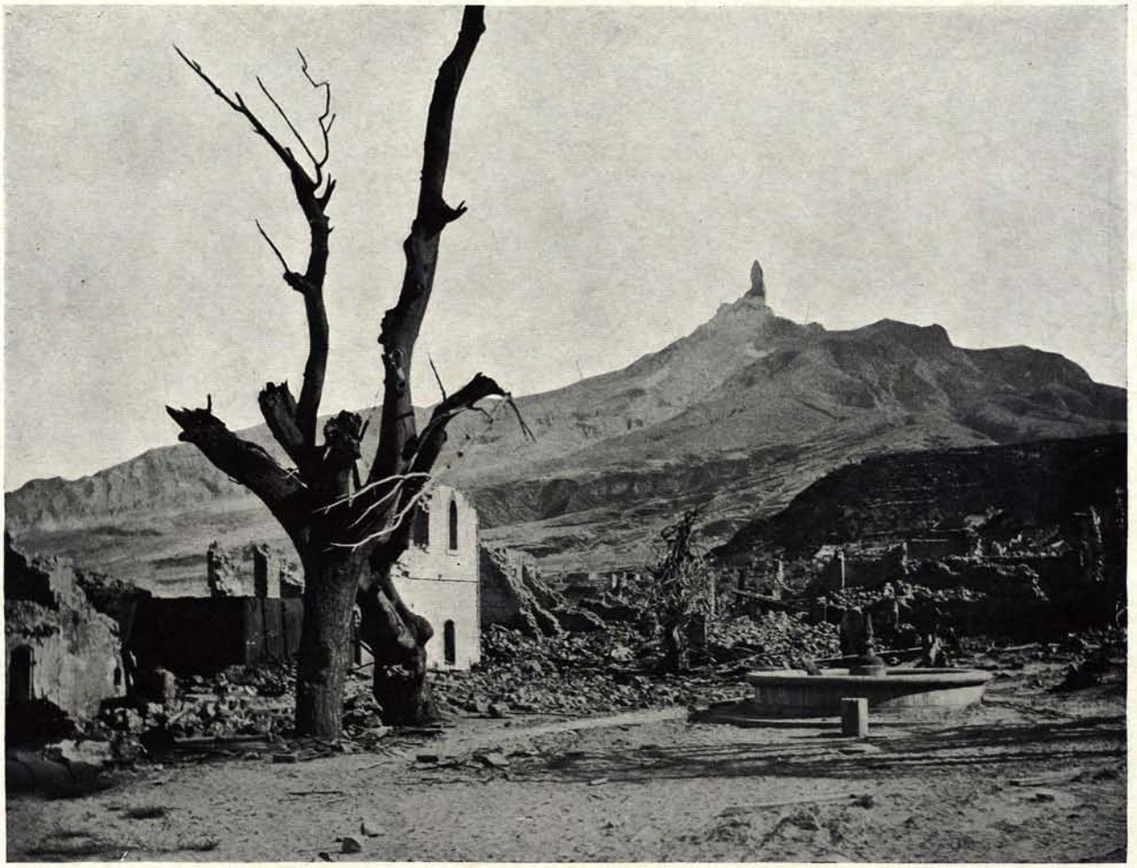


XXIX

XXX

PELÉE WITH ITS TOWER OR OBELISK

View taken from the southern section of Saint-Pierre.



XXXI

THE TOWER OF PELÉE, LOOKING SOUTH BY WEST

View taken near the crater's edge June 13, 1903.

Photo. Heilprin

XXXI

XXXII

THE TOWER OF PELÉE, LOOKING NORTH

The breaking clouds and vapors uncovering the giant obelisk. Photograph taken June 13, 1902.

Photo. Heilprin

XXXII

XXXIII

THE TOWER OF PELÉE WITH ITS SUPPORTING DOME

View looking north-northwest. Photograph taken at the crater-rim June 13, 1903.

