# The Relation of the Blue Veins of Glaciers to the Stratification, with a note on the Variations of Glaciers.

By **Harry Fielding Reid.**

Since the blue veins first received the careful attention of glacialists in 1841, their origin has been the subject of much discussion. Forbes thought they were surfaces of disruption due to the differential motion. Agassiz divided them into two groups: one he considered the original strata of the névé-fields and the other he looked upon as due to infiltration. Schlagintweit thought they were due to infiltration along surfaces made porous by tension. Tyndall thought they were due to pressure and were analogous with the slaty cleavage of rocks; he supported his ideas with such cogent arguments, and with such apt experiments and illustrations that his views were accepted: and since the publication of his „Glaciers of the Alps" in 1861 until recently these views have not been seriously called in question.

Since 1896 I have given much attention to this subject; I have visited and examined many glaciers, though more time has been given to the Forno glacier in the Engadine than to any other; that glacier is very simple and shows the relation of the stratification to the blue veins unusually well. I have also examined the glaciers which Agassiz, Forbes and Tyndall especially studied: and my definite conclusion is that the blue veins in the dissipator represent the strata of the névé.

Many objections have been made to this view, which can be stated and answered as follows:

**1st.** Strata are destroyed by ice-falls such as that of the Rhone, but the blue veins appear below the fall.

The measurements made on the Rhone glacier reveal a very regular movement of the ice down the fall, showing that the distorted portion of the ice is only superficial; the fact is also overlooked that the distorted ice is not recemented at the bottom of the fall, but is melted off, leaving at the surface the ice which flowed down the fall under the broken surface ice.

**2nd.** The blue veins at the end of a glacier are very regular, whereas the strata in the upper part of the dissipator are often much folded.

Where glaciers are made up of several tributaries each has its own system of strata; but unless these tributaries are of somewhat equal sizes, the smaller will melt before reaching the end of the glacier, which then consists of a single tributary with corresponding regularity of stratification. Where two or three tributaries attain the end of the glacier the blue veins are not so simply arranged; but still the more rapid movement of the centre of the glacier, and the fact that the ice at the glacier's end has always been near the glacier's bed, result in less irregularity than occurs in the upper part of the dissipator.

**3rd.** Blue veins represent the surfaces where the differential motion is greatest.

**4th.** Blue veins are developed where the pressure is strongest and are at right angles to the pressure.

The blue veins do not always lie in surfaces of greatest differential motion, nor are they always at right angles to the greatest pressure. In composite glaciers there are several groups of blue veins in the same cross-section, whereas there can be but one system of surfaces of greatest differential motion, or one system of surfaces at right angles to the greatest pressure; indeed, the blue veins are not related to the form of the valley in the lower part of the glacier, where they are most distinct, but are related to the tributaries of which the glacier is composed. It is a better description of the position of the blue veins to say that near the boundaries of the tributary in which they lie they are in general parallel with these boundaries, but that in some cases, especially at a distance from the boundaries they may be folded; and there are even cases where they may be crumpled.

**5th.** In places the blue veins are tilted up at a high angle; this occurs especially at the foot of ice-falls and at the sides of glaciers, and it seems difficult to believe that the horizontal strata of the névé could be so greatly tilted up.

On a small tributary of the Forno glacier the nearly horizontal strata become nearly vertical within a distance of about a hundred metres; the steep strata are close to the side. The „*glaciers remaniés*“ (regenerierte Gletscher) of the Great Scheideck also show a great change in the dip of their strata within a very short distance. So that instances are known where strata are actually tilted up. [Lantern slides of these cases were thrown on the screen.]

**6th.** Blue veins occur in *glaciers remaniés* where the original stratification is undoubtedly destroyed.

The blue veins seen in these glaciers are merely the marks of the secondary stratification formed by the successive avalanches which form these glaciers. The stratification is very marked on account of the large amount of débris brought down by the avalanches and concentrated on the surface by melting. [A lantern slide showed the blue veins in the Brenva glacier, and their absence from the *glacier remanié* which lies on it.]

**7 th.** The blue veins and the strata have been found coexisting and cutting each other at a high angle.

Tyndall searched thoroughly for this phenomenon, and only succeeded in finding it in two places. When we remember that blue veins may be caused by infiltration or may be the scars of former crevasses, and that there are frequently deceptive appearances of stratification on the walls of crevasses, it is quite possible that Tyndall was mistaken in his observation and reasoning. If the blue veins and stratification were entirely distinct we should expect frequently to find them together.

**8 th.** The strata of the névé-fields cannot be seen to change by insensible degrees into the blue veins.

Of many glaciers this is certainly true, but Agassiz claimed to have followed this change on the Unteraar glacier, and I also have succeeded both on this glacier and on the Forno. On small glaciers it is easy to follow the strata from their origin to the end of the ice, but here the blue veins are not well developed. [A large number of lantern slides were shown illustrating the gradual change in the appearances of the strata from the névé-fields to the lower part of the glacier, where the surface markings of the strata were seen to correspond exactly with the blue veins in the crevasses.]

## A note on the Variations of Glaciers.

At the VIII Session of the Congrès géologique international in Paris [1]) I called attention to the fact that we should expect a great variation in the length of a glacier when the névé-line occurs on a wide part of the glacier and the dissipator runs into a narrow valley, for then a small change in the position of the névé-line would mean a considerable change in the relative areas of the reservoir and the

[1]) Compte rendu, 2me fascicule, pag. 753.

dissipator, and the latter would have to lengthen much in order to restore the proper ratio.

The same condition would also cause a rapid rate of advance. The excellent observations of Prof. Finsterwalder and Drs. Blümcke and Hess on the Vernagtferner have shown that the advance of a glacier is the result of a thickening of the ice which begins in the reservoir and advances down the glacier like a wave; when it reaches the lower end there is a rapid advance. Now if the dissipator is broad in its upper part where the wave enters and contracts towards its end, the wave must diminish in breadth and increase in height (though much of its energy is undoubtedly lost in friction) and therefore it is much higher when it reaches the lower end than it would be if the glacier had a uniform width; and the advance of the end is correspondingly more rapid.

