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ART. XXXIII.—*Observations on the Eruptions of 1902 of La Soufrière, St. Vincent, and Mt. Pelée, Martinique;** by EDMUND OTIS HOVEY.

THE chain of islands bounding the Caribbean Sea on the east, and known as the Leeward and Windward Islands, the Lesser Antilles or the Caribbean Islands, are almost wholly of volcanic origin, the most important exception to this rule being Barbados. From Grenada northward the chain of volcanoes extends in a grand curve for about five hundred miles, with its convex side toward the east, indicating a line of weakness in the earth's crust comparable with those which are outlined by the festoons of volcanoes along the northern and western coasts of the Pacific Ocean. The volcanic nature of these islands has been known ever since they first were explored, but only a few eruptions have been recorded during the past four centuries—the most important being those of La Soufrière on St. Vincent in 1718 and 1812, with Mt. Pelée on Martinique in slight eruption in 1851. Continuous solfataric action, which sometimes has been quite violent, is known in the crater of Mt. Misery on St. Kitts, the "Soufrières" of Guadeloupe and St. Lucia and the Boiling Lake of Dominica. Hot springs have been a feature of several localities on Martinique, St. Vincent and other of the islands.

LA SOUFRIÈRE, ST. VINCENT.

At least as early as April, 1901, earthquakes became more frequent and noticeable than usual in St. Vincent, but, with

* The author was sent to the islands of Martinique and St. Vincent as the representative of the American Museum of Natural History, New York, to study the phenomena connected with the recent eruptions. The article here published is a condensation of the "Preliminary Report" prepared for the Museum authorities and published in the Bulletin of the Museum, vol. xvi, pp. 333–372, pls. xxxiii–li. The author's field work on the islands covered the period from May 21 to July 6, inclusive, and his Report and this article pertain almost solely to the personal observations made during that time.

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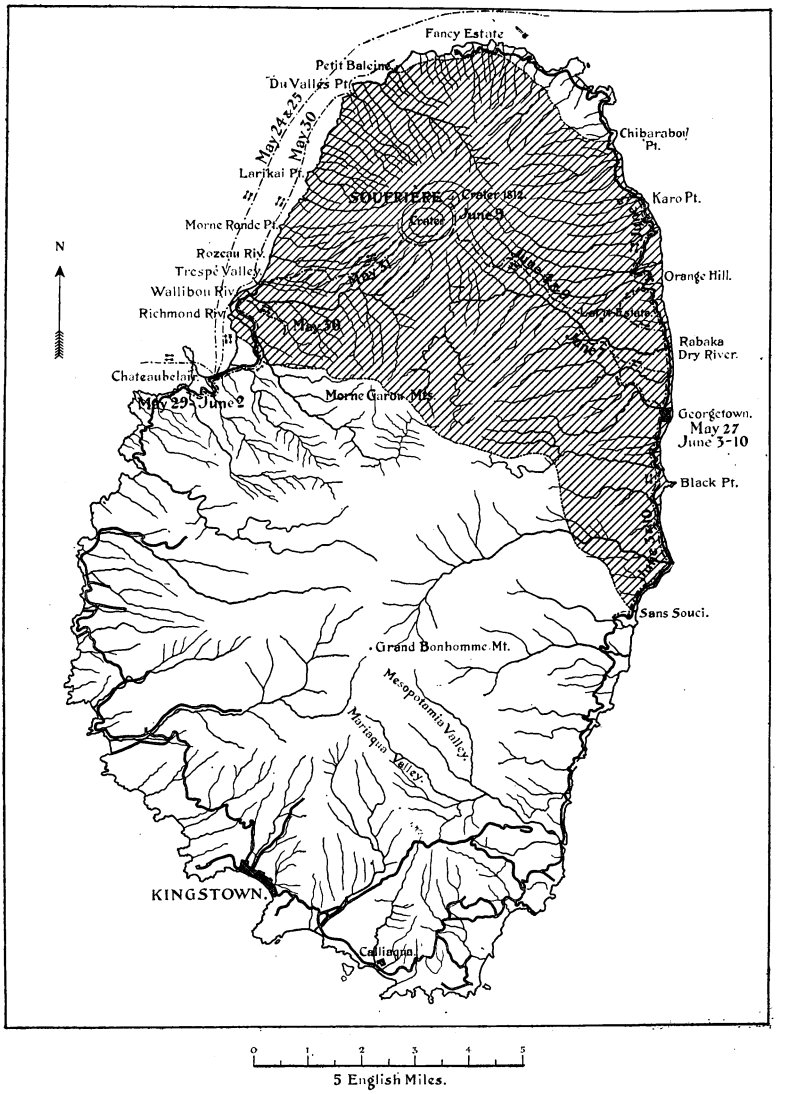

FIG. 1. MAP OF THE ISLAND OF ST. VINCENT, B. W. I.

The cross-lined area shows approximately the portion of the island which was devastated by the May, 1902, eruptions of La Soufrière. The violent outburst of September 3–4 deposited much additional material on the leeward (west) side, and extended the zone of devastation about four miles south of the boundary here indicated for that side of the island. The dot-and-dash lines show the principal routes traversed by the author while on and near the volcano.

the exception of Mr. F. W. Griffith, of Kingstown, no one seems to have connected them with an impending eruption of the Soufrière. In December of that year, however, the people living on the western slopes of the volcano began to feel anxious on account of the subterranean noises heard occasionally. By February, 1902, the rumblings had become so frequent that the inhabitants were very uneasy and began to leave the district, so that but one person was left within the fated area when the great eruption of May 7 occurred. The rumblings were less distinctly heard on the eastern or windward side of the island, and the warnings were not heeded so generally, because it was supposed that the prevailing winds would carry to westward any ejecta from the crater, in case of an eruption. The loss of life was confined to the windward side of St. Vincent.

The first ascent of the Soufrière, since the eruption of May 7, 1902, was made on Saturday, May 31, by Dr. T. A. Jaggar, Jr., George Carroll Curtis, T. MacGregor MacDonald* and myself with six porters. We went up from the site of Wallibou village, on the leeward (west) side, following the remains of the old trail to the rim of the crater at 2790 feet above the sea, an elevation obtained by taking the mean of the readings of three aneroid barometers.† We found the crater unchanged in diameter, as nearly as Mr. MacDonald could tell, and therefore to be about nine-tenths of a mile in diameter from east to west and eight-tenths of a mile from north to south, judging from measurements made on the map. The beautiful crater lake, for which the Soufrière was famous before the eruption, had disappeared of course, but there was a small lake of boiling water in the bottom of the pit, from the southeastern quarter of which steam was ascending in a strong column. See figs. 4 and 5, p. 351.‡ This column at intervals was carrying up quantities of black sand with it to moderate heights above the bottom of the crater. We estimated the surface of the boiling lake to be about 1600 feet below the point on

* Mr. MacDonald is the owner, with his brother, of several estates on the leeward side of St. Vincent. One of these was destroyed in the May eruptions, and three others suffered the loss of their growing crops through the outburst of September 3. Mr. MacDonald had the presence of mind to remain in one of his houses, the Richmond Vale estate, from which there was an uninterrupted view of the upper portion of La Soufrière, and to take notes in detail of what happened on May 7 up to the time of the great eruption which took place at 2 P. M., when he fled for his life. His notes have been published in full in the Kingstown Sentry of May 16, 1902, and in the Century Magazine, vol. lxiv, pp. 638-642, August, 1902.

† All the altitudes recorded in this article were obtained by means of aneroid barometers, except as otherwise stated in the text.

‡ For convenience of printing, the views illustrating this article have been placed together on pp. 351 to 358.

which we were standing, and 2400 feet below the highest point of the rim. The lake seemed to be shallow, judging from some nearly flat ground in the bottom of the crater northeast of the water. The surface of the old crater lake was 1930 feet (chart) above tide. Its depth in the center was 87½ fathoms, according to the statements of P. F. Huggins, engineer, of Kingstown, St. Vincent, who told me that he sounded it in 1896. His line was too short to reach bottom in the northwestern part of the lake.

Almost directly opposite the point where we first reached the rim was the saddle between the "Old" crater and the crater of 1812, apparently unbroken by the eruption. From the lower third of this nearly vertical rock-face there issued a strong stream of water which cascaded down the precipices and flowed across a rather narrow strip of nearly level ground in the bottom of the crater and emptied into the boiling lake. It seemed as if this stream must be the discharge of the waters now collecting in the crater of 1812, itself the possessor of a little lake before the eruption of the present year. The western side of the crater rim showed a gash on its western side, leading into the Larakai Valley, but the bottom of the gash was more than a thousand feet above the bottom of the crater. Mr. MacDonald said that the gash was there before the eruption took place, but that it seemed to him to have increased in size since the outbursts began. The gash is very much smaller than that in the southwest side of Mt. Pelée, and it does not seem to have had any appreciable, or, better, any determinable, effect in concentrating the force of Soufrière's volcanic hurricanes. Tremendous avalanches of rocks and earth descended the inner precipitous slopes of the crater at intervals during our stay on the rim. They made a great deal of noise, and probably occasioned some of the "groaning" of the volcano reported by the islanders.

On June 4 Jaggar, Curtis and I made an attempt at the ascent from the windward side. We reached the altitude of 3200 feet, but turned back without getting to the crater itself, on account of dense trade-wind clouds. On June 9 Curtis and I made our third ascent, alone, except for one guide, and reached the rim of the crater on the southeastern side two or three hundred yards beyond the spot at which we had turned back on the preceding occasion. For fifteen or twenty yards back from the edge of the rim in the ground there were crevices many yards long and up to three inches wide, which formed lenses with the edge itself and indicated the imminence of landslides into the crater. We pushed along the rim northward, until, at an altitude of 3550 feet above the sea, we stood between the large crater and the crater of 1812. The summit

of the Soufrière east of the large crater and south of the small one is formed by a rather small plateau which slopes gently toward the southeast, closely analogous in position to the small high plateau on Mt. Pelée. This plateau was covered with a bed of dust, lapilli and bowlders which was ten and fifteen feet thick in places, and the trenches cut by recent rains made traveling very laborious, except near the edge of the crater.

In spite of clouds and rain, this visit, through occasional glimpses of the interior, enabled me to determine that the crater of 1812, which for nearly a century has gone by the name of the "New" crater, took no active part in the eruptions of May of the present year, a conclusion based on the following considerations: the saddle between the two craters appeared to be intact, confirming the observations made from the other side of the large crater; a knife-edge ridge which ran at a steep incline from the saddle to the bottom of the small crater and formed the pathway for descent into it before the eruption, was still there, and had on its slopes bare trunks of trees standing; in the bottom of the crater along the base of this ridge one could see talus slopes of dry (?) dust and lapilli which had slid and rolled down its sides; although the roaring of the steam and boiling water nearly half a mile below us in the large crater was obtrusively discernible, no sound whatever came from within the crater of 1812; the rim of the small crater showed less and less dust as one receded from the edge of the great crater. Samuel Brown, a ranger, or caretaker, on the Lot 14 estate on the southeast slopes of the Soufrière, who was our guide when we reached the small crater, told us that he watched the eruption of May 7 until the great outburst at two o'clock and that no cloud of steam or "smoke" rose from the small crater. Furthermore, at the time of my leaving the island, June 10, no column of steam had risen above that crater since May 7. Brown was at the sugar factory of the estate, three and one-half miles in a straight line east-southeast from the crater, a most favorable spot from which to observe what was going on at the summit of the mountain, and he saved his life by running into the rum cellar of the factory and closing the door and the window shutters just before the volcanic blast swept over the building. Inquiry in Georgetown found persons who had watched the eruption from the town and had noted the fact that no column of steam rose from the small crater.