Photo. Heilprin

XXXIV

THE TOWER OF PELÉE, LOOKING WEST-SOUTHWEST

View impressively showing the cork-like extrusion from the cone or dome. Photograph taken June 13, 1903.

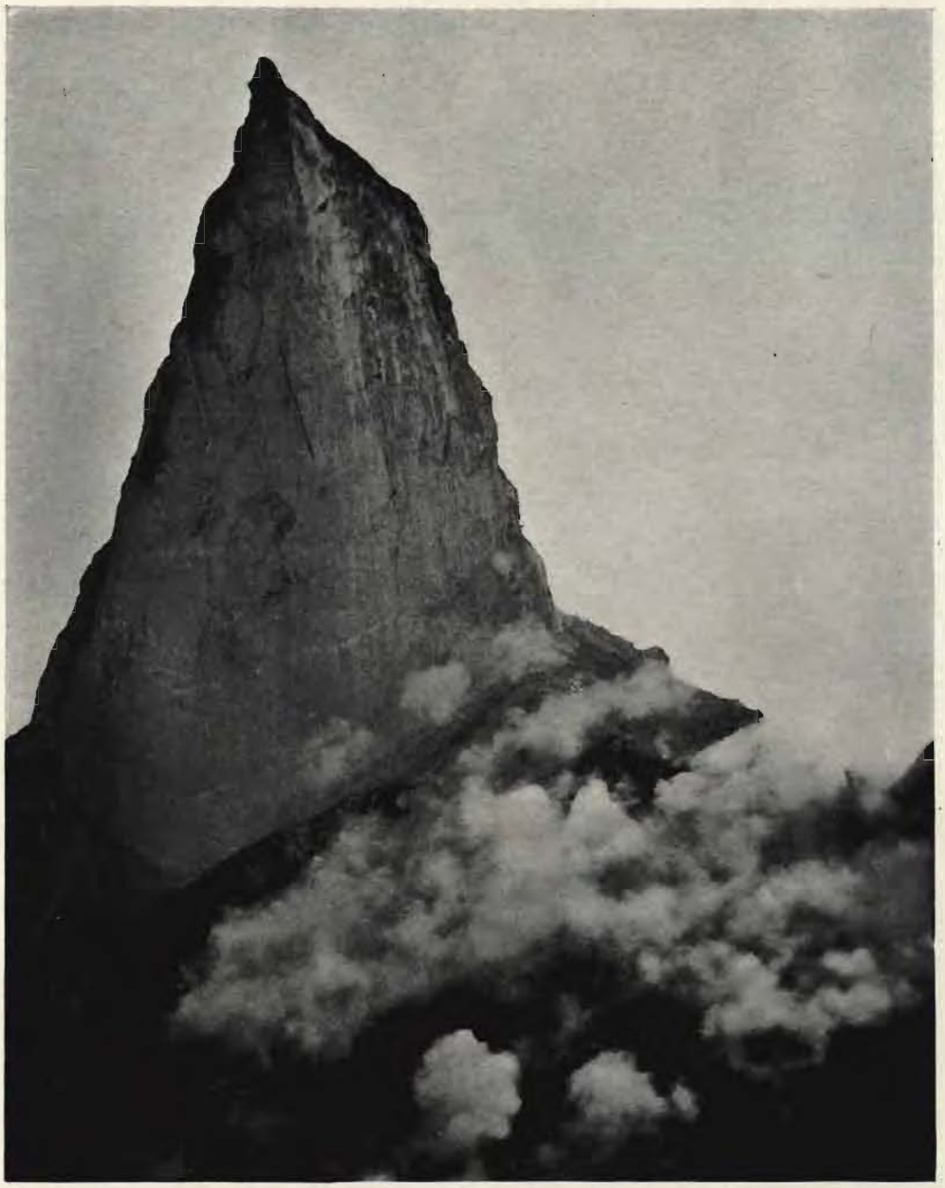


Photo. Heilprin

XXXV

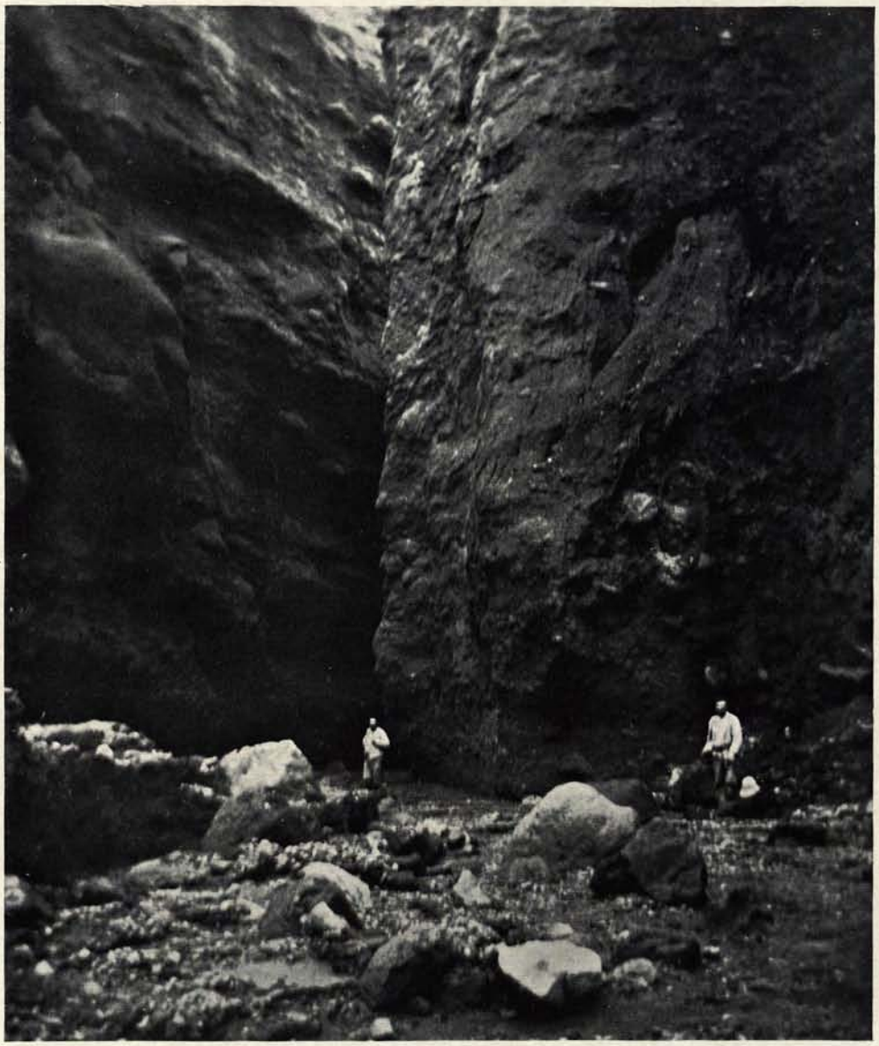
PELÉE'S CRATER—VIEWS OF AND FROM THE SUMMIT OF THE VOLCANO

1. Looking into the basin of the Étang Sec. 2. Remains of the Morne de la Croix, the former highest point of the volcano. 3. The rim of the volcano (edge of the crater-wall of the basin of the Étang Sec).

Photo. Heilprin 1 2 3

XXXVI

THE GORGE OF THE FALAISE



Photo, Heilprin

XXXVI

XXXVII

PELÉE AFTER THE DESTRUCTION OF THE OBELISK

View taken March, 1904.

Photo. Murray Jordan

XXXVIII

THE SHATTERED OBELISK OF PELÉE

Photograph taken on the northeastern face of the dome February 27, 1906.