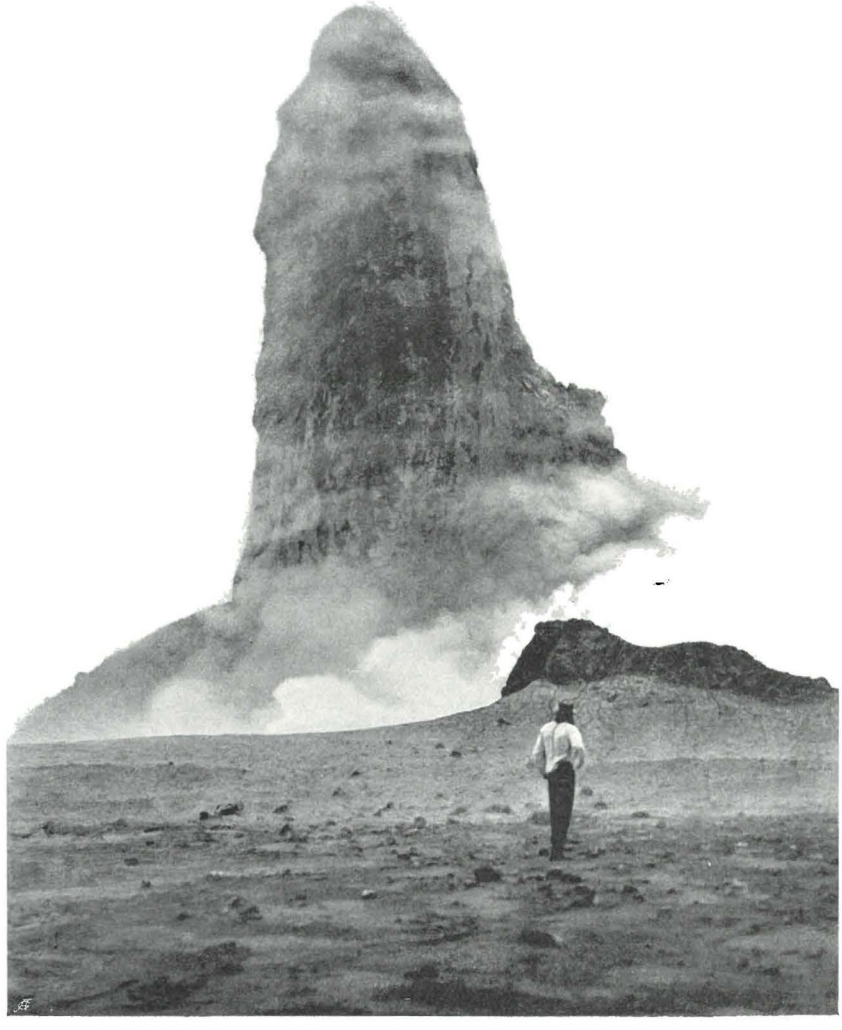
The Vernagtferner occasionally makes remarkable advances, and the quantity of ice poured down its valley at these times is very great though the slope of the surface is not materially altered. What force causes so great a flow? If we consider that the time necessary to produce a given shear in glacier ice is proportional to the force, and that the force acting in each section is the weight of the ice of that section, we find that the average velocity is proportional to the square of the thickness of the ice; in the case of a somewhat V shaped valley, the area of the cross-section is also proportional to the square of the thickness; hence, the quantity of ice flowing, which is equal to the product of the cross-section and the average velocity, is proportional to the fourth power of the thickness. It is probable that the shear in glacier ice increases more rapidly than the first power of the force, and the flow through a cross-section may be proportional even to the fifth power of the thickness. But axsuming the law of the fourth power, an increase in thickness of one twentieth would result in an increase of one fifth in the amount of flow; and an increase of one tenth would cause an increase of nearly one half in the flow. It becomes very evident that a small increase in the accumulation of snow in the reservoir causes a very great increase in the outflow, and supplies the ice necessary for the increase of the dissipator.

# Explanation of Plate I.

(Frontispiece.)

**Mont Pelé.** The great spine or obelisk from the ash-filled basin of the Lac des Palmistes, looking nearly S. 60° W. The apex is about 358 *m* above the crater-rim, which is directly in front. The rock mass at the right on the edge of the crater is the remains of Morne Lacroix.

Photographed 25 March, 1903, for the American Museum of Natural History by E O. Hovey.



Photographed by E. O. Hovey. (Frontispiece.)

**Mont Pelé. The great spine.**

# The 1902—1903 Eruptions of Mont Pelé, Martinique and the Soufrière, St. Vincent[1]).

By **Edmund Otis Hovey.**

(With eleven Plates.)

When Columbus discovered the island of Martinique in 1502, he found the natives living in a village on the site of the present hamlet known as Le Carbet. They were afraid to dwell in numbers nearer the peculiar mountain which towered 1350 *m* above the sea, for their traditions taught them that an uneasy monster had his home there. Perhaps the Carib name for the mountain has been preserved in the present name, „la montagne Pelée", or as more commonly given „Mont Pelé", meaning „bald mountain". Such an appellation would refer to some prehistoric condition and might indicate the occurrence of one or more volcanic eruptions within the traditions of the natives. No one would deny the applicability of the term „bald" to the mountain in its present state of devastation. Mont Pelé, however, was considered, by the white inhabitants of Martinique at least, to be an extinct and therefore harmless volcano, in spite of the recorded slight eruptions of 1762 and 1851, until the events of May, 1902, placed it at once in the front rank of active and destructive vents. The history of the island of St. Vincent has been almost the same. An ancient Carib tradition declared that La Soufrière would be the death of the tribe, unless the vindictive spirit dwelling beneath the placid waters of the crater lake were kept pacified by continuous sacrifices. The fear voiced in this tradition has been shown to have foundation, for in 1718 and 1812 there were great volcanic outbursts from the mountains, while in

[1]) This paper is based upon the data obtained for the American Museum of Natural History, New York City, during two expeditions 14 May to 15 July, 1902, and 5 February to 8 May, 1903. It gives almost exclusively the result of the personal observations of the author, and is substantially what was presented orally at the session of 20 August, 1903, but the history of the volcanoes has been brought down to the time of putting this matter into shape for the printer 1 February, 1904.

May, 1902, began the series of eruptions now so well known, which have far surpassed the preceding in violence and magnitude. The outbreak of May 7, 1902, destroyed a large proportion of the few Caribs still living upon the island. The terrible loss of life, 32.000 persons having been killed on Martinique and 1600 persons on St. Vincent, has been the feature of the present series of eruptions which has appealed most strongly to the minds and the hearts of the civilized world, but it is not the purpose of the present paper to dwell at length upon this feature of the eruptions.

The volcanoes under our consideration are found in the central third of the chain of islands called the Lesser Antilles or the Caribbees. The entire chain extends as a great festoon almost 800 *km* in length, from Saba on the north to Grenada on the south. Such festoons appear in several chains of volcanic islands, for example the Aleutians, the Kuriles and the islands of Japan; they show lines of weakness in the crust of the earth, and are held to be the result of the contraction of the sphere. The Caribbean chain is composed of a double series of islands, an inner line almost entirely volcanic, and an outer line, sedimentary or partly sedimentary. Of the first line are Saba, St. Eustatius, St. Christopher, Nevis, Montserrat, the Basse Terre of Guadeloupe, Dominica, Martinique, St. Lucia, St. Vincent, the Grenadines; of the outer line are Anguilla, St. Martins, St. Bartholomew, Barbuda, Antigua, Barbados, the Grande Terre of Guadeloupe, Marie Galante. The Barbados are composed of limestone. Martinique shows limestone in its southeastern part.

## Mont Pelé.

The island of Martinique lies almost in the middle of the Caribbean festoon, with the summit of Mont Pelé in lat. 14° 49″ N., and long. 61° 10′ W. of Greenwich. The island is of very irregular shape, is about 72 *km* in length, is from 16 to 24 *km* in width, and has an area of about 975 *sq. km.* It is the second largest of the Lesser Antillean group, being exceeded in size by Guadeloupe alone. Before the year 1902 Mont Pelé was one of the higher mountains of the Caribbean islands, its accepted altitude being 1350 *m* above the sea. Mont Pelé is situated, in relation to the rest of Martinique, as the Soufrière is to St. Vincent. At the base on the south and southeast there are two great transverse valleys, that of the Roxelane river on the west and that of the Capot river on the east, corresponding to the gorges of the Wallibou and of the Rabaka at the base of the Soufrière. The mountain consists for the most part of tuff agglomerate which has resulted from the weak consolidation of débris which has

been thrown out in ancient explosive eruptions. There are some lava beds in the composition of the mountain, certain of which, like the „Goffin" near the Rivière Blanche, are flows, while some in the upper part of the old cone may have been plugs or the remains of spines. Deep gorges proceed in all directions from the summit of the mountain. Most of these are largely or wholly valleys of erosion; but one, the gorge of the Rivière Blanche, seems to have resulted in part from the action of volcanic forces. It appears to have begun as a rent torn in the rim of the crater by one or more explosive eruptions.

## The crater.

Before the eruptions began the crater of Mont Pelé was somewhat oval in shape, with its longer axis of about 800 *m* extending from northeast to southwest. The highest point of the rim, and of the mountain as well, was at the northeastern side, where Morne Lacroix rose to the altitude of 1350 *m* above the sea, forming a rudely conical mound of andesite about 140 *m* higher than the general level of the rim along the east side. From the foot of Morne Lacroix the crater-rim decreased gradually and irregularly in both directions, until the great V-shaped cleft in the southwest quarter was reached. At the north side of this cleft rose the rock-mass known as Petit Bonhomme (Ti-Bolhomme, in the vernacular), which probably had an altitude of 1220 *m* before the eruptions. On the south side of the cleft, the obtuse angle of the rim which may be taken as marking the limits of the crater, was at about 1070 *m*, according to aneroid measurements made in June, 1902, and March, 1903.