The Soufrière, and, in fact, the whole of the island of St. Vincent, is made up of ancient lava flows alternating with volcanic fragmental deposits or tuff agglomerates.* These ancient

* The alternation of lava beds and tuffs is well illustrated in fig. 5, p. 351.

agglomerates show that there have been many eruptions of the volcanoes of St. Vincent of the same character as that of 1902. They contain bombs as well as blocks. The beds of solid rock on the island show that many of the ancient eruptions were accompanied by extensive flows of molten lava. The porous agglomerates have suffered much from the decomposing action of percolating waters, and the lava beds show extensive alteration due to the same agency. Beautiful spheroidal weathering is common in the basalts of the southeastern part of the island and in the elevated beach conglomerates of the windward coast.

Although there are many ancient lava beds in the composition of the mountain, no *stream* of melted lava has issued from the Soufrière during the present eruption. The "bread-crust" bombs, however, which occur plentifully on the mountain sides, especially on the windward slopes, show that during the present eruption molten lava has been present in the throat of the volcano, and that many lumps of half-melted rock were thrown into the air. Besides the bombs, the volcano ejected blocks of ancient andesitic lava of several kinds and of varying degrees of coarseness of grain, and of all sizes up to masses six or eight feet across, and vast quantities of coarse and fine lapilli and dust. Most, if not all, of the blocks were thrown out at very high temperatures, as is shown by their cracked condition, though they were not actually fused. Although a few bombs, some of which were twelve to fifteen inches across, were found on the leeward side as far away from the crater as the site of Richmond village, three and one-half miles distant, by far the largest number of both bombs and blocks, as well as the largest specimens, were found on the windward side, bombs fifteen to eighteen inches in diameter being common in the bed of the Rabaka Dry River.

The area of devastation on St. Vincent is very large in proportion to the total area of the island. After plotting it out carefully on the British Admiralty chart and measuring the area with a planimeter, I find it to be forty-six square miles, practically one-third the entire area of the island. From much of this devastated area, however, the ashes are being washed off so rapidly by the rain that vegetation is already asserting itself, and within another year crops will be growing there again.*

Extensive landslides have taken place on the western side (see Plate VIII), removing a strip of coast, in places one

* Newspaper reports and private advices from St. Vincent show that the area of devastation has been extended on the leeward side of the island by the tremendous eruption of September 3–4 about four miles south of the boundary indicated on the map herewith presented (fig. 1), while the whole western portion of the devastated area got a heavy additional coat of lapilli. The windward side did not suffer materially from this eruption.

hundred yards wide, continuously from the mouth of the Wallibou River to Morne Ronde village, a mile and a half to the north, and at intervals for two miles farther north. These landslides have left precipitous walls along the shore-line, and deep water is found where villages stood and prosperous plantations existed before the eruption. We had no sounding line, but our boatmen could not touch bottom with a twelve-foot oar three feet from shore on the site of Morne Ronde village. The sections left by the slides show that the land which has disappeared consisted of delta and coast-plain deposits, material which would easily be shaken from the more substantial lava flows and agglomerate beds by the vibrations due to the eruptions. The eastern, or windward, side of the island is not nearly as steep as the leeward, and landslides have not occurred there as features of this eruption. On the contrary, the windward shore-line from Black Point, a mile south of Georgetown, northward almost to Chibarabou Point, more than six miles distant, has been pushed out by the vast quantities of fresh lapilli which have been brought down from the slopes of the volcano by the rivers and the heavy rains, during and since the eruptions, and distributed by the ocean currents.

A large amount of material, too, was brought down by the Rabaka Dry River an hour in advance of the great outburst of May 7, which seems to have been due to the bodily discharge of a portion, at least, of the old crater lake into the headwaters of that stream. Survivors who attempted to cross the Rabaka Dry River toward noon of that day report that they were prevented by a torrent of "boiling hot" water and mud rushing down the valley, and that a wall of water and mud fifty or more feet high (they compared it with the height of a factory chimney) came out of the upper reaches of the river and swept out to sea. There was no heavy rain that day before the eruption took place, but the lake still was in the crater early in the day, according to the tale of a fish-woman who had ascended the mountain from Georgetown that morning on her way home to Chateaubelair. The trail led along the rim of the crater for half a mile. The woman reached the rim at nine o'clock and found that fissures had appeared in the ground and that the lake was at a higher level than usual and boiling. She rushed back to Georgetown to warn the people, but her tale was discredited. Mr. MacDonald's notes contain the entries: "12.55 P. M. Enormous discharge to windward side, color darker. 1 P. M. Tremendous roaring, stones thrown out to windward thousands of feet."* While this does not *prove* the bodily outthrow of the lake, it shows that there was

* Century Magazine, vol. lxiv, p. 630, August, 1902.

a great outburst from the crater just in advance of the flood in the Dry River Valley.

It is evident that there was a blast or a series of blasts of hurricane violence from the crater of the Soufrière as well as from that of Mt. Pelée, as a feature of the eruptions of 1902. The effects were not so appalling, however, on St. Vincent as on Martinique, because no large city was destroyed there. The overturned trees constitute the principal evidence on the island of St. Vincent. They all point away from the crater, except for slight modifications due to local topography (see fig. 10). The blast extended radially in all directions from the crater, suggesting the explanation that some great volume of steam, rising from the throat of the volcano, could not find room for expansion upward, on account of the column of steam and ashes which had preceded it, and the ashes falling therefrom, and that it expanded with explosive violence horizontally and downward, following the configuration of the mountain. This accords with the testimony of Mr. MacDonald and other eye-witnesses of the eruptions, who say that they saw the clouds of "smoke" (dust-laden steam) rushing down the sides of the mountain with terrific speed. This dust-laden steam was able to do much work of erosion, as is shown by the horizontally scoured sides of some of the exposed cliffs and by the trunks and roots of trees. The roots particularly have been charred by the heat and have been carved into fantastic, pointed shapes, as if they had been subjected to the action of a powerful sand-blast. Erosion has not materially affected the original surface of the ground as yet, because almost everywhere one can find the living roots and charred blades of grass and other vegetation beneath the covering of dust and lapilli, the first of which acted as a protection against the heat of the rest. Now, however, the heavy rains take up vast quantities of the loose lapilli for use as a powerful scouring agent in attacking the denuded hillsides, and thus old valleys are being deepened and widened.

The particular feature of the May eruptions of the Soufrière was the enormous amount of dust* which was thrown into the air and distributed over a vast circle or ellipse the area of which cannot yet be calculated for lack of data. The British steamship Coya had an eighth of an inch of volcanic dust

*The following chemical analysis is of dust from the May eruptions which I collected May 27 in a room in the Langley Park estate house, about one mile north of Georgetown, St. Vincent, in which twenty-one dead bodies were found after the eruption of May 7. The analysis was made by Dr. W. F. Hillebrand of the United States Geological Survey, to whom my acknowledgments are due, and is the unpublished analysis referred to in his article in the National Geographic Magazine for July (vol. xiii, p. 297) as emphasizing the greater amount of sulphur present in the ejecta of La Soufrière

from this volcano fall on her deck when she was two hundred and seventy-five miles east-southeast of St. Vincent. The steamer encountered the dust at 10.30 P. M., May 7, eight and one-half hours after the eruption of the Soufrière began, indicating transport against the prevailing surface wind at more than thirty-two knots per hour. Reports of vessels from the west (leeward) of the island are curiously lacking. The dust was spread like a gray mantle over the island, generally diminishing in thickness from the crater outwards, but collected in vast deposits in certain valleys on the sides of the mountain, where the conditions seem to have been particularly favorable. The chief of these beds were formed in the Wallibou, Trespé and Rozeau valleys on the leeward side, and in the valleys of the Rabaka Dry River and its tributaries on the windward slope, with by far the greatest thickness along the Wallibou and Rabaka Dry Rivers. In the valley of the Wallibou the deposits were not less than sixty feet deep in places, while in the Rabaka Dry River the fresh material filled a gorge which is said to have been two hundred feet deep before the eruptions began (see fig. 9). From a distance this deposit looks as if it were a glacier coming out of the mountains.

Such great accumulations of hot lapilli and dust retain their heat for a long time and they have given rise to secondary, or superficial, eruption phenomena of striking character and considerable interest. The river water and the water from the

than in those of Mt. Pelée. The absence of chlorine is interesting as indicating fresh waters as the source of the steam of the eruptions.

SiO_2	55·08	
Al_2O_3	18·00	
Fe_2O_3	2·46	(Only approximate, because of effect of pyrrhotite, 0·91 %—see below.)
FeO	4·57	
MgO	3·34	
CaO	7·74	
Na_2O	3·45	
K_2O	0·65	
H_2O at 100° C.	0·66	
H_2O above 100° C.	1·39	
TiO_2	0·80	
ZrO_2	?	
CO_2	none	
P_2O_5	0·17	
SO_3	0·24	
Cl	none or faint trace	
S	(0·36)	included in pyrrhotite below
NiO	none	
MnO	0·21	
BaO	trace	
SrO	none	
Li_2O	faint trace	
Fe_7S_8 (?)	0·91	
	99·67	

tropical showers percolating through the beds have come into contact with the still highly heated interior, causing violent outbursts of dust-laden steam. We saw one of these outbursts from the Wallibou Valley send up a column of such vapor fully a mile in height. The action lasted for nearly an hour. The secondary eruptions illustrated by figures 7 and 8 took place on a clear, dry morning and must have been caused by the percolating river waters. On May 30 we witnessed the throwing of a dam across the stream and the formation of a temporary lake by a heavy secondary outburst of dust-laden steam from the lapilli-bed in the Wallibou Valley. This eruption is illustrated in fig. 7. After the eruption ceased the little lake soon rose to the top of the dam and quickly cut its way down to the old level, sending a "mud-flow" down the gorge to the sea. Such a lake in the valley of the Rabaka Dry River cut its new outlet through a narrow ridge of the old agglomerate constituting the wall of the canyon, forming as it did so a beautiful series of channel-bowls, pot-holes and scratched corkscrew channels.

When we first reached St. Vincent, the dust, especially that covering the Richmond estate, showed in marked manner the wind-drift surface so familiar in the case of freshly-fallen snow, and in many places these drifts were from three to four feet deep (see fig. 6). There were several heavy rains between May 24 and 29, so that the appearance of the surface was very different on May 30 from what it was when I first saw it. Its drifted character was not nearly as evident, and the beautiful dendritic drainage, which was already in evidence on May 24, had been greatly extended and intensified. Geological operations, which under ordinary conditions are performed so slowly as to be imperceptible, were being carried forward rapidly under our very eyes. One item of interest was the action of the Wallibou River itself under the influence of the loose dust and lapilli along its banks.* Its waters became so overloaded with sediment that they could only flow in pulsations, showing that intervals of time were needed by the stream to gather strength to force its way along with its load. On May 24 these waves or pulsations were from fifteen to forty seconds apart. Such mud streams carried large bowlders down the river bed to the sea.