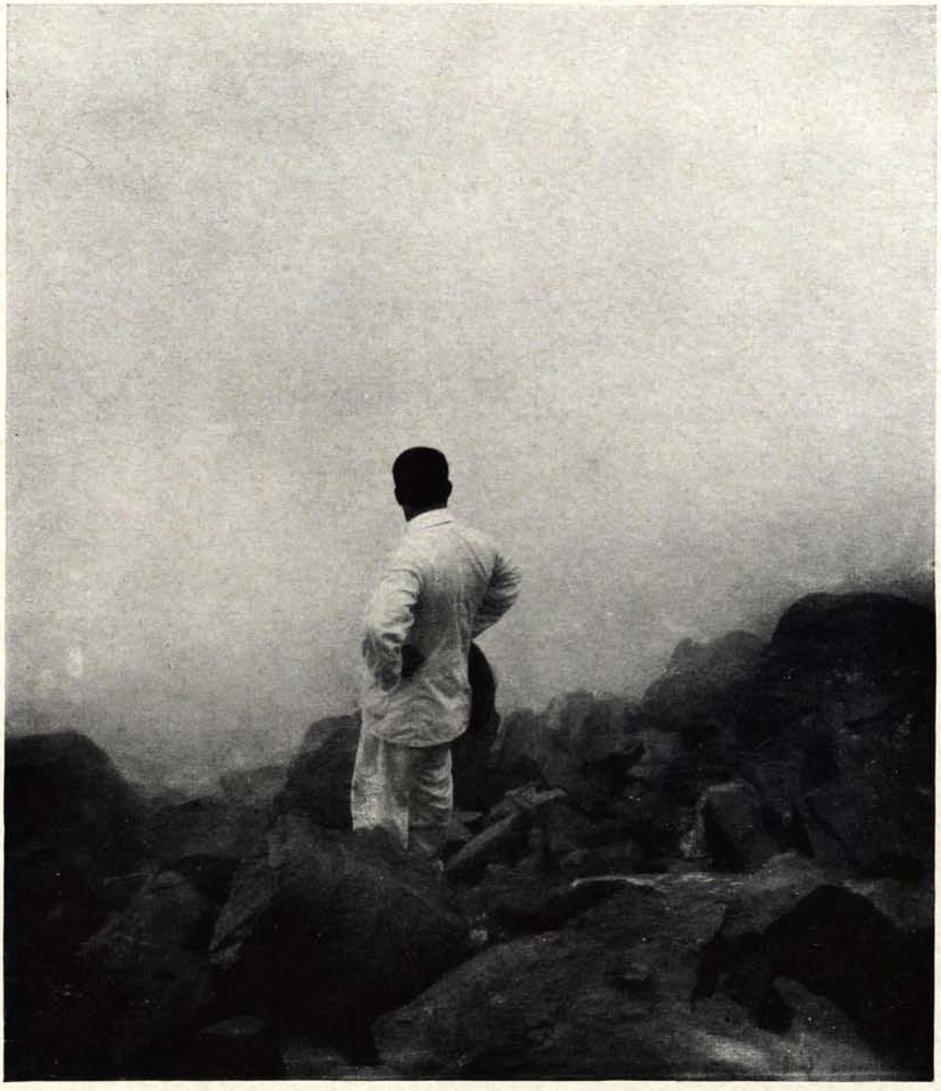


Photo. Heilprin

XXXIX

THE SHATTERED OBELISK OF PELÉE

Giant blocks of hypersthene-andesite lying near the base of the dome. Photograph taken February 27, 1906.