The two rock-masses just mentioned (Morne Lacroix and Petit Bonhomme) seem to have been the only rock-masses in the rim or walls of the crater. In the south side of the gorge of the Blanche within 100 *m* of the point above indicated as the limit of the crater, there is (or was in June, 1902) a comparatively small boss of rock. Other rock-masses in the make-up of the old cone are at the head of the Rivière Sèche; in two pronounced shoulders in the southeastern part of the mountain (headwaters of Rivière Roxelane), and in a bluff at the head of the Rivière Falaise. These indicate the occurrence of lava as flows or plugs in connection with one or more ancient eruptions of the volcano. The author is inclined to refer the origin of Morne Lacroix to the formation of a spine or plug like that which has characterized one phase of the present activity, and the other masses of rock noted to the extrusion of lava in a highly viscous condition which cooled without forming a flow, in the same manner as has happened

with the present new cone. In the Somma-ring just to the north of the great crater there are two or more masses, or plugs, of rock.

The inner walls of the old crater dropped precipitously to the altitude of 700 *m* above the sea, where there was an uneven plain 300 *m* across in which was situated the periodical lake known as „l'Etang Sec". The gorge of the Rivière Blanche continued into the crater through the great gash, or cleft, in the southwest wall. Hot springs were known to exist within this crater. On 4 June, 1900, M. Roger Arnoux[1]), a member of the Société Astronomique de France, visited the summit of the mountain and noticed two small fumaroles in the basin of l'Etang Sec, where a year previously the same observer had seen nothing but rich vegetation. The foliage about the fumaroles had been destroyed over areas 30 to 40 *m* in diameter. M. Ferdinand Clerc, a planter of Martinique, told the author that he visited the top of Morne Lacroix on 8 May, 1901, and from that point saw steam issuing from a new locality in the southeastern part of the crater. Others report having observed several fumaroles in l'Etang Sec in the spring of 1901, but it was not until March, 1902, that the fumaroles were sufficiently strong or active to cause general comment in St. Pierre[2]).

The ancient crater has been almost filled by the formation of the new cone of eruption within it. The spiral valley which extended in June, 1902, from the gorge of the Blanche around the new cone has been completely filled on the west and northwest sides. The old rim has been cut back from Morne Lacroix toward the south and southwest to an indeterminable extent. The enlargement is indicated by the widening of the V-shaped gash and by the sharp, ragged edge which has taken the place of the rounded edge of the rim which existed in June, 1902, and by the lenticular portions of the rim which had slipped down or were on the point of slipping down into the crater in March, 1903. The enlargement was particularly noticeable in March, 1903, in the southeastern part, where an angle existed in place of the curved contour of the crater which was observed in June, 1902. On the other hand, not much enlargement can have taken place toward the northeast, judging from the fact that in March, 1903, the roots of plants were observable in this part of the wall of the crater.

[1]) See Camille Flammarion, „Les éruptions volcaniques et tremblements de terre", pag. 224, where M. Arnoux's account of the eruption is given in full.

[2]) Arnoux, loc. cit.

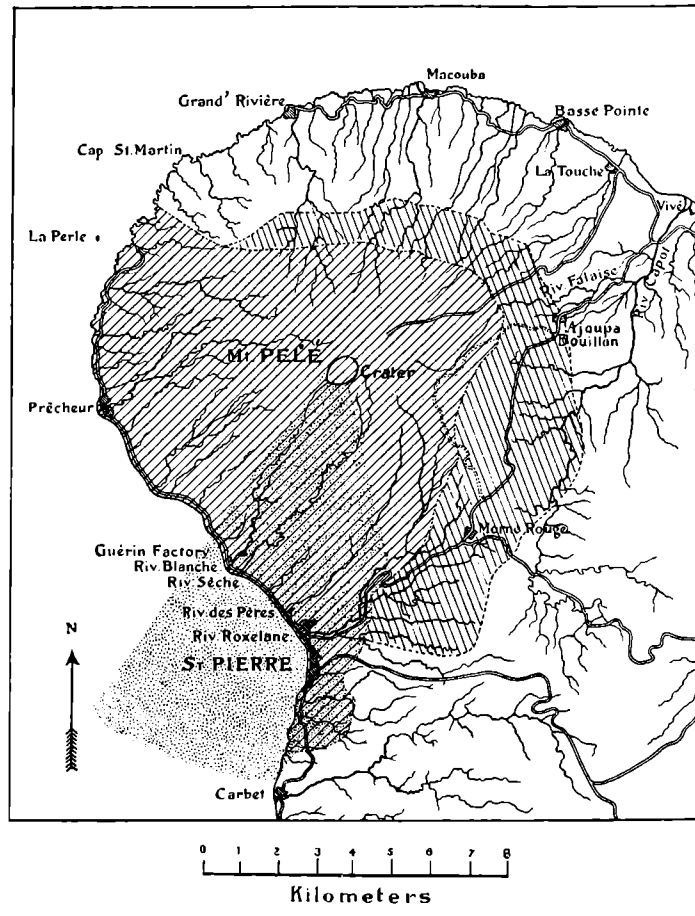



**Fig. 1. Mont Pelé and Vicinity, Martinique, F. W. I.**

Based upon the Chart of the French Hydrographic Service.

The area cross-lined obliquely from right to left is that which received serious injury from ash during the eruptions of 8—26 May, 6 June and 9 July, 1902. It is a surface of about 83 *sq. km.* The portion of the map lined from left to right represents the additional area (about 35 *sq. km*) devastated by the eruption of 30 August, 1902. The dotted sector is the zone of annihilation (about 23 *sq. km*) of the eruption of 8 May, 1902. The boundaries of this zone were rather sharp, and were indicated by the position of the destroyed cable-repair ship „Grappler" off the mouth of the Rivière Blanche, on the west, and the burning of men and horses on the Grand Réduit, half-way from St. Pierre to Morne Rouge, on the east.

The eruptions of August and September, 1903, seriously affected an area extending about 3 *km* in every direction from the crater, judging from the reports of M. J. Giraud published in the Journal Officiel de la Martinique.

The coating of ash gradually diminished in thickness from these areas outward over the remainder of the island.

Reproduced, with additions, from the author's sketch-map in Bulletin Am. Mus. Nat. Hist., Vol. XVI, Pl. 35.

## The eruptions of 1902.

Mont Pelé, after the prolonged warnings already mentioned, began in March, 1902, to pour out sulphurous gases in sufficient volume and strength to be a source of inconvenience to the inhabitants of the coast region between Ste. Philomène and Le Prêcheur [1]). The first outthrow of cinders or lapilli seems to have taken place 23 April, 1902. On 3 May, the Usine Guérin at the mouth of the Rivière Blanche was overwhelmed by the mudflow resulting from the bursting of the retaining wall of l'Étang Sec in the crater. The following day ashes and lapilli fell to such an extent on the Pinaud estate at Macouba, 7 *km* north of the crater, as to interfere with work in the canefields. At about 7:50 A. M., 8 May, occurred the terrific explosion which destroyed the beautiful city of St. Pierre, the „Pearl of the Lesser Antilles".

After the first eruption the walls of that part of the city south of the Roxelane river were almost altogether entire. The explosion of 8 May killed the inhabitants and set the city on fire. Several eruptions between 8 and 19 May sent their dust clouds as far as the city, but seem to have wrought little damage. The second great eruption, that of 20 May, caused much havoc among the walls left standing by the first. This eruption completed the destruction of the quarter of the city lying north of the Roxelane, razing to the ground every building that was not protected from the fury of the blast by being under the lee of the bluff along the river. The third first-class eruption, which occurred 6 June, was considered more severe than those preceding it, but it would be hard to say that it wrought additional havoc in St. Pierre, for by this time the new cone rising within the great crater had reached such proportions and had filled the gorge of the Rivière Blanche to such an extent that the V-shaped gash had lost much of its directive effect upon the explosions.