When the great cloud of ejecta rose from the Soufrière at 2 P. M., May 7, the portion which was traveling eastward seemed suddenly to split, according to the accounts of eye-witnesses, when it was some distance beyond the island, and to send a part back to the land. This accounts for the fact that unprotected windows in the eastern side of houses in the

* First described by the author in the New York Times, June 29, 1902.

devastated district along the windward coast were all stripped of their glass.

An official's estimate of the loss of life on St. Vincent by the eruption places the number of killed at 1350. The actual number of bodies buried was 1298, including those of the wounded who died in the hospitals. Almost all of the people who passed through the fury of the eruption and escaped uninjured had taken refuge in cellars the only openings into which were on the side farthest from the crater and were, moreover, tightly closed with wooden doors or shutters. The most striking example of such protection was at Orange Hill, on the windward coast, two and one-half miles north of Georgetown, where one hundred and thirty-two persons were saved unharmed in an empty rum cellar. This cellar, which is only partly underground, is part of a sugar factory situated on a rather flat divide between two ravines which may have tended to separate the volcanic storm somewhat, though the roof of the building over the cellar was demolished by the ejecta. The only openings into the cellar were a door and two windows on the side opposite the crater, and these were provided with heavy wooden shutters which were kept closed during the fury of the eruption. The experiences of the people in these cellars suggest the great desirability of constructing similar places of refuge for use in time of hurricane as well as of volcanic eruption.

The deaths on St. Vincent seem to have been due, principally, to the following causes: (1) asphyxiation by hot, dust-laden steam and air, (2) burns due to hot stones, lapilli and dust, (3) blows by falling stones, (4) nervous shock, (5) burning by steam alone, and (6) strokes of lightning. The last mentioned cause is perhaps somewhat doubtful, for though it is very generally named by the survivors, there has been no substantiation mentioned beyond the fact that there was a great deal of extremely vivid lightning during the eruption. The action of steam would account for burns received underneath the clothing where the clothing was not even charred. Sulphur dioxide, SO_2, and hydrogen sulphide, H_2S, were observed in troublesome quantities in the steam coming from the crater, and it is more than probable that these gases, especially the former, added very materially to the deadly character of the dust-laden steam. Not an autopsy was made on any of the hundreds of victims of the catastrophe, so that it never can be known definitely what part was played by these or other poisonous gases in the destruction of human life.

Under date of September 5, Wm. J. Durrant, druggist, of Kingstown, St. Vincent, writes me that great volumes of

"smoke" and steam began rising from La Soufrière at 1 P. M. of September 3, but that the violent outburst did not begin until 9.30 that night. Three hours later the eruption was at its height and the last explosion occurred at 5.40 A. M. The roaring of the volcano from midnight onward was continuous and was terrifying even at Kingstown, while the electric display about the great column of dust-laden steam surpassed those of May 7 and 18. The matter ejected by this last eruption is described by Mr. Durrant as being "a heavy, black sand* of the coarseness of blasting powder, with plenty of pumice, but very few stones." Very little light-gray ash like that of the May eruptions fell this time. Richmond Vale estate received about eight inches of ash, Chateaubelair about six inches, Petit Bordel about four inches. Southward the coat of ash diminished to Peter's Hope, an estate on the west coast about ten miles southwest of the crater, where it ceased to be of importance. The beginning of this eruption was a mud-flow toward the site of Morne Ronde village.

Under date of September 26 Mr. T. MacGregor MacDonald writes me that three men, two brothers and a cousin by the name of Richards, visited the summit of La Soufrière August 19. From their accounts it was evident that relations within the crater had not changed materially from what we found on May 31. On September 17 Messrs. J. Adams and W. Cummings made the ascent to see what changes had been wrought by the tremendous eruption of September 3–4. They reported that the crater was filled up to about the level of the surface

* A sample of the material thrown out by the eruption of the Soufrière September 3 was received from Mr. Durrant September 25 and has been examined under a hand-lens. It consists of fine and coarse volcanic sand and gravel, apparently for the most part comminuted ancient lavas of the volcano. The fragments from 3 to 15 millimeters across show the coarsely crystalline structure of the old lavas and many of them show that they are parts of weathered masses. Olivine, pyrite (pyrrhotite ?) and porphyritic crystals of feldspar, hypersthene and hornblende are abundant in these fragments and the separated minerals make up a large proportion of the particles about 2 millimeters in diameter. A comparatively large fragment (20^{mm} in diameter) shows phenocrysts of feldspar imbedded in dark brown and light brown scoriaceous glass which is apparently fresh. All the fragments and the particles of sand are coated with dust which seems to be as fine as any that fell during the May eruptions, so that the explanation of Mr. Durrant's statement regarding the relative absence of fine dust from the ejecta of September 3–4 may be that the wind carried most of such material northward and westward away from Kingstown, his point of observation. The cloud from this eruption of La Soufrière is reported to have produced darkness for about six hours on September 4 in Fort de France, Martinique.

The dust-coated sand is dark gray when dry, but is almost black when wet, justifying the description quoted from Mr. Durrant's letter. Comparison of this new material, however, with that collected by myself, May 23–June 10, indicates that there is no essential difference between the ejecta of the earlier and the later eruptions.

of the old lake (the one existing prior to May 7) with ash, and that there was a sloping surface from all sides down towards a depression in the middle. The slope was such that from almost any point they could have descended to the bottom. Steam was rising from several points, the most vigorous being from the spot most active on May 31. Around the central opening there was mud, and from the opening "fire" was being thrown up every two or three minutes, which fell back again, giving place to steam. There was an eruption during the night of September 17, and Mr. Cummings made another ascent on the 19th, when he found the crater cleared of ashes to the depth observed May 31 and with a small amount of water in the bottom, from and through which steam and "fire" were rising. The "fire" mentioned by Mr. Cummings must have been red-hot fragments of rock. A short violent outburst occurred about 6 P. M. September 21, lasting about ten minutes in its most vigorous stages.

La Montagne Pelée, Martinique.

The destruction of human life overshadows every other consideration, in popular estimation, at least, when one speaks of the eruption of Mt. Pelée, Martinique, which took place May 8, 1902. The sweeping of between twenty-five and thirty thousand human beings out of existence almost in a moment presents a holocaust with but few parallels in the history of the world. The present eruptions of Pelée and the Soufrière will not, however, take first rank among those which have torn these and other Caribbean volcanoes, but they are extensive enough and are of such a character as to merit the study they have been and are receiving.

Mt. Pelée, like La Soufrière, gave warnings of the approaching catastrophe, but they were not heeded by the inhabitants of Martinique. The waters of the Lac des Palmistes became very noticeably warmer than usual several months before the eruption took place; rumblings were heard and steam began to issue from the old crater some weeks before dangerous activity began; a fortnight before the first great eruption took place the earthshocks were sufficiently strong to displace dishes on the shelves of the house of Mr. Prentiss, the American Consul in St. Pierre. The volcano became so threatening that some uneasiness was felt by the people dwelling on the slopes of the mountain, but the citizens generally were so deeply interested in a political contest in which race prejudice was playing an important and bitter part, that they paid little attention to the returning activity of the dangerous mountain on and near which they lived, until it was too late for them to escape with their lives.

The area of devastation caused by the eruptions of Pelée from May to July inclusive was less than that due to that of La Soufrière (compare maps, fig. 1, p. 320, and fig. 2, below.

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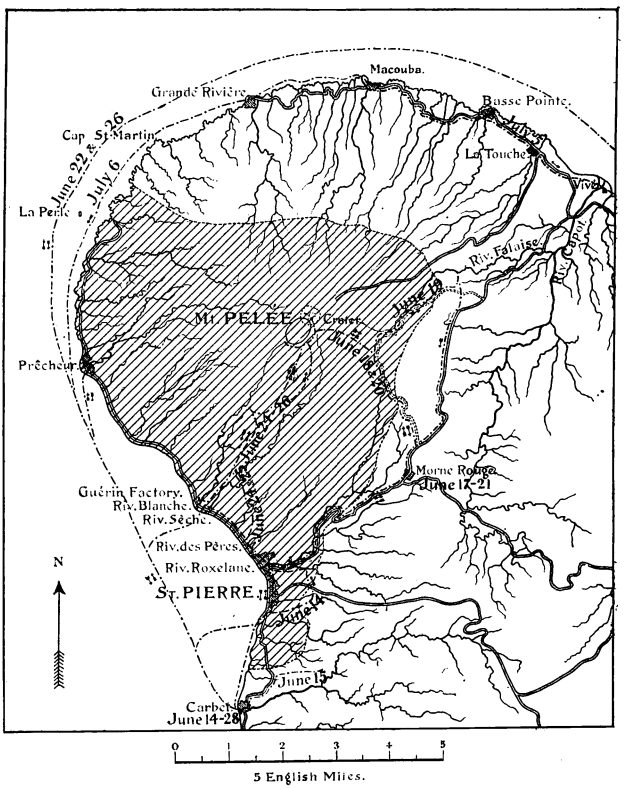


FIG. 2. MAP OF THE NORTHWESTERN PART OF THE ISLAND OF MARTINIQUE, F. W. I.

The cross-lined area shows approximately the portion of the island devastated by the eruptions of Mt. Pelée, from May 5 to July 6, 1902. The tremendous outbursts of August 25, 28 and 30 and September 3 extended the ruin greatly on the north, east and southeast sides of this area, so that nearly all of the region represented here, with the exception of a few square miles in the southeastern corner, now is included within the zone of destruction. The dot-and-dash lines indicate the principal routes traversed by the author while on and near the volcano.

Plotting the area on the Admiralty chart as well as possible, after inspecting all sides of the volcano, and measuring it with a planimeter, I find that thirty-two square miles of Martinique were laid waste by dust, lapilli, stones and "mud." The area is not as symmetrically disposed about the crater as is the case

on St. Vincent, probably because the crater of Pelée is so much lower on the southwest than on the other sides and the great gash opening into the gorge of the Rivière Blanche, together with the configuration of the neighboring "mornes," or ridges, has given direction to all the violent explosions which have occurred. Although the whole island has received débris from some of the outbursts and dust has been scattered over a wide area, the district over which the vegetation was killed, at least temporarily, is included within a line beginning at the sea coast, about midway between St. Pierre and Carbet, though the palm trees along the coast at the base of the bluffs were scorched as far as Carbet Point itself. Passing inland about a mile, the line curves sharply to the north and east of north to the Roxelane River, then goes northeastward along this river and one of its tributaries, paralleling the main street of Morne Rouge within a quarter of a mile, swings then to the east of La Calebasse and rises somewhat on the northeastern flanks of Pelée, apparently passing along the south side of Pain de Sucre and then northwestward, leaving the island midway between La Perle Rock and Cap St. Martin. Much of this area is already springing into verdure again; the grass was already very noticeable on the hill slopes encircling St. Pierre by July 1, and green vegetation was to be seen even nearer the source of destruction. When I first arrived at Martinique (May 21) the line between the scorched and unscorched areas was strikingly sharp, and was still very noticeable six or seven weeks later. In many places the line of demarkation passed through single trees, leaving one side scorched and brown, while the other side remained as green as if no eruption had occurred.*

The material ejected by Pelée during this series of eruptions consists of dust in vast quantities,† fine and coarse lapilli, breadcrust bombs (see fig. 3) of all sizes from one inch to three feet and more across, and blocks of small and great size, the cracked condition of which shows that they have been highly heated. The freshly fallen ashes had a curious resemblance to snow, which gave a peculiar Alpine aspect to the

* The tremendous eruptions of August 25, 28 and 30 and September 3 have extended the devastated area greatly on the northeast, east and southeast sides of the area of destruction indicated on the accompanying map. It now extends as far as Carbet, and includes Morne Rouge, but the reports thus far received do not clearly show whether it reaches quite to the coast on the north and northeast or not. The eruption of Mt. Pelée now must nearly if not quite equal that of La Soufrière in magnitude.