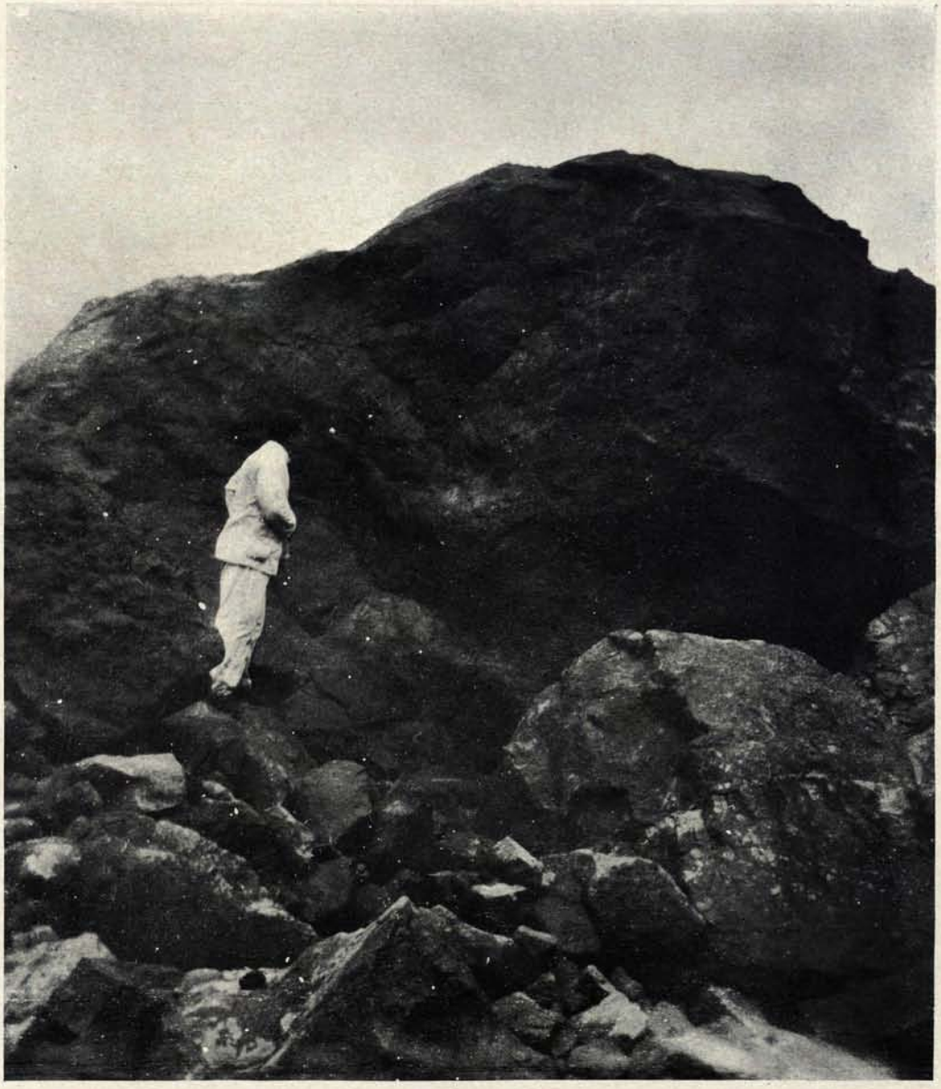
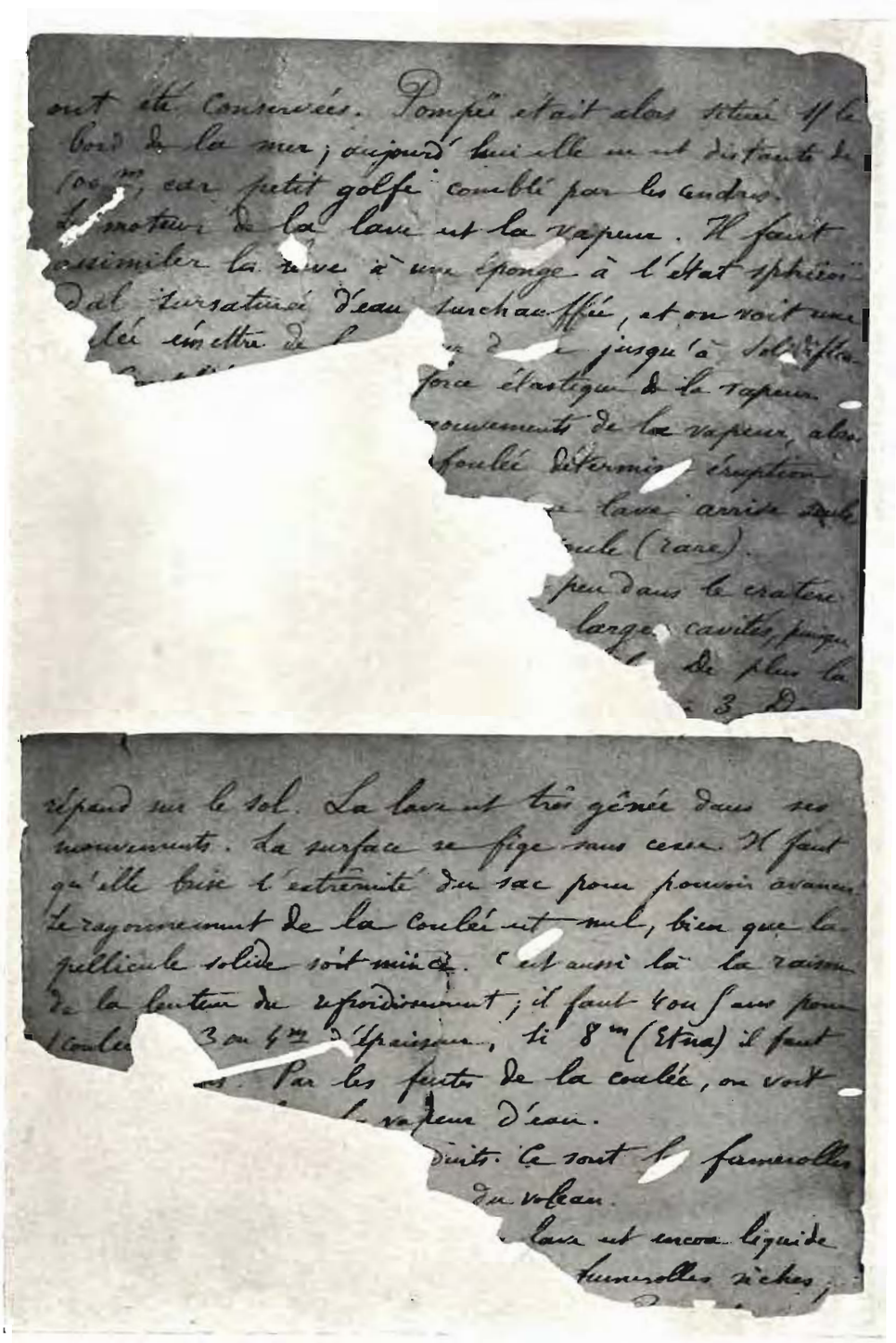