The 8 May eruption seems to have left comparatively little dust, ashes and other volcanic debris in the city. The daily record for the immediately succeeding days is incomplete, but the next eruption cloud to reach the city seems to have been that of 19 May, when the party searching for the body of the United States consul was driven from the ruins. Then came the heavy eruption of the 20th. On the 21st, when an eruption sent its cloud down to the northern part of the city, and on the 22d the author was in the ruined city.

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[1]) „Les Colonies", 25 April, 1902, quoted by Hovey, Am. Jour. Sci., vol. XVI, p. 270, October, 1903.

He observed 1·5 to 2 *m* of dust, etc., in Rue Victor Hugo near the theatre. The amount diminished toward the south until at the end of town there was less than 30 *cm*. The subsequent eruptions seem not to have augmented this amount materially, the rains, however, washed great quantities of dust and lapilli down from the surrounding hills, until the deposit was from 3 to 4 *m* deep in many parts of the city, and one walked along the street on a level with the second floors of the houses.

There are said to have been two persons in the city during the eruption who escaped with their lives. The author saw one of these, the prisoner Joseph Ludger Sylbaris [1]), at Morne Rouge 18 June, 1902. Sylbaris, who is an ignorant negro, born about 1875, was in a solitary confinement cell within an open court in the prison. The prison was at the angle of Morne Mirail in the middle of the city, and the main portion of the structure caught the full fury of the explosion. The cell was entirely above ground, but it was partly protected by the bluff behind it. It was perhaps 2·5 by 3·5 *m* in size, had thick, strong walls, double door, small (about 20 by 30 *cm*) grated window and a chimney-like ventilator. Sylbaris was confined here the week before the eruption, because he had broken his parole as a prisoner at large. The man saw and knew nothing of the eruption or its phenomena aside from the facts that the prison burned, and that red hot dust and sand sifted into his cell burning him terribly. Two persons from Morne Rouge passing through the city on Sunday rescued the prisoner after he had lain half-conscious in his cell, without food or water for nearly four days. Sylbaris did not note any strong sulphurous or other peculiar odor in the eruption cloud, but his evidence on this point would not be conclusive.

There were many illustrations of the hurricane force with which the volcanic blast swept over the city, but in addition to the demolition of the walls of the houses, two examples stand out with particular prominence [2]). The famous statue of Notre Dame de la Garde, which overlooked the city from the heights of Morne d'Orange, was

[1]) This name is spelled differently in various reports. The form adopted here is that found in the Martinique newspaper „L'Opinion", 7 August, 1902.

[2]) The oft-quoted statement that the guns of the battery of Ste. Marthe on Morne d'Orange were dismounted by the volcanic tornado is erroneous. The author too has made the statement (Am. Jour. Sci., XIV, p. 548, Nov., 1902) on the authority of others. In February, 1903, he visited the battery and saw that the very position of the guns and their dismembered carriages show that they were dismantled by man. Persons familiar with the history of the colony state that the dismantling was done years before the eruption took place.

hurled from its pedestal to the ground, and directly after the eruption lay on the farther side of the pedestal from and in line with the crater, with its foot 15 *m* from its former position on the pedestal and the head of the statue was still farther away from normal. The statue was hollow, about 3·5 *m* high, of cast iron. A still more striking example of the violence of the propulsion of the cloud was the condition of the two pairs of double storage tanks of a distillery in the Fort Quartier, as that part of the city lying north of the Roxelane river was called. These tanks, which were made of boiler iron fully a centimeter in thickness, were riddled with holes as if they had been bombarded with artillery. The holes were various in size, some being about 50 *cm* × 60 *cm*, though a strip a meter long and 25 or 30 *cm* wide was torn from the edge of one of the tanks. Some holes were mere cracks in the bottoms of dents, not piercing the iron. The direction of impact was from the crater, and it was evident that the stones which had pierced the tanks had originated there. Two theories to account for the projectiles present themselves: either the stones were a feature of the eruption cloud which rolled down the side of the volcano, and give us some measure of its force, or they were ejecta which had been cast high into the air and in falling back earth had encountered an eruption cloud which diverted them from their course . . The former seems by far the more reasonable supposition.

Everywhere on the flanks of the mountain one sees the evidences of mud-flows. These flows were of two kinds; torrents, and streams of thick material like molasses. Both were formed in the same manner, through the saturation of cinders or dust by water beyond the point of equilibrium. The author had a near view of these torrents and flows on 24 June, 1902, in the valley of the Rivière Sèche. The transporting power of the ash-laden waters was great. Boulders 2 *m* in diameter were observed carried along by the torrent, as if they had been corks. One of the floods in the Basse Pointe river left a rock 4 *m* in diameter perched upon a bridge pier 5 *m* above the bed of the stream after the flood had subsided Where the angle of slope was sufficient, the eroding power of these heavily laden streams was very great. One feature of this erosion was the planing and grooving of the surface of the old agglomerate where the avalanches of mud, sand and gravel swept over it on the exterior slopes of the old cone. One of the torrents in the valley of the Sèche, which have just been mentioned, deepened its gorge about 4 *m* during the hour in which it lasted. It should be said however, that the material excavated was the somewhat loosely compacted recent ejecta of the volcano.

On the middle slopes of the mountain, 300 *m* above tide, on the plateau between the Rivières Blanche and Sèche, there was a place where many of these avalanches of mud and stones had come suddenly to rest and had formed a great pile of débris. This was where the 28° slope of the old outer cone of the volcano changed to the 8° or 10° slope of the lower portion. This heaping up of débris was observed particularly in June, 1902. The subsequent activity of the mountain covered this region with fresh ashes and lapilli, and in February and March, 1903, the author observed there some enormous ejected blocks. The largest one noted was about 13 *m* long before it was broken by its fall. Masses 4 and 5 *m* across were common. Some were broken as they came to rest, others were not even cracked. A part of the journey of these blocks must have been through the air as projectiles, but undoubtedly many of them rolled and bounded long distances after reaching the ground. Most of those in the gorge of the Rivière Blanche were transported by the dust-flows which traversed that region so frequently. On the southeast side of the mountain where suitable soil was left to preserve the record, many depressions were seen in June, 1902, which had been caused by the impact of falling bombs and blocks. Such depressions were like the splashes made by throwing stones into soft mud. These masses were thrown from the new cone in an incandescent condition, but they do not seem to have been actually molten. The blocks that were in a molten or partly molten condition when they left the cone formed the bread-crust bombs which are to be found in large numbers on the slopes of the mountain. These bombs are small in size when compared with the ejected blocks, rarely exceeding 70 *cm* in greatest dimension. The largest bombs seen by the author were 1·5 and 2 *m* across, aside from one nearly 5 *m* in length which lay upon the slope of Morne Lacroix in June, 1902.

Before the eruption, as has been stated already, the crater of Mont Pelé was characterized by a great V-shaped cleft in the southwestern wall, extending to the bottom and opening directly into the gorge of the Rivière Blanche. This cleft, in connection with the confining effect of the high walls forming the other sides of the crater, directed toward the city of St. Pierre the horizontal component of the explosions of 8, 19, 20, 26 May and 6 June. Ever since the beginning of the eruptions the gorge of the Blanche has been the favorite route of the dense clouds of steam charged with dust, cinders and blocks which have issued from the throat of the volcano. Before the eruptions began the gorge had a depth of 100 *m* or more in its upper reaches, but the hundreds of dust-laden steam-clouds, or,

more briefly, „dust-flows“ [1]), which have traversed it have nearly filled the half of its length near the crater and have completely obliterated the half toward the ocean. In fact, the latter has been changed from a gorge into a sloping plain several meters above the old borders of the gorge.