† One hundred and twenty tons of dust and lapilli were removed from the decks of the Roddam after her arrival in the harbor of Castries, St. Lucia, according to the personal statement of one of the agents of the line to which the steamer belonged.

mountain, and is noticeable in some of the photographs. No *stream* of molten lava has issued yet from the volcano as a feature of this eruption, though such flows were common in the early history of Pelée, as they were in that of St. Vincent's Soufrière. The bread-crust bombs prove, however, that much lava has been thrown out in the condition of half-melted

3

FIGURE 3.—"BREADCRUST" BOMB FROM MT. PELÉE.

Collected on the Sèche-Blanche plateau, three miles from the crater. The specimen is two feet two inches high.

masses. These bombs usually are more or less pumiceous in texture, and they show the "bread-crust" surface much more distinctly than do the more basic bombs of the Soufrière. The largest of the bombs observed was one fifteen feet long on the southeast slope of Morne Lacroix at an elevation of 3950 feet above the sea. The largest ejected block that we saw was one on the surface of the mud-flow between the rivers

Blanche and Sèche and not more than two hundred yards from the sea coast. Its dimensions are about 22 feet high, 30 feet long and 24 feet broad (see fig. 16), and it is of the light-gray andesitic lava forming one of the ancient lava beds near the summit of the mountain. When I inspected this block on June 25, I found it too hot on the surface to bear the hand upon it long at a time; the great mass was cracked in several directions, and steam and sulphurous gases were emanating from the cracks. It seems certain that this enormous block was thrown out of the crater in a highly heated condition during the present eruption, but it may have reached the place where it now is partly through the agency of the great mud-flow on which it rests. Many other great bowlders, some of which are of nearly half the dimensions of the one just described, lie near by on this mud plain.

The area of distribution of the ejecta cannot be designated accurately yet for lack of data. The U. S. collier Leonidas received a quarter of an inch of dust on her deck from the great outburst of June 6 when she was 102 miles west of Martinique. It took the ship from 3 P. M. until nearly 6 o'clock to traverse the cloud of dust. This eruption began at 10.15 A. M. and was one of the heaviest of the whole series. I was in Georgetown, St. Vincent, at the time and felt the shock distinctly. From 3 o'clock onward that afternoon until after sunset heavy clouds of dust from the Pelée eruption passed over St. Vincent, much of it falling upon the island. The top of the cloud of dust as it passed over the mountains seemed to me to be about 6000 feet above the sea, so that the last deposits must have been made far south of St. Vincent. Kingstown is about 110 miles south of Mt. Pelée. The shocks or detonations from some if not all of the great outbursts were felt in St. Kitts and Trinidad, though not in some of the intervening islands.

Two illustrations of the force with which the bombs and blocks strike may be permitted here. On the sea coast near the Fort Villaret church in the portion of St. Pierre north of the Roxelane River there was a large distillery in which there were four big storage tanks constructed of quarter-inch boiler iron plates riveted together. These tanks look as if they had been through a bombardment by artillery, being full of irregular holes which vary in size from mere cracks at the bottom of indentations to great rents 24, 30 and even 36 inches across, while a strip several feet long was torn off from each of two. The direction of impact was essentially the same in all instances, namely, from the crater. The other illustration is found on the southeastern flanks of Mt. Pelée, along the trail leading from

Morne Rouge to the summit, where numerous spoon-shaped depressions occur in the rather loose soil of the mountain side, especially between the elevations of 2400 and 3000 feet above tide. These holes are of all sizes from 2 feet in diameter upward, the largest one which I saw being 40 feet long, 25 feet wide and 5 feet deep, but the depth had evidently been reduced by the sand which had been washed into it by recent rains. The longer axis of this depression was N. 50° W., pointing directly at the crater, and the longer axes of all the other holes observed were pointing toward the same center. The deepest part was on the up-hill side. On the down-hill side of each depression was found the cause of the phenomenon, and it was a bomb or ejected block from the volcano, which had struck the ground with a splash, throwing the earth in all directions and usually bounding or rolling out of the hole which it had made. Sometimes the blocks which did the work were found intact, but more frequently they had burst asunder after striking. All showed that they had come out of the volcano in a highly heated condition. Such splashes as these can be made experimentally on a small scale in any bed of stiff mud by means of well-directed stones.

Many stones must have fallen in St. Pierre, but they are so mingled with the rubble stones from the walls of the ruined buildings that usually they are not easily distinguishable therefrom. Great quantities of small, rounded fragments of yellow pumice are to be found now amid the ruins, the fine gray dust having been washed away to a considerable extent by the copious rains which have fallen since the great eruptions. Most of the pebbles of pumice were less than three inches in diameter. They are evidently from the old tuff agglomerate and must have been torn from the beds through which the volcanic vents pass and from the interior of the old cone. Stones fell all over the island in some of the eruptions.

Four ascents of Mt. Pelée, in the course of which the crater rim was traversed from the great chasm on the southwest along the southern and eastern edge more than two-thirds of the way around the circle, and the remainder also of the rim was clearly seen, enabled Curtis and me to form a reasonably definite idea of the center of activity and what was going on therein. Twice we followed the trail from Morne Rouge to the summit, which led us for a considerable distance along the right (southern) brink of the canyon of the Falaise River, and on the day intervening between these ascents we examined the gorge of the Falaise carefully from the point where the Morne Rouge trail to the summit strikes it nearly to its junction with the Capot River, a mile or more beyond the area of devastation. The upper reaches of the gorge certainly present the scene of deso-

lation so graphically described by George Kennan,* but the "Falaise crater" mentioned by him and by Professor Heilprin† and indicated on Hill's map‡ can hardly be a true crater. We saw the same accumulations of volcanic ash in the gorge at an elevation of 1800 to 2000 feet above the sea (aneroid reading) that Heilprin and Kennan mention as forming a crater from which mud-flows were hurled down the gorge to the sea, and we saw steam issuing from them, but to us who had studied the phenomena on St. Vincent it seemed perfectly evident that the outbursts in the gorge of the Falaise were comparatively feeble examples of secondary or superficial eruptions of the same character as those which took place on such a grand scale from the ash-beds of the Wallibou and Rabaka Dry Rivers. This was the history of events in the Falaise and probably at Basse Pointe, Macouba, Grande Rivière and other places; and it was the history of some, but not all, of the mud-flows in the Prêcheur, the Mare, the Blanche, the Sèche and the Des Pères Rivers. Since the eruptions began there have been great floods in the Roxelane River, but it seems doubtful whether or not this stream has carried any true mud-flows down its gorge.

The actual crater is apparently somewhat oval in shape, with its longer axis stretching northeast and southwest. The highest point of the rim is on the northeast side and is what is left of the peak known as Morne Lacroix. By taking the average between the readings of our two barometers, we determined its altitude to be 4200 feet above the sea.§ It consists of ancient andesitic lava. Almost directly opposite this is the lowest point of the crater, where the great gash formed by the gorge of the Rivière Blanche occurs. The bed of andesite forming what may be considered the rim of the crater on the southeast side of the gash is 3350 feet above the tide, while the real bottom of the gorge where it issues from the crater is five or six hundred feet less in altitude. From this lava bed the rim rises rapidly (30° to 35°) to about 3750 feet above tide (see fig. 13), and then more gradually along the southern edge until 3950 feet is reached on the eastern edge. The northwest side of the southwestern gash is formed by a pinnacle of ancient lava which appears to be about 4000 feet above the sea, but may be higher. From this point the rim drops somewhat toward the north, but gradually rises again toward the east

* The Outlook, vol. lxxi, pp. 773, 774, 26 July, 1902.

† McClure's Magazine, vol. xix, p. 363, August, 1902.

‡ National Geographic Magazine, vol. xiii, p. 260, July, 1902.

§ The French engineers located at Martinique are reported to have determined (by triangulation?) that Morne Lacroix had lost 150 feet during the eruption, making its present altitude 4273 feet above tide.

until the point of rock on the northeast, already mentioned, is reached again. This great crater is about half a mile across, an estimate that is based upon the proportion which it bears to the height of the mountain, looked at from the sea, and from the fact that it took us twenty minutes to walk along the southern third of the rim from our first cairn to the Rivière Blanche gorge without stopping. The walking was not bad, considering the location of the route, and I should estimate the distance traveled in this time at not less than half a mile.

The breadth of the rim varies from a mere knife-edge on the south, north and northeast sides to a sloping plateau fifty to one hundred yards wide on the eastern side. This plateau is the site of the Lac des Palmistes, which was considered to be the old crater lake of Mt. Pelée. Studying this plateau carefully, we saw that it sloped gently southward and eastward from one side of a low divide running northeastward from Morne Lacroix across to a high ridge which paralleled the northern and northeastern sides of the crater. On the northwest side of this divide, the altitude of which was 3950 feet above tide, there is a shallow valley which rapidly changes into a gorge discharging into the canyon of the Prêcheur River. Heilprin's description* and his unpublished photographs show the existence on the plateau of a small lake-basin not more than five or six feet deep. He and his companion, E. E. Leadbeater, a New York photographer, state, furthermore, that this plateau and this portion of the crater rim were entirely or practically free from ash and dust deposit. When Curtis and I visited the spot, June 18 and 20, the surface was coated with a thick layer (more than four feet deep in places) of dust and ashes, probably from the great eruption of June 6. This materal had drifted into depressions to such an extent that we saw no indication of the existence of a lake-basin in this plateau. We had a perfectly clear and cloudless period when on the spot, and saw the topography with distinctness. I cannot think that the plateau, including the lake basin, ever has been a primary crater or center of eruption, though at the time of my visits the ground was hot, a scalding temperature being reached less than a foot from the surface, and steam was issuing from numerous crevices. This was the site of the Lac des Palmistes, but that lake was not located in the great ancient crater of Mt. Pelée.†

* Op. cit., p. 360.