Photo. Heilprin

XL

FRAGMENTS OF MANUSCRIPT FROM THE DÉBRIS OF SAINT-PIERRE

Mention of Pompeii in the first line of the upper figure.



ont été Conservées. Pompéi était alors situé sur le bord de la mer ; aujourd'hui elle en est distante de 700 m, car petit golfe comblé par les cendres.

Le moteur de la lave est la vapeur. Il faut assimiler la roche à une éponge à l'état sphéroïdal saturée d'eau surchauffée, et on voit une coulée s'mettre de l[illegible] jusqu'à sol[illegible] force élastique de la vapeur. [illegible] mouvements de la vapeur, alors [illegible] coulée détermine éruption [illegible] lave arrive [illegible] ule (rare). [illegible] peu dans le cratère [illegible] large cavités, jusqu[illegible] de plus la [illegible] 3 D[illegible]

répand sur le sol. La lave est très gênée dans ses mouvements. La surface se fige sans cesse. Il faut qu'elle brise l'extrémité du sac pour pouvoir avancer. Le rayonnement de la coulée est nul, bien que la pellicule solide soit mince. C'est aussi là la raison de la lenteur de refroidissement ; il faut [illegible] sous pour [illegible] coulée [illegible] 3 ou 4 m d'épaisseur, et 8 m (Etna) il faut [illegible]. Par les fentes de la coulée, on voit [illegible] vapeur d'eau.