These dust-flows are of the same character as the volcanic hurricanes which destroyed St. Pierre. They consist of highly heated steam charged with volcanic dust to the point of forming a mass which acts like a very mobile fluid. Their downward motion was due to the force of the explosively expanding steam, influenced always by the shape of the opening of the conduit and affected by the „cushioning“ of the atmosphere. Such clouds often have traversed the slope of the cone of eruption and the upper part of the gorge of the Blanche at a velocity of from 80 to 100 *km* per hour. The eruption cloud of the morning of 8 May, 1902, is said to have reached the city in less than three minutes. Since the governor's house, the prison, etc., forming the part of the city to which reference probably was made, were distant about 7 *km* in a straight line from the crater (l'Étang Sec), this would indicate an average velocity for that cloud to that point of not less than 140 *km* per hour (about 39 *m* per second). Inasmuch as such a cloud loses velocity very rapidly through expansion and through friction against the atmosphere, its initial speed must have been enormously greater than 140 *km* per hour. Such a blast would have great transporting power without any contained dust or sand, while with the enormous amount of such material which have characterized these flows from Mont Pelé the transporting power would be greatly increased, as is evidenced by the great blocks of stone to be seen in the débris filling the gorge of the Rivière Blanche.

The eroding power of these dust-flows or clouds was great. The best examples of such erosion which were seen by the author were along the upper portions of the bluffs forming the left (southeastern) wall of the gorge of the Rivière Sèche, and on both sides and the eastern end of Morne Saint Martin, though the effects were to be observed on all vertical or highly inclined surfaces opposed to the blast from the volcano. Morne Saint Martin is one of the radial ridges of old tuff-agglomerate upon the flanks of the mountain. Its top is 490 *m* (aneroid) above the sea, and it rises abruptly about 200 *m* above the Sèche-Blanche divide, or plateau. On the north and northwest it descends precipitously into the gorge of the Blanche, at the place where some of the first observers of the May, 1902,

[1]) The „nuages denses“ of Lacroix.

eruptions erroneously located their „lower", or „Soufrière", crater from which they supposed the first great eruption clouds to have originated. The ridge is about 2 *km* distant from the nearest part of the great crater, and is directly in line with the great V-shaped cleft and the upper part of the gorge of the Blanche. On account of its position it has been traversed by scores of the dust-flows, or clouds, and the surfaces which have been exposed to their action have been planed and grooved as if by a gigantic artificial sand-blast. On the map published herewith the cross-lined portion shows approximately the surface devastated by the eruptions. The zone of annihilation was a „V" with the point at the crater, one arm passing about 750 *m* east of St. Pierre, the other near the mouth of the Rivière Blanche where the Guerin sugar factory is located. The eruption of 30 August, 1902, continued the devastation much to the east and southeast, and destroyed the town of Morne Rouge and the villages of Ajoupa Bouillon and Morne Balai. The ashes and the sand fell everywhere upon the island and farther away. The dust was carried hundreds of kilometers. That of 30 August fell in abundance at Guadeloupe, 200 *km* to the north.

## The „Spine".

The most remarkable feature of the eruption of Mont Pelé and the one which distinguishes it from all other volcanic eruptions within historic times, is the formation of the enormous „spine" or „obelisk" which protruded from the top of the cone of eruption and attained, at one time the altitude of 1585 *m* above the sea.

Such spines on a small scale are reported to have been elevated during the eruption of Santorin in 1866, and that of Vesuvius in 1895, but they were covered up or destroyed so soon by the further activity of the volcanoes that their existence was lost sight of or forgotten.

Persons who visited the crater of Mont Pelé on 27 April, 1902, found [1]) l'Etang Sec transformed into a lake 200 *m* in diameter, to the east of which, „back against the walls of the basin, and overhanging it slightly, rose a cone ten meters high and fifteen meters in diameter across the summit". This cone seemed to be composed of cinders or ordinary lapilli

On 5 May Professor Landes of the Lycée in St. Pierre was inspecting the crater from the Perrinelle estate, well up upon the

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[1]) Les Colonies (St. Pierre, Martinique), 7 May, 1902. Cited from the Century Magazine (New York) for August, 1902.

western slopes of Mont Pelé, when l'Etang Sec burst its retaining wall and rushed down the gorge of the Rivière Blanche and overwhelmed the Usine Guerin. He makes no mention [1]) of the presence of a new cone within the crater, so that the new feature could not have been prominent at that time.

When the author and other observers on board the U. S. tug „Potomac" first saw the mountain on 21 and 22 May, they noted the existence of a cone within the great crater which evidently was the centre of eruption. The cone seemed to be between 100 and 150 meters in height, and was assumed to be an ordinary fragmental cone. Three first-class eruptions (8, 19, 20 May) had occured by this time and the volcano was almost continuously in great activity. On 26 May there was a fourth heavy eruption. On 1 June Messrs. Heilprin [2]), Varian and Kennan [3]) stood upon the crater-rim and saw the top of the new cone about on their level, 1200 *m* above the sea. This indicates a growth of 500 *m* in less than a month, if we accept the altitude of l'Etang Sec as being 700 *m* above tide, the elevation usually given. Great masses of rock were seen protruding from the sides of the new cone, but no one doubted the fragmental character of the cone. No spine or tooth projected far above the general top of the new cone then or on 20 June when Mr. George Carroll Curtis and the author [4]) stood on the eastern rim of the great crater. To the author it seemed that there was a shallow crater in the top of the new cone, surrounded by jagged masses of rock. On 29 June, from the French gunboat „Jouffroy", Professor A. Lacroix [5]) saw a point emerge from the clouds, but its altitude (1353 *m*) was so nearly the old altitude of Morne Lacroix that it was not recognized as being new. On 6 July Dr. T. A. Jaggar, Jr. [6]), saw a projection like a shark's fin rising from the southwestern part of the summit of the new cone to a height estimated at about 60 *m* above the remainder of the summit. About the middle of August it was reported on the island that there was a prominent projection rising from the top new cone [7]), but Heilprin's photographs [8]) taken 24 August do not show

[1]) Les Colonies, 7 May, 1902.

[2]) Mont Pelée and the Tragedy of Martinique, pag. 163. — The J. B. Lippincott Co, 1903.

[3]) The Tragedy of Pelée, pag. 157. The Outlook Co., 1902

[4]) Bull. Am. Mus. Nat. Hist, Vol. XVI, pag. 356.

[5]) Journal officiel de la Martinique, 24 October, 1902.

[6]) Am. Jour. Sci, IV, XVII, pag. 34. Jan., 1904.

[7]) L'Opinion, 19. August, 1902. Fort de France, Martinique.

[8]) Mont Pelée and the Tragedy of Martinique, plate facing pag. 188.

such a feature, though he states [1]) that on that day he saw „horns" projecting obliquely from the southwestern part of the new cone.

Early in October began the second phase of the activity of the volcano, the elevation of the great spine from the eastern part of the new cone. On 10 October from the observatory at Assier, east of the mountain, Lacroix [2]) saw the top of the new cone projecting above

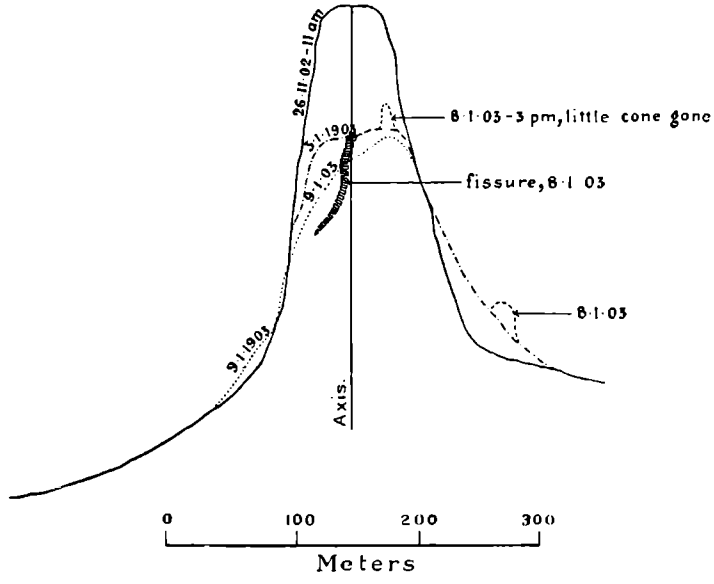


**Fig. 2. Mont Pelé.**

Profile of spine as seen from Morne Fortuné, St. Lucia, in November, 1902, and January, 1903. After sketch by Major W. M, Hodder, R. E., communicated to the author and published in Am. Jour. Sci., Vol. XVI, p. 273, 1903.

the crater-rim and he soon became convinced that the new portion consisted of solid rock, not débris, and that Pelé was to be classed as a cumulo-volcano, a theory which his subsequent observations [3]) and those of his colleague Giraud, and of Sapper [4]), Heilprin [5])

[1]) Ibid., pag. 181.

[2]) Comptes Rendus, 27 October, 1902 Author's separate, pag. 2.

[3]) Comptes Rendus, 6 April, 1903 La Dépêche coloniale, 30 April, 1903, pag. 97 etc.

[4]) Centralblatt für Min., Geol. u. Pal., 1903, pag. 348.

[5]) Science, Vol. XVIII, pag. 184, 7 Aug., 1903.

and the author [1]) have fully confirmed. On 15 October it was noted [2]) that one tooth of the dentate ridge along the eastern edge of the top of the new cone rose rather prominently above the others. Three weeks later this tooth, or spine, was 100 *m* high, and in eighteen days more (26 November) another 224 *m* had been added to the altitude. The rate of elevation between 8 and 26 November averaged not less than 12·4 *m* per day. The apex of the spine at the later date was 5032 ft. (1534 *m*) above the sea, according to Major W. M. Hodder [3]),

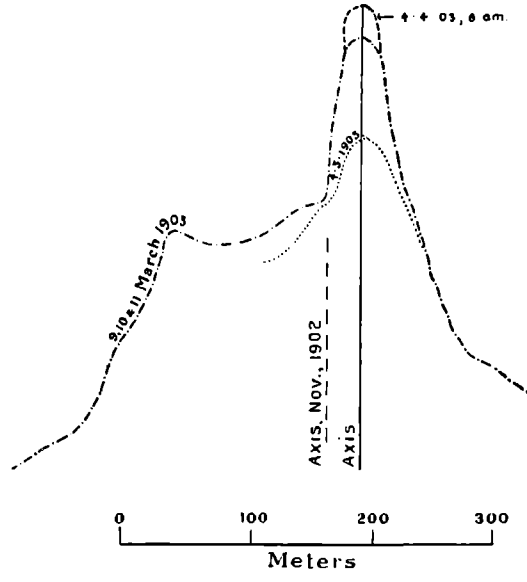


**Fig. 3. Mont Pelé.**

Profile of spine as seen from Morne Fortuné, St. Lucia, in March and April, 1903. After sketch by Major W. M. Hodder, R. E., communicated to the author and published in Am. Jour. Sci., Vol. XVI, p 273, 1903.

of the British Royal Engineers stationed at St. Lucia. The rate of growth was not uniform, the official bulletins of the French commission showing that at times during this period there were losses in altitude which were quickly recovered

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[1]) Am. Mus. Journal, Vol. III, pag. 45, July, 1903. — Century Magazine. Vol. LXVI, pag. 757, September, 1903. — Am. Jour. Sci., IV, XVI, pag. 269. October, 1903.

[2]) Lacroix, Comptes Rendus, 1 Dec., 1902. Author's separate, pag. 4.

[3]) Hovey, Am. Jour. Sci., IV, XVI, pag. 275.

was due to the vapor rising from the enormous beds of hot cinders which almost filled the gorge of the Wallibou river, and which were being drenched with rain.

From the edge of the gorge, one could examine with some satisfaction the beds of cinders and the secondary [1]) eruptions. These eruptions acted like geysers of mud or of black sand. When they ceased, it seemed as if one looked upon a manufacturing village with myriad jets of steam. The appearance on 30 May, 1902, is shown in Plate IX, figure 1. The storms of the succeeding winter-season carried almost all these cinders to the sea, clearing the gorge. The same region on 7 March, 1903, is shown in Plate IX, figure 2. An enormous amount of erosion has been effected in this gorge, since the eruptions of May, 1902, filled it with ashes.

On 30 May, 1902, the author was fortunate enough to see several secondary eruptions in the gorge of the Wallibou. Such eruptions took place when the water of the river or of a shower crept in among the hot cinders, until the steam engendered produced an explosion more or less violent. One observed late in the afternoon of this day showed the cauliflower clouds of dust-laden steam and other features of an eruption of the crater itself, and sent its cloud to a height roughly estimated at 1·5 *km* into the air.

One of the smaller secondary eruptions lasted a half-hour, and constructed a dam across the stream. Shortly afterward, the little lake thus made rose to the summit of the dam, and rapidly cut its way to the bottom. In this manner a torrent of mud was formed which ran to the sea. In general, during this time, the river was so charged with cinders and mud that it could not flow except in irregular pulsations; it showed the action of a heavily overloaded stream. Its eroding power was great.

The beds of ash left in the angles of the gorges retained their heat for months. The author saw a secondary eruption from one of the residuary beds in the gorge of the Wallibou on 6 March, 1903, and on the following day found that this eruption had been attended by a dust-flow which possessed all the characteristics of the more famous dust-flows from Mont Pelé. At first the beds of ash in the Wallibou had a thickness of 20 to 30 *m*. Their cross-sections as seen in March showed a sinuous line near the top which distinguished the surface of the May, 1902, ash from the ash deposited by the eruption on 3 and 4 September, 1902.

[1]) By a „secondary" eruption is meant one which does not have a profound source.

in the extreme northern and northeastern part of the island, did not receive a large quantity of ashes, probably being protected from the low dust cloud by the Somma ring. The portions of the island suffering the most were, on the windward side of the mountain, Georgetown, Langley Park, Orange Hill, Tourema, Lot 14 and several other estates and the Rabaka river (a „dry" river, in local parlance): on the west side, Chateaubelair; Richmond and Wallibou estates; Wallibou river (another „dry" river) and Trespé and Rozeau valleys. The loss of life (about 1600 persons) took place only upon the windward side (the east). The inhabitants of the leeward side were alarmed by the rumblings of the mountain, and on the evening of 6 May all had made their escape from the most dangerous zone, excepting one man, a Portuguese, who remained at the Wallibou factory and was burned to death. The first devastating eruption took place 7 May. The population of the devastated area was estimated at 4382 before the eruptions began

In the residence of the director of the Langley Park estate, one mile north of Georgetown, twenty-one bodies were found the day after the first great eruption. An eye-witness (W. J. Durrant) of this eruption told the author that the black cloud that rose from the crater at two o'clock in the afternoon of 7 May passed with the greatest rapidity toward the east, contrary to the direction of the trade-wind. After some moments the cloud split, one part continuing its direct motion, the other returning toward the island. All the windows of the east side of this house, not the side toward the crater, were broken, and the breakage was caused by the returning cloud. The return cloud was driven by the trade wind, assisted by the sucking of the atmosphere toward the cone, caused by the great column of vapor rising from the crater and by the condensation of the highly heated cloud after its first displacement of the air.

There are persons who were saved, in spite of their presence in the devastated region at the time of the eruption. A large number escaped destruction through crowding into the rum cellar of the distillery of the Orange Hill estate, several in the cellar of the house of the director of the Lot 14 estate, and here and there one or more persons who had taken refuge in a cellar or elsewhere. In almost all cases the people saved were in rooms with all the openings closed against the entrance of the ominous cloud with its burden of fatal burning dust.

The secondary phenomena of the eruption were wonderful. When, on 24 May, 1902, the author approached the Wallibou river (on the west side), so much steam was rising that at first it seemed that an eruption from the crater was in progress. It was like the roaring of a thousand locomotives. A little later it was perceived that the noise

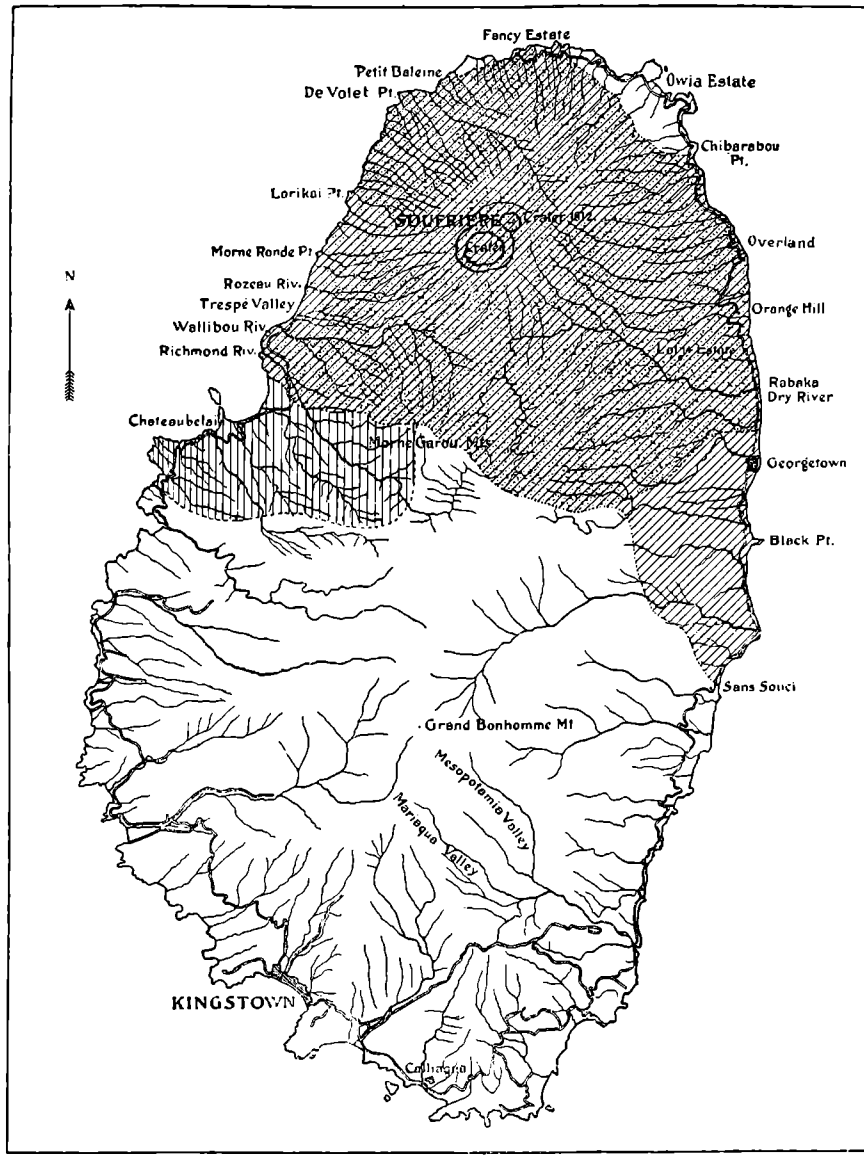


**Fig. 6. The Island of St. Vincent, B. W. I.**

Based upon the British Admiralty Chart.

The area cross-lined obliquely is that which received serious injury from ash in the eruptions of May, 1902. This is about 118 *sq. km* in extent. The dotted portion of this section represents the area of annihilation (about 102 *sq. km*), corresponding to the fan-shaped zone of similar destruction at Mont Pelé. The area cross-lined vertically represents the additional portion of the island (about 19 *sq. km*) which was temporarily devastated by the eruption of 3—4 September, 1902 (communication of T. Mac Gregor Mac Donald, Esq.). The heavy eruptions of 15—16 October, 1902 (Mr. W. J. Durrant), and those of 22—30 March, 1903 (Rev. Thomas Huckerby), seem not to have extended the area of destruction beyond the limits of the preceding outbursts. The coating of ash gradually diminished in thickness from these areas outward over the remainder of the island.

Reproduced, with additions, from the author's sketch-map in Bulletin Am. Mus. Nat. Hist. Vol. XVI, Pl. 34.

of the cone: The northern portion of the cone rose as a whole to a greater degree than the southern portion and would have formed a continuous dome, had there been no continued series of slight eruptions. These repeated slight eruptions, however, kept destroying the southwestern portion of the mass as fast as it rose, but left the northeastern part to form the spine. The spine was much rifted and was therefore too weak to withstand heavy shocks, hence it lost parts of its top and sides from time to time. The activity of July and August, 1903, shook off the spine above the transverse ridge at 1400 *m*. The great activity of the volcano in August and September, 1903, was accompanied by the elevation of the whole dome by a net amount of 120 *m* and by the vivid incandescence of the whole mass. Diminution of the eruptions led as before to renewed destruction of the southwestern portion of the dome and left an elevated ridge along the northeastern portion of the cone [1]), and, as already stated, according to the January official bulletins of M. J. Giraud, chief of the French volcano commission on Martinique, a new spine is becoming prominent on the spot where the old great obelisk stood.

## The Soufrière.

The island of St. Vincent has a length of about 30 *km*, a width of 16 *km*, and is about 350 *sq. km* in area. It is entirely volcanic in origin, and the activity has progressed from the south to the north. The Soufrière is the only active volcano in the island and the only mountain possessing a crater. Its summit is about 165 *km* nearly due south of the summit of Mont Pelé, in lat. 13° 20′ N. and long. 61° 12′ W. of Greenwich. The island of St. Lucia which lies between Martinique and St. Vincent, seems older than either. Upon it there is said to be no crater or crateriform mountain, erosion having continued long enough to destroy such topographic features.

The Soufrière, St. Vincent, has two craters: the great or „Old" crater, utilized by the eruption of the year 1718, and the „New" crater, formed at the side of the old crater by the eruption of the year 1812. Around these craters upon the north rises a wall like that of Monte Somma around Vesuvius. It is the remains of an enormous crater more ancient than the present craters. Upon the accompanying map the cross-lined portion represents the part of the island most desolated by the eruptions which began in May, 1902; it comprises about 130 *sq. km*, a third of the entire surface of the island. The estates Fancy and Owia,

[1]) Communication from Major W. M. Hodder, R. E, of St. Lucia. December, 1903.

There is no central opening or pit-like depression in the top of the new cone corresponding to the general idea of a crater. Steam issues with vigor from all parts of the cone and even issued from the spine, but most of the explosions have taken place from the southwestern slope, above the gorge of the Rivière Blanche. Minor outbursts have occurred from the northwestern slope of the new cone on the side toward Prêcheur. There is no one definite conduit through the cone to the exclusion of others. During the greatly renewed activity of August and September, 1903, the whole mass of the cone was seen again and again to glow with vivid incandescence [1]).

The vertical fissures in the spine were observed to become luminous at night from below upward and the light died out gradually from above downward [2]). The angle of slope of the northeast side of the spine, the side that seemed to form its original exterior, was from $75^0$ to $87^0$.

All these considerations lead to the conclusion that the cone and its surrounding spine consist of recently solidified lava which has been pushed up bodily into its elevated position, the viscosity of the imperfectly molten andesite being sufficient to prevent the formation of a flow. This condition was first recognized by Lacroix [3]).

The pumiceous texture of the lava shows that it has expanded as it has issued from the conduit below the new cone. This expansion in connection with the ascensive forces acting from below, has maintained the great mass in place. Of course the pumiceous nature of a portion of the new cone and spine has reduced the specific gravity of the whole mass and has rendered easier the task of keeping it up. The central and northeastern portion of the new cone, bearing the great spine, has kept rising with reference to the southern and southeastern portion of the same cone, leading one to infer that the main conduit of the volcano is below the northern portion of the new cone. The cathedral-like outline as viewed from the south (see figs. 2—4); the curved form of the northeastern side of the spine, together with its external „skin"; the vertical, freshly fractured southwestern face of the spine, and the concentration of continued eruptions in that part of the new cone near the base of the spine on the southwest and on the northwest (on both sides of a ridge extending southwestward from the spine at an altitude of about 1400 *m* above the sea), indicate an explanation of the origin of the spine as distinguished from the dome

[1]) J. Giraud. Bull. off. de la Martinique, August and September. 1903.

[2]) Lacroix, Comptes Rendus, 1 December, 1902. Author's separate, p. 5.

[3]) Comptes Rendus, 27 October, 1902. Author's separate, p. 2. Idem, 1 December, 1902. Author's separate. p. 5.

derived from any of the superficial ancient lava flows or beds of the volcano. The pumiceous breadcrust bombs have the usual densely vitreous skin characterizing such masses. The author found near the basin of the Lac des Palmistes one partly pumiceous bomb with some of the old tuff agglomerate adhering to it. Evidently this mass had been in contact with the walls of the conduit through the old tuff beds of the mountain. The great spine showed on its northeast side a comparatively smooth, almost polished, surface which was vertically grooved. When viewed from the east in the light of the rising sun the spine resembled an enormous white monument rising above the

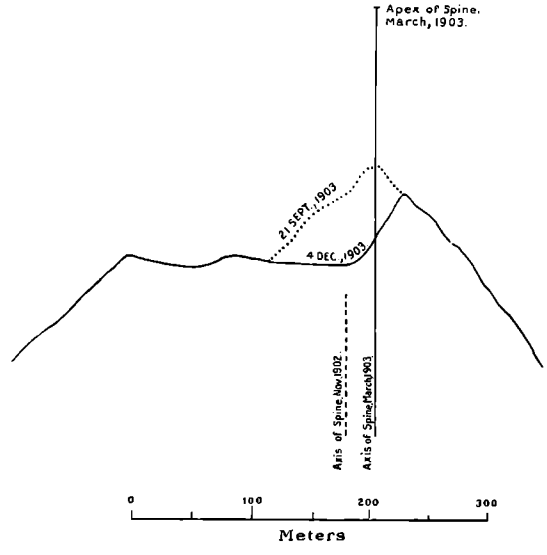


**Fig. 5. Mont Pelé.**

Profile of the „dome" as seen from Morne Fortuné, St. Lucia, in September and December, 1903. After sketch communicated to the author by Major W. M. Hodder, R. E.

mountain. The true color, however, of the northeast side of the spine was a reddish brown with a whitish incrustation over part of it. The southwest side constantly showed fresh surfaces on account of the masses which kept falling from it. This face was gray or reddish gray in color. The spine and a large proportion of the cone is composed of „solid" lava, i. e., it does not consist of débris, except for the portion which has fallen or been blown off from the solid masses and the relatively small amount of ordinary volcanic fragments. The spine and the ribs of lava have been rifted in every direction and steam and sulphur gases issue at times from the cracks.

In April the official bulletins of the French commission (from which most of the following items are taken) record a loss, but in May the gain was greater than the loss and on 30 May the maximum altitude of 1585 *m* was attained [1]). During the night of 30 May the spine lost 50 *m* of its altitude, but during June half of this loss was recovered. The activity of the volcano during July and the early part of August changed the spine completely, causing a net loss of 175 *m*, or 200 *m* since 30 May.

## The „Dome".

On 17 August M. Giraud at Morne des Cadets noted that the „dome" or main mass of the new cone was rising bodily in connection with a marked increase in the activity of the volcano. This inaugurated the third phase in the history of these eruptions. The dome rose with occasional losses until it had recovered 127 *m* of the altitude lost by the spine, but 22 *m* of this height was lost in November and December. Much fear was felt during August and September, on account of the marked increase in activity, that there was to be another great eruption of the volcano. The dome altered much in shape from day to day. At one time a spine 20 *m* high appeared on the northwestern part, but it endured only a few days. The activity of the volcano was centred at the two places, one in the southwestern and the other in the northwestern part of the new cone, which were particularly important during the formation of the great spine. The numerous slight eruptions which have occurred since September have destroyed the western portion of the „dome", leaving the eastern part as a long, abrupt ridge. The latest reports [2]) received state that the remains of the old great spine have begun to rise again with reference to the rest of the cone.

## Origin of the „spine".

The ejected blocks and the bombs, especially those to be found in the material filling the gorge of the Rivière Blanche, give some notion of the composition and texture of the new cone and the great spine. They are of lithoidal as well as densely vitreous hypersthene andesite. Pumice too occurs in abundance. Most of this material is perfectly fresh in appearance and therefore does not seem to have been

19 March to 3 April inclusive, together with a perfect view of the cone from a sloop becalmed off St. Lucia, 15 March.

[1]) Heilprin, Science, Vol. XVIII, pag. 184. 7 August, 1903.

[2]) Bulletin officiel de la Martinique, 5 and 8 Jan., 1904.

Between 26 November, 1902, and 3 January, 1903, the losses were greater than the gains and the net diminution in altitude was about 104 *m*. Great slabs fell or were blown from the western portion of the almost prismatic column, making it more slender in form, and

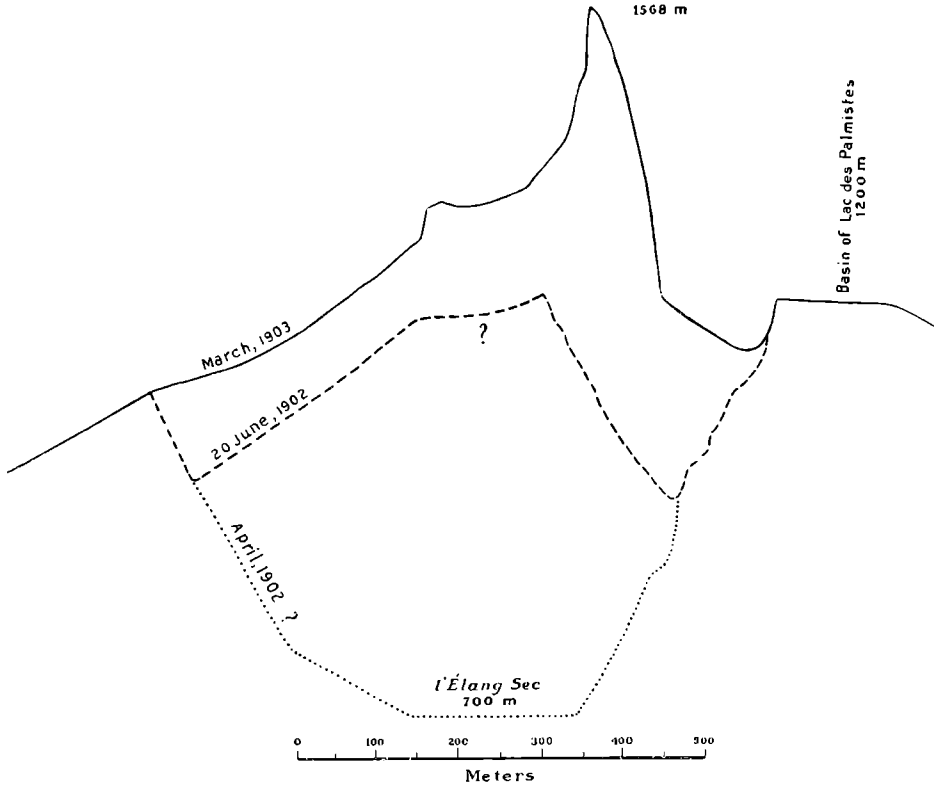


**Fig. 4. Mont Pelé