† The photograph of the Lac des Palmistes published by Dr. Emil Deckert on page 425 of the Zeitschrift der Gesellchaft für Erd-kunde zu Berlin for 1902 shows that body of water as it appeared in the rainy season of 1898. Deckert describes the lake as being but 2 meters deep and as lying in the middle of a morass or swamp upon a bed of lava. He regards this as a crater lake, though he mentions the fact that there is not and probably never could have been any crater wall on the east and north [south] sides. The

Judging from the account of the guide Romain,* from the "Notes relating to the history of the eruption of 1902," as translated in the Century Magazine† from the issue of Les Colonies for May 7, from the description by Lafcadio Hearn‡ and from my own observations while on and near the mountain, the Étang Sec was the real crater lake of Mt. Pelée corresponding, though dry since the eruption of 1851, to the crater lakes of La Soufrière, on St. Vincent, Mt. Misery, on St. Kitts, and others. Its basin is said to have contained water until the eruption of 1851 drained it. The Étang Sec is stated to have been 700 meters (2300 feet) above the sea; its plain was estimated to be about 300 meters (986 feet) across, and the great circle surrounding it was judged to be about 800 meters (2628 feet) in diameter at top. This last estimate agrees closely with my estimate of the diameter of the present crater at top. The walls of the ancient crater must have risen almost precipitously from 1600 to 2100 feet above the Étang Sec, except on the southwest, where was located the great gorge through which flowed the waters of the Rivière Blanche, the sources of which were in the eastern side of the ancient crater.§ Before the eruption which began last April, the crater of Pelée, except for the size of the great gash, must have been very much like the crater of St. Vincent's Soufrière and that of Mt. Misery, St. Kitts, as I saw it July 8 on my way home, and probably those of the other volcanic cones of the Lesser Antilles.

The whole interior of the crater was not seen entirely free from steam at any one time, but enough was observed to determine its character in its eastern, southern and western portions and to infer the shape of the remainder. The crater, like that of the Soufrière, is in the top of a broad, truncated

eastern end of the "Somma" ring of Pelée bounds the little plateau on the north, but there is no cliff to the south; on the contrary, the plateau slopes off to the south into the head ravines of the Falaise River. It seems as if Deckert must have gotten his north and south points interchanged in his description. The two small craters of 1851 mentioned by Deckert (loc. cit., p. 426) are covered now, probably, by the inner cone, while the series of little craters in the gorge below those of 1851 must have become covered by the débris from the same cone, or have had the evidences of their existence destroyed by the tornadic blasts of the present eruption.

* The Century Magazine, vol. lxiv, p. 623, August, 1902. Translation from Les Colonies of May 5.

† The Century Magazine, vol. lxiv, p. 631, August, 1902.

‡ "Through a cloud-rift we can see another crater-lake twelve hundred feet below, said to be five times larger than the Étang we have just left [the Lac des Palmistes, near the summit]; it is also of more irregular outline. . . . . It occupies a more ancient crater and is very rarely visited: the path leading to it is difficult and dangerous,—a natural ladder of roots and lianas over a series of precipices."—Two Years in the French West Indies, by Lafcadio Hearn, p. 288.

§ See Romain, loc. cit.

cone of ancient tuff agglomerate alternating with lava beds. Some diametral enlargement has taken place, perhaps, during this eruption, though not enough to change the sky-line of the top to any great degree, except in the southwest side, where the old gash has been greatly widened, and perhaps deepened. The lower part of the outside of this old cone has an angle of slope of 20°, while the upper part is as steep as 30°, according to my determinations. Measurements of the inner slope gave values of 40° to 65° in the portion carved out of the old agglomerate, but the angles increased to 75°, 85°, and even showed great overhanging blocks on the eastern side where

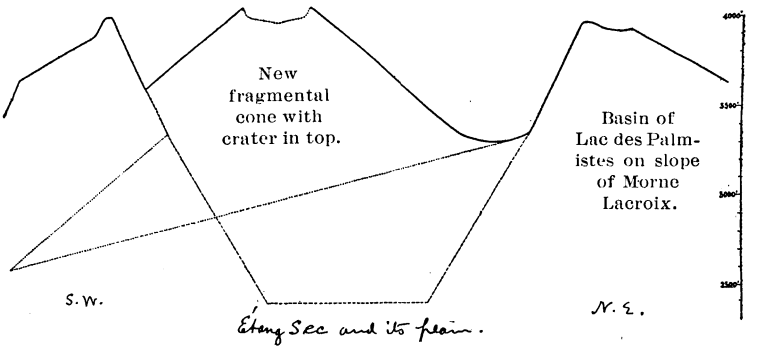


FIG. 2a. SECTION ACROSS SUMMIT OF MT. PELÉE FROM S.W. TO N.E. JULY 6, 1902.

Horizontal and vertical scales the same. Elevations estimated, except on northeast side. The shape of the crater in the inner cone is entirely inferential. The relation of the great southwestern gash to the fragmental cone is indicated by the dotted line. The broken lines complete the profile of the great ancient crater as it existed, probably, before the eruption of May 8, 1902. The fragmental cone was the scene of greatest activity, but there seemed to be another important center of eruption in the northeastern portion of the crater at the base of Morne Lacroix.

the old lava beds form the rim. In the western portion of the crater rises a cone of fragmental material, consisting of dust, ashes and large and small blocks and bombs. This cone is the scene of the greatest activity in the crater and it grew materially in size between the day when I first saw it, May 21, and July 6, when I got my last glimpse of it. It now entirely covers the site of the Étang Sec and partly fills the old crater, and probably more than compensates for the material torn and undermined from the old walls and thrown out by the eruptive action of the volcano. A large proportion of the activity of the volcano, aside from that of the great outbursts, has gone into the building of this cone. The accompanying profile

(p. 340) indicates the probable relationships between the inner cone and the old crater.

The illustration, fig. 14, gives the sight I obtained of the inner cone from the eastern side of the crater. At that time its top must have been just about on a level with or, perhaps, somewhat higher than the camera, which was 3950 feet above tide, by aneroid reading. The photograph shows that there was a depressed crater in the top of the inner cone. My measurements of the angle of slope of the southern side of this cone determined it to be 38° to 40°, but there were precipitous portions. The material which rolls and slides down the southwest side of this cone continues directly into the gorge of the Rivière Blanche. The steep-sided valley formed by the inner cone and the inner slopes of the crater-rim forms a continuation of the gorge of the Blanche and rises at a considerable angle from the southwestern gash to the base of the rocky precipice on the eastern side of the crater, where it may be 800 feet in depth. The valley probably continues around the northern side of the inner cone rising in a spiral, for it appears at an elevation of at least 3600 feet on the western side, between the rim of the crater and the cone on the northwest side of the great gash. The new fragmental cone rises, apparently, on the site of the new crater mentioned by Romain, a conclusion which seems to be in agreement with the account of the eruption of May 8 by M. Fernand Clerc as given by Kennan,* which is as follows: "About eight o'clock, with a rending, roaring sound, a great cloud of black smoke appeared suddenly on the southwestern face of the volcano near its summit, and rushed swiftly down in the direction of St. Pierre, . . ." Before this outburst, M. Clerc had been observing the great column of vapor rising from the other principal center of eruption, which is located in the valley within the great crater at the base of the high point of rock on the eastern edge (the remains of Morne Lacroix). At intervals columns of steam rise energetically from other parts of the crater valley.†

* The Outlook, vol. lxxi, p. 683, July 12, 1902.

† Morne Lacroix is reported to have disappeared altogether and the crater to have extended greatly toward the east during the great outbursts which occurred from August 25 to September 3. This may indicate that the vent under the new inner cone above described has become partly clogged, and that the main activity has shifted to the vent mentioned (see p. 340) as being east of the Étang Sec at the base of the western face of Morne Lacroix. If this has taken place, as seems highly probable from the reported destruction of Morne Lacroix, the new inner cone acted as a dam in the great southwestern gash which played such an important part in the destruction of St. Pierre, so that the last eruptions came from a centrally located vent (like that of La Soufrière, St. Vincent) and the débris from the crater was distributed more symmetrically about the cone. The position of the great gash

The history of the present series of eruptions may be epitomized somewhat as follows: the gradually returning activity of the volcano began to make itself very manifest in the latter part of April, since visitors to the crater found warm water in the basin of the Étang Sec on the 25th of that month, and the lake was deep. Columns of dust-laden steam rose from an opening within the old crater on the east side of the Étang Sec and from one on the west side of the same basin, and cones rose about these openings. Water in large quantity collected in the old lake basin, assisted, perhaps, by a dam formed across the gorge by the ejecta from the western crater. The water was heated by the action of volcanic forces. On May 5 the heated waters of the crater broke through this dam and rushed, as a deluge of mud and bowlders of all sizes, down the gorge of the Rivière Blanche, and overwhelmed the Guérin sugar factory, which was situated at the mouth of the stream. On May 8 began the series of great explosions which have sent steam, laden with sulphurous gases, dust, ashes and stones, again and again over the southwest slope of the mountain with the violence of a tornado, several times reaching to St. Pierre and beyond. The author would explain the blasts in the same way as in the case of St. Vincent (see p. 326), but the great gash in the side of the crater of Pelée and the position of the neighboring ridges concentrated the force of the explosions in a certain direction and along a comparatively narrow zone—and the city of St. Pierre with its 26,000 inhabitants* and thousands of refugees lay in an amphitheatre, a regular *cul-de-sac*, directly in the path of the blasts.

There seems to be no crater or center of primary eruption in the gorge of the Blanche below the great crater, or in the gorge of the Sèche,† but there has been much secondary

and neighboring cliffs with reference to the vent on the western side of the Étang Sec, which was the most active center of eruption in May, June and July, directed the blasts of the earlier eruptions toward St. Pierre and away from Morne Rouge. That directive factor having ceased to have force, through the growth of the inner cone and the (apparent) shifting of the center of activity to the eastern vent, Morne Rouge, a mile and a half nearer the crater than the middle of St. Pierre, came far within the area of destruction and received the full fury of an eruption.

*Population in 1895, 25,382, according to the Century Atlas.

†Prof. Angelo Heilprin has stated in his article in McClure's Magazine for August, 1902, and elsewhere, that eruptions have taken place from a crater located in the gorge of the Rivière Blanche some distance below the great crater. R. T. Hill has expressed the same idea in his extended article in the National Geographic Magazine (vol. xiii, pp. 251, 261) for July, 1902, and speaks of this as the center from which came the blast that destroyed St. Pierre, calling it the "Soufrière crater." He has recorded the matter on a map which was published on p. 260 of the National Geographic Magazine. Curtis was with Hill when the latter made the observations on which this map was based, and therefore knew the spot intended to be represented. Curtis and I stood on the brink of the gorge of the Blanche overlooking it on June 24, examined it again with field glasses from the rim

action along the lower portion of their courses, and much steam, with or without large quantities of dust, has been thrown high into the air when water has reached the heated interior of the vast beds of volcanic ash deposited there during this eruption. Mud-flows and torrents have been very numerous down the gorges of these streams and on the plateau between them. Some of these flows have come directly from the crater, especially in the case of the Blanche; others have originated on the exterior slopes of the old cone, while others have started in the heavy ash-beds in the gorges in the manner already described in connection with the Wallibou River, St. Vincent, and the Falaise River on the eastern side of Mt. Pelée. The surface of one of the mud-flows on the plateau between the Sèche and the Blanche is shown in fig. 17. Subsequent rain has washed the fine mud from the stones.

These streams of mud and stones present some characteristics which distinguish them clearly from the surfaces of undisturbed ash-beds. The most striking of these is the existence of curved folds or wrinkles transverse to the direction of flow of the stream, the folds varying in size with the size of the flow. The surface of an unmodified deposit of ash presents a drifted appearance like that of a field of snow or of dry sand on a sea beach, and the Richmond estate as illustrated in fig. 6 is a typical example. The plateau between the Des Pères and Roxelane Rivers, on which was located the Fort Quarter of St. Pierre, was covered with several feet of wind-drifted ash, and it was not a mud-flow or a series of mud-flows which destroyed this portion of the city, as has been stated in several publications.

In addition to the showers of dry dust and ashes, there fell during the eruptions an immense amount of liquid mud which

of the crater, where we obtained a view directly through the gorge lengthwise, and repeated the examination from the crater rim on June 26. We could see no crater or center of eruption in the gorge of the Blanche below the great crater, though there has been much secondary or superficial eruption of steam from the ash-beds along the gorge.

I cannot agree with the distribution of the "zones of devastation" indicated on Hill's map or with the location of "mud craters" as the origin of the mud-flows of the Sèche, the Blanche, the Falaise and other valleys. It is well to separate the devastation into zones of "annihilation" and "singeing," in a general way, but the crater of the volcano should certainly be included within the former instead of being placed outside of the latter, as is done on Hill's map. The real location of the singe line of the May eruptions is nearly that of Hill's "ash line" and is indicated approximately on my map (p. 332), where it is called the limit of devastation. The "ash line" should be placed at some undetermined distance far beyond the shores of the island of Martinique. The existence of real "mud craters" on the slopes of Mt. Pelée seems very improbable, for the reasons given on pages 337 and 338 and elsewhere in this article. The mud-torrents of the Grande Rivière, which were among the heaviest of those experienced on the north and northeast side of the island, are not indicated on Hill's map.

had been formed within the eruption cloud through the condensation of its moisture. This mud formed a tenacious coating over everything with which it came in contact. That drops of mud, too, formed in the air and fell as a feature of the eruption is proven by the condition of the walls of the houses in Prêcheur, on which I found flattened spheroids of dried mud which could have formed only in the manner indicated. These flecks of mud were two, four and even six inches across, where two or more had coalesced. They occurred mostly on the northern and eastern walls of the houses. The testimony of the people as to the occurrence of rain during the great eruptions is conflicting, but the existence of this coating and these drops of mud proves that much aërial condensation of steam accompanied the outbursts.

During the latter part of our stay on the crater rim on June 24 the rain fell in torrents, and the deluge continued until we reached the foot of the outer cone on our return journey, the heaviest portion of the storm lasting for an hour or an hour and a half. Here we found the fumaroles sending out more steam than they did on our upward journey. When we crossed the Sèche River, we found a foot and a half of yellow, muddy water in place of the two or three inches which we had noticed there in the morning. We had not climbed out of the lowest gorge of the river before our attention was attracted by the heavy eruption that was taking place from the crater, and that was sending enormous clouds of dust-laden steam down the gorge of the Blanche to a point below the so-called Soufrière crater. Thunder-like noises nearer at hand had already made themselves heard and in another minute a wall of hot water, ten or fifteen feet high, swept with railroad speed over the place where we had crossed the river, and rushed on to the sea. The roar of the torrent was like that of a train, and the water dashing from side to side of the narrow gorge caused the ground on which we were standing to tremble like a ship when her propeller "races." The water was thick and as black as ink with its load of volcanic ash, and it transported with ease bowlders five feet in diameter which it had excavated from its banks. In many, if not most instances, these bowlders were the ejecta of the present eruption. To the left a stream of thick, yellowish mud was flowing down from the plateau of the Sèche-Blanche which we had left a quarter of an hour before and was cascading into the Sèche directly beneath us. Soon the black torrent cut into the ash-beds along its banks sufficiently to reach their still highly heated interiors and cause columns of steam to shoot hundreds of feet into the air. The steam columns carried great clouds of black and light-brown volcanic sand scores of feet upward. The hot area of the

plateau also was sending skyward great columns of steam, and the whole formed a scene seldom witnessed, difficult to describe, and never to be forgotten. The next day we measured the gorge and found that the Sèche had deepened its channel at least ten feet in the loosely compacted recent ash during the hour which the flood lasted.

In this instance it seems evident that there was close connection between the heavy rain, the eruption, and the black torrent. Two explanations present themselves for consideration: (*a*) the crater may have thrown a mass of accumulated rainwater and ashes bodily over into the head canyon of the Sèche; (*b*) the rain which fell into the crater may have been the exciting cause of the eruption, but the mud-torrent may have been due to the soaking of the heavy coat of ashes on the steep outer slope of the old cone at the head of the Sèche until the resulting fluid mass slid off from the comparatively hard surface beneath and poured down the gorge of the river. There was plenty of water-soaked mud and ashes on the upper part of the mountain to supply the avalanche and some of it was on the verge of fluidity at the time of our visit, hence the latter explanation seems the more reasonable. The little tributary of the Sèche which empties into it on the southeast side close to our point of observation, did not show any corresponding torrent, because it does not head on the side of the great cone.

The mud-flows which have descended the Prêcheur River canyon have had ample collecting ground in the "Atrio del caballo," to use a Vesuvian term, on the north and northeast sides of the great crater, where the fine dust settles in vast quantities ready, when sufficient water has been added to it, to descend through a narrow gorge into the valley of the Prêcheur. When I was walking along the crater rim above the "Atrio" June 20, my footsteps started small mud-flows down the outer cone, so liquid was the mud at that time. The ordinary action of the volcano is to deposit dust of impalpable fineness on the inner face of the crater rim. When this deposit becomes thick, it is ready to be swept off by a copious rain and carried through the great southwestern gash, out of the crater and down the gorge of the Rivière Blanche as a mud-torrent or flow. There does not seem to the writer to be any need of locating "mud craters" at the heads of or along the line of the gorges which have been the courses which these torrents of liquid mud have followed to the sea.

Where the tuff agglomerate of the old (outer) cone had been freed from its coat of ashes, especially in its lower portion, i. e., from 1000 to 2000 feet above tide, it showed a smooth, somewhat fluted surface, the soft bowlders having been planed

off even with the matrix. The whole showed striations parallel with the slope, so that the surface looked like the glaciated rock surfaces so common in northern latitudes. The planing and the striations seem to have been due to the scouring action of the ash avalanches in this part of their course. They ceased where the steep slope of the cone changed to the gentle slope of the plateau, and thus gave opportunity for the material of the avalanches to check its descent and pile up. The sides of the radial gorges on the flanks of Mt. Pelée show approximately horizontal striations. Near the stream-beds such striations occur on both sides of the gorges, and are due to abrasion by the sand and stones carried by the torrents. High above the stream on the bluffs facing the crater there are similar striations, but these must have been made by sand-blast action during the hurricanes of dust-laden steam, resulting from the explosions during the recent great eruptions. These striations extend to the very tops of bluffs rising 500 feet and more above the stream beds at their bases (see fig. 15).

Erosion seems not yet to have cut deeply into the old land-surface since or as a feature of the eruptions, because here and there all over the mountain side one can find undisturbed roots and charred grass still in place. The shore line from Ste. Marthe Point nearly to Cap St. Martin has been somewhat altered since the eruptions began, some of the river deltas having been built out by the new material brought down by stream and torrent, while others have been cut back by the waves. The most important example of the cutting back is near the mouths of the Sèche and the Blanche, where local land-slides have assisted the sea in forming nearly vertical bluffs from ten to thirty feet in height. These bluffs show sections of the old and the new material now composing the plain. The little ash island* which was formed near the mouth of the Rivière la Mare between May 8 and 23, and which was visited on May 23 by Mr. Curtis and two companions, had been washed away by June 14. The stone pavement laid on the beach of St. Pierre was cut into in places, perhaps by the return waves from the ocean accompanying the great outbursts.

The mud-flow which swept down the Grande Rivière reached the village of the same name at 4 A. M., May 8, four hours before the eruption occurred which destroyed St. Pierre. Three other great mud-flows have traversed this river: on May 11, June 6 and June 22, though no great eruption of Pelée took place on May 11 or June 22. The eruption of June 6 was one of the heaviest that occurred; this time the mud-torrent reached Grande Rivière village about an hour and a half before

* Mentioned by Hill; The Century Magazine, vol. lxiv, p. 773, September, 1902.

the eruption took place. The flood of May 8 was the most violent and was three meters (about 10 feet) deep where the valley of the river opens onto the sea coast, according to M. Delsol Désiré, the mayor's deputy of Grande Rivière. He gave me the foregoing particulars in regard to these floods. The fine mud of these flows entered the buildings on the banks of the river as if it had been thick syrup. In one room that we examined the line of highest level was even with the top of an ordinary table, which would show that the mud was 30 inches deep in the room. At the time of our visit the deposit was nearly dry and it showed a shrinkage of but eight inches or 27 per cent. In another room the shrinkage was greater, showing that the mud there was thinner when it flowed in. Streams composed of such material as this would have great power in the transportation of bowlders. The sizes of the bowlders brought down by the mud-torrents and deposited on the flood plain of the stream above the village and in its old channel may be inferred from figure 18. Some of those measured were eight feet across. The bowlders seem to be from old deposits, since they have weathered surfaces. They show fresh abrasion along edges and at corners, due to their recent trip down the gorge. The mud is made up of gray material from the present eruption, together with a large proportion of yellow sand from the old beds through which the river runs. The vast amount of material brought down by the torrents has extended the delta plain fully five hundred feet into the sea and has pushed out the shore-line for several hundred yards on either side of the mouth of the river.

At Basse Pointe the history in regard to floods or torrents of mud has been similar. The principal disasters occurred on May 8 and 27, but the latter was the greater and most of the destruction was wrought on that occasion. Here too the deltal plain has encroached five hundred or six hundred feet on the sea and the ocean currents have spread the surplus material as a new beach for a long distance north and south of the mouth of the river, destroying the little artificial harbor of the town. Bowlders ten feet across were brought down and left in the town by the floods, and a deposit of sand, gravel and bowlders fifteen to eighteen feet deep rests upon the site of the old market place, which was at the mouth of the river.

The ruins of the city of St. Pierre presented a very interesting field of study, but mostly in the line of speculations as to the cause or causes of the terrible destruction of human life. The walls of the houses (see fig. 11) showed that one or more blasts of tornadic violence had swept over the city and that they came from the direction of the crater of Pelée, for the east and west walls—transverse to the direction of the

crater from the city—were demolished more generally than the north and south walls. The direction in which most of the trees were felled indicates the same thing, but the trees in the angle of Morne Mirail, which rises behind the middle of the city, were thrown over at all angles progressively, showing that a vortex was formed there. As is indicated by the gradually decreasing degree of destruction in passing from the northern to the southern part of the city, the blast diminished in force as it progressed and expanded, but when it reached Ste. Marthe Point it still had strength enough to throw the statue of Notre Dame de la Garde from its pedestal. The statue, which is of hollow iron ten or eleven feet high, now lies on the edge of the bluff with its foot about fifty feet S. 10° W. from its original position on the pedestal, and directly in line with the crater.* The guns in the Ste. Marthe and Morne d'Orange batteries were thrown from their carriages in the same direction. More than once when I was on the rim of the crater or on the west flanks of the mountain I saw great clouds of dust-laden steam come out of the gash in the side of the crater with sufficient force to descend the gorge of the Rivière Blanche with great rapidity a full mile before rising in columns. It was not difficult to imagine that, if this happened when the crater was sending a steam and dust column only one or two thousand feet high, the action would be vastly greater and even like a hurricane in violence when the crater was in full eruption and was sending its ash-laden steam column from five to seven miles into the air.†

It does not seem necessary to call in any forces new or strange to the history of vulcanism to account for the phenomena attending the eruption of Mt. Pelée, or the destruction of St. Pierre and its people. The "flames" reported were perhaps the incandescent stones and bombs flying through the air; and these certainly would set fire to any combustible material upon which they fell. The officers of the French cable-repair ship Pouyer Quertier were eye-witnesses of the eruption of May 8 and describe the cloud as being black when it issued from the crater, but say that it became luminous as it approached the coast.‡ Several times at night during our stay we saw the inner cone of the crater outlined and streaked with

* See Bul. Am. Mus. Nat. Hist., vol. xvi, pl. xlvi, fig. 2; and Nat. Geog. Mag., vol. xiii, p. 250, for illustrations.

† Lieut. B. B. McCormick, U. S. N., in command of the Potomac, was on his vessel in the harbor of Fort de France May 20 and made measurements of the angular distance to which the steam column rose during the great outburst that morning. The column subtended an angle of about 30° and the tug was thirteen and one-half nautical miles in a straight line from the mountain.

‡ Heilprin, loc. cit., p. 367.

lines of "fire" due to the rolling and sliding red-hot rocks and lapilli, and this light was reflected from the steam clouds above the cone. The existence of notable quantities of burning or inflammable gases in the discharges from the volcano seems to me to be as yet undemonstrated.

On two occasions, June 24 and 26, I went into the crater for a short distance beside the southwestern gash and several times was surrounded with heavy clouds of steam from within the abyss. The steam, which was warm, but not hot, when it reached me, contained much sulphur dioxide, SO_2, and at times some hydrogen sulphide, H_2S, but I could not detect the odor of any other gas. The sulphur gases made the atmosphere difficult to breathe, but the most uncomfortable sensation was due to the irritation caused by the fine, angular dust getting into the respiratory passages and the eyes. Such a mixture, raised to a high temperature, and containing a large amount of dust and a considerable percentage of sulphur gases, would be almost instantaneously fatal to life. It was a cloud like this that rolled over and enveloped St. Pierre for several minutes about eight o'clock in the morning of May 8, and must have caused most of the deaths. Some of the other causes of death were, (1) blows from falling stones which had been hurled out from the volcano, (2) crushing beneath falling walls and various objects (one man was found with his back broken by a sign which had fallen from over a store front), (3) burns due to hot stones and dust, (4) burns caused by steam alone and (5) by steam mingled with dust, (6) cremation in burning buildings, (7) nervous shock, (8) suffocation from lack of respirable air and, perhaps, (9) lightning. No autopsy was made on any of the thousands of victims of the disaster on Martinique, although men capable of performing such operations had the opportunity of making them within a very few hours after the eruption; hence there is no sure way of determining whether poisonous gases other than those mentioned played any part in the destruction of life. Immanuel Lédée, one of the survivors of the crew of the Roraima, told me that when the mucous membrane of his mouth, throat and nose sloughed off on account of the burning, it was found to be full of the fine black (gray) dust. He was taken to the hospital at Fort de France after the eruption. Samson Cil-Barice,* the prisoner who is the sole survivor of the persons within St. Pierre at the time of the eruption, told me in Morne Rouge on June 18 that it was the hot dry "sand" which sifted in through the window of his cell that caused his terrible burns.

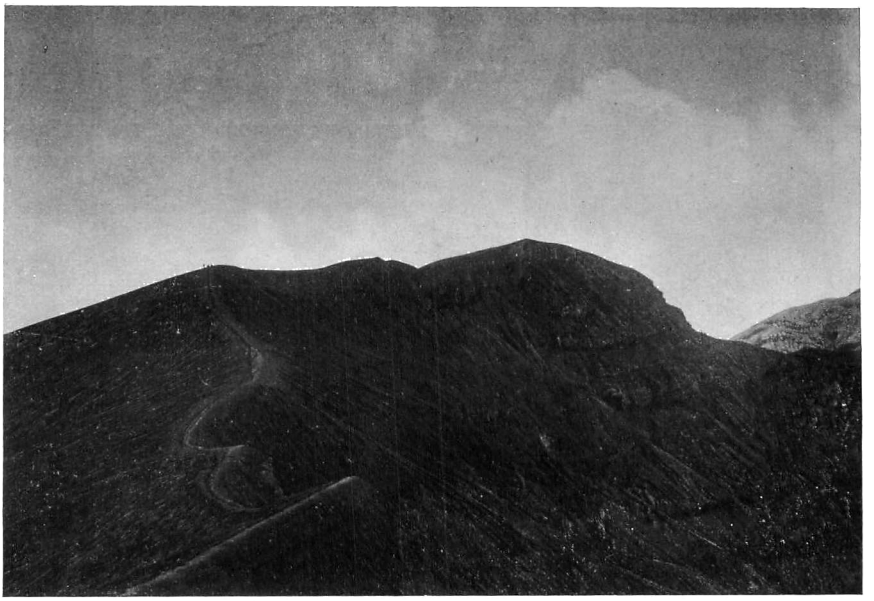
* This name is spelled very differently in the various accounts of the disaster. The spelling here adopted is that given me by my interpreter.

The term "stellar lightning" has been proposed by George Kennan for the particular form of electrical discharge characterizing the eruptions of Mt. Pelée. This expression, however, implies that the bolts shot out radially from a center in all directions at the same instant, whereas the shafts flew out successively in the different directions. Often they seemed to come from centers, but this appearance probably was due to the foreshortening of the line along which the successive flashes originated. The amount of electricity generated by the friction of the ascending column and the moving clouds of dust-laden steam against the surrounding atmosphere was very great, but much of the discharge seemed to be comparatively noiseless. At midnight of June 26 an eruption occurred which sent up a steam column to a height estimated at 12,000 feet above the top of the mountain. Much of this scintillating* lightning played about the column and the "mushroom" cloud above, but no sound of thunder could be heard from our sloop, which was at anchor off Carbet, seven miles distant. The same form of electrical discharge was observed in connection with the great outbursts of La Soufrière on St. Vincent. The electrical phenomena attending the September eruptions of Mt. Pelée are described as having been even more magnificent and terrifying than those observed in connection with the earlier explosions.

American Museum of Natural History.
October 11, 1902.

* "Coruscating" is the excellent descriptive term applied by Dr. Jaggar to these discharges.

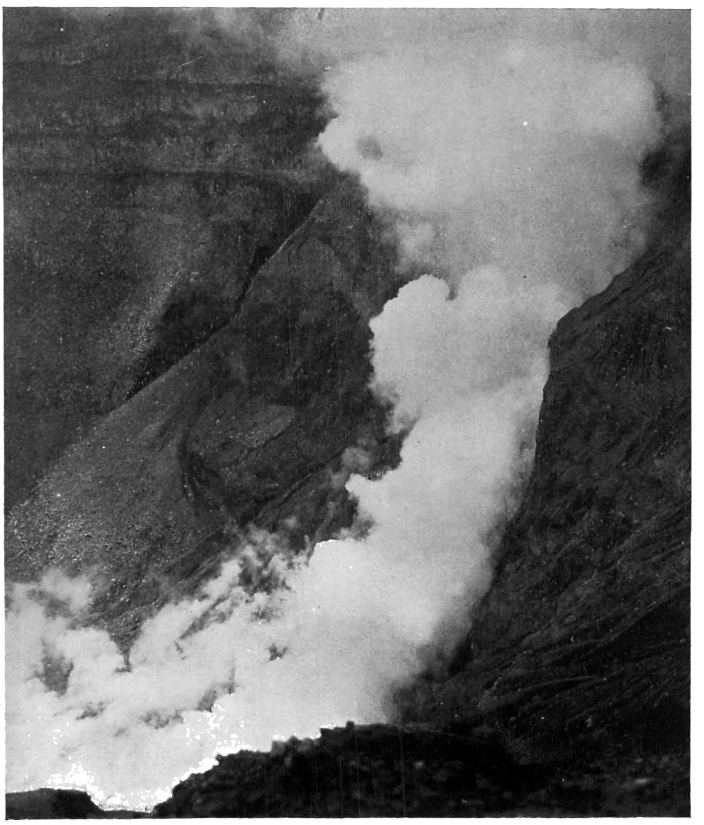
4



Photograph by E. O. Hovey.

LA SOUFRIÈRE. SOUTHWESTERN PART OF CRATER-RIM.

5



Photograph by E. O. Hovey.

LA SOUFRIÈRE. SOUTHEASTERN PORTION OF CRATER. [Page 351.

Photograph by J. C. Wilson.

THE RICHMOND ESTATE, ST. VINCENT.
Wind-drifted surface of undisturbed ash-bed.

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Photograph by E. O. Hovey.

La Soufrière. Secondary outburst in ashbed of Wallibou River.
Dendritic erosion developing.

8

Photograph by E. O. Hovey.

La Soufrière. Mud-covered ridge at 1500 feet altitude. [Page 353.

9

Photograph by E. O. Hovey.

La Soufrière. Ash-filled gorge of the Rabaka Dry River.
New deposit is said to be 200 feet deep.

10

Photograph by E. O. Hovey.

La Soufrière. Windward side. Trees felled and carved by volcanic blast.

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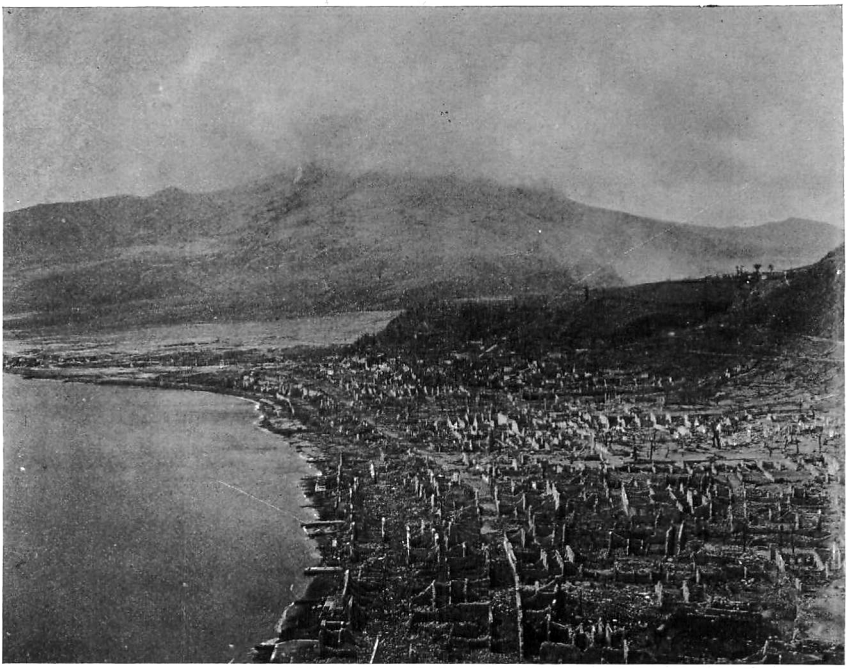

Photograph by E. O. Hovey.

RUINS OF ST. PIERRE, MARTINIQUE. MT. PELÉE IN BACKGROUND.

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Photograph by E. O. Hovey.

RUINS OF ST. PIERRE, MARTINIQUE. VALLEY OF RIVIÈRE ROXELANE.

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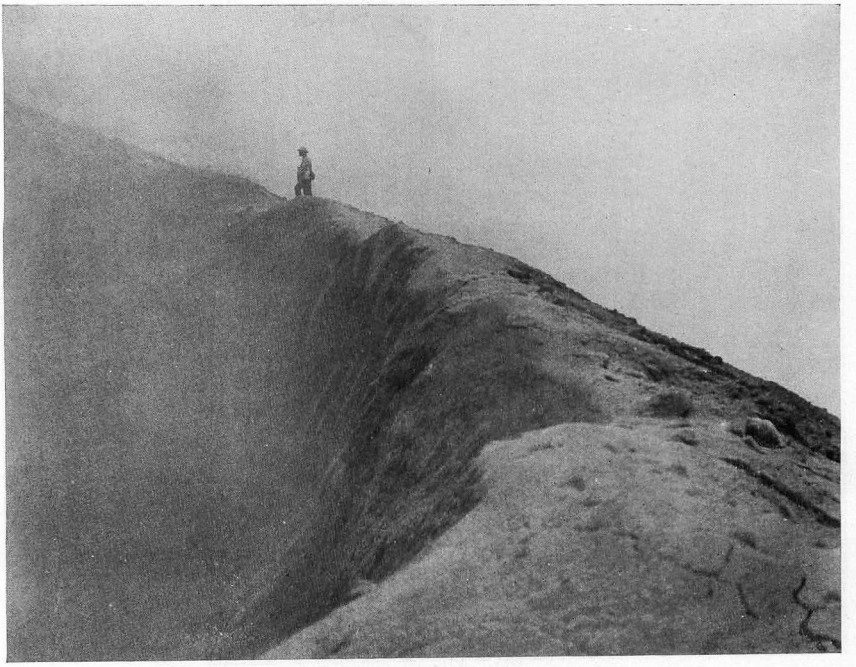
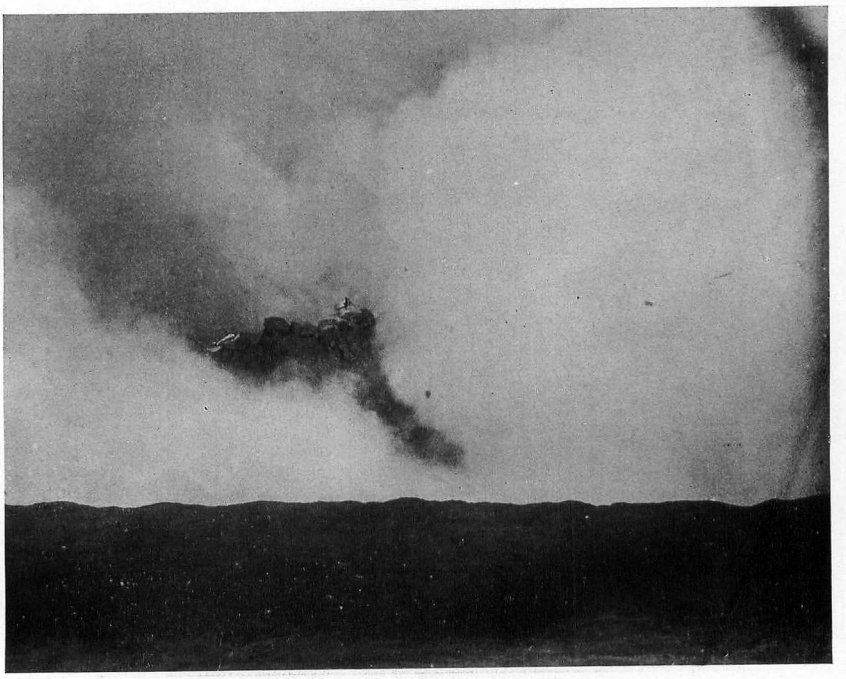


Photograph by E. O. Hovey.
MT. PELÉE. SOUTHEASTERN PART OF CRATER-RIM AT 3750 FEET ALTITUDE.

14



Photograph by E. O. Hovey.
MT. PELÉE. INNER CONE; FROM EASTERN EDGE OF CRATER AT 3950 FEET ALTITUDE.
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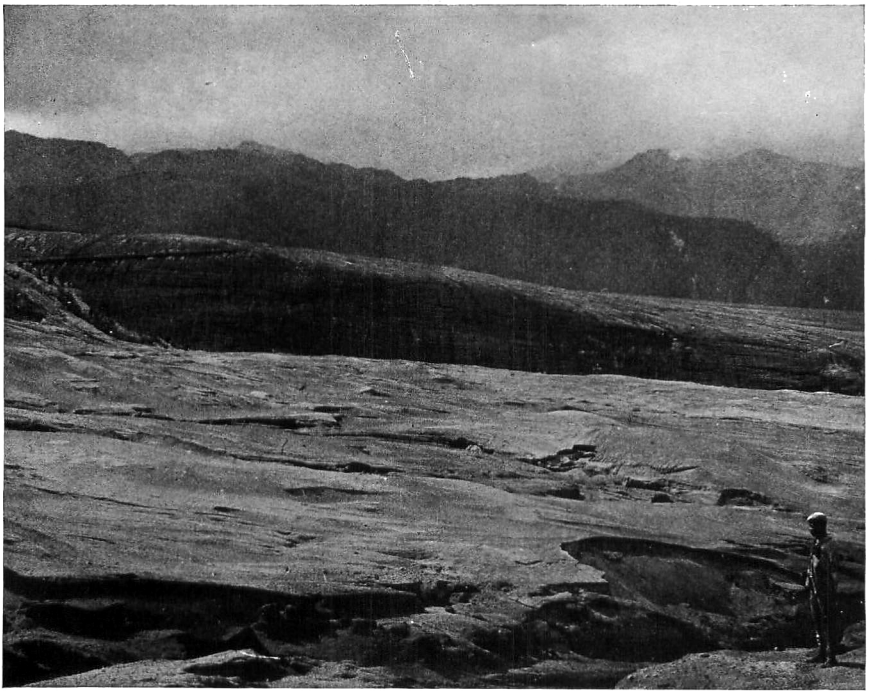

Photograph by E. O. Hovey.

MT. PELÉE. BLUFF IN CENTER OF VIEW SHOWS SAND-BLAST ACTION OF VOLCANIC TORNADO.

16

Photograph by E. O. Hovey.

MT. PELÉE. EJECTED BLOCK OF ANDESITIC LAVA ON SÈCHE-BLANCHE PLATEAU, 3 MILES FROM CRATER.

Dimensions 30′ × 24′ × 22′. [Page 357.

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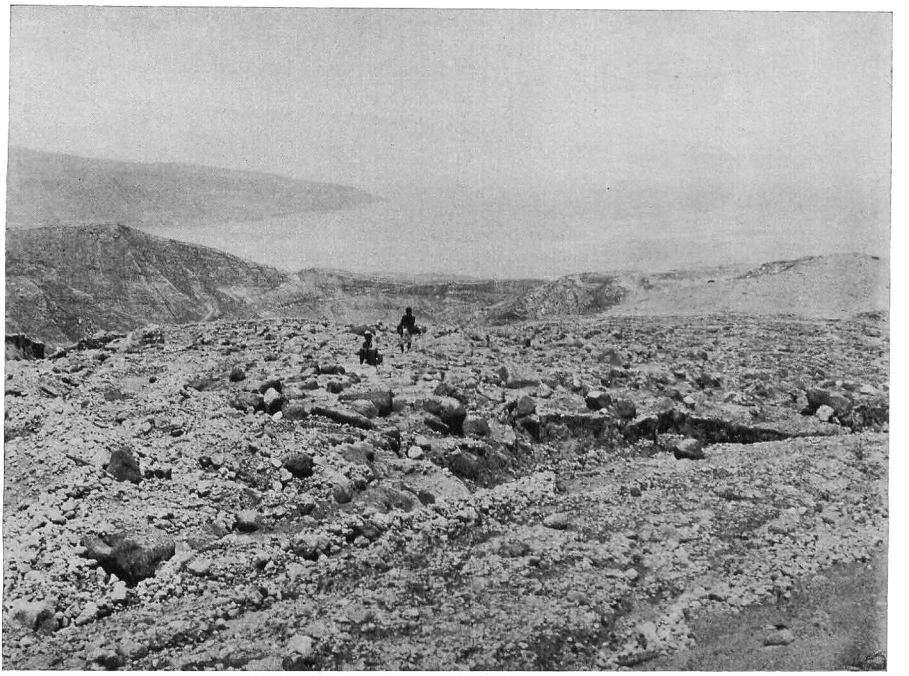

Photograph by E. O. Hovey.

MT. PELÉE. SURFACE OF "MUD-FLOW" ON SÈCHE-BLANCHE PLATEAU AT 800 FEET ALTITUDE.

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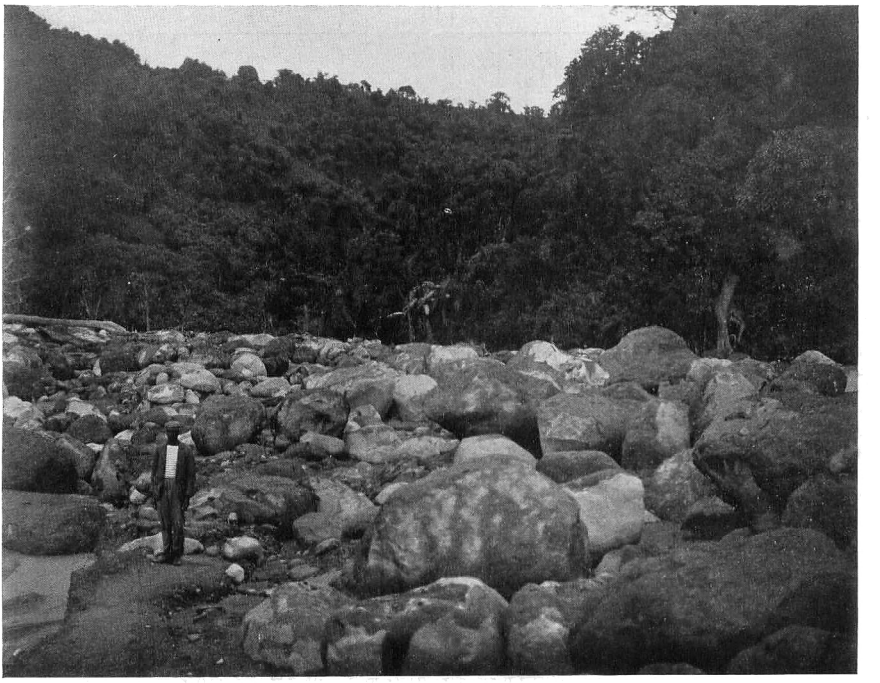

Photograph by E. O. Hovey.

GRANDE RIVIÈRE. GREAT BOWLDERS BROUGHT DOWN BY MUD-TORRENTS OF MAY AND JUNE, 1902.

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Photograph by C. E. Taylor.

LA SOUFRIÈRE, ST. VINCENT, FROM RICHMOND ESTATE.
Local landslides along coast.