[illegible] disent : ce sont les fumerolles [illegible] du volcan.

[illegible] lave est encore liquide [illegible] fumerolles riches [illegible]

Photo. Heilprin

XLI

BRONZE STATUETTE RECOVERED FROM SAINT-PIERRE

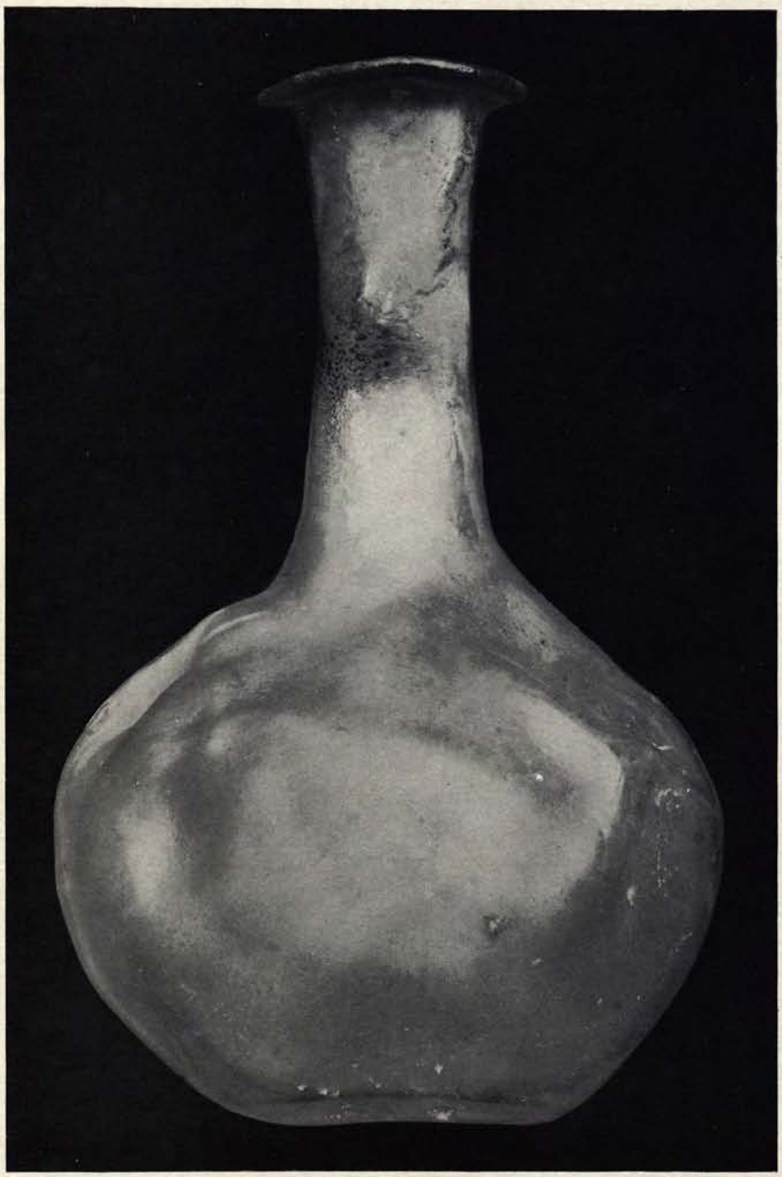
Pitted appearance of the surface due to the inwelding of particles of volcanic ash through the action of heat.

Photo. Heilprin

XLI

XLII

CARAFFE FROM SAINT-PIERRE
exhibiting deformation without breakage.



Expl. Heilprin

XLII

XLIII

DEFORMED WINE-GLASSES FROM SAINT-PIERRE

XLIII

C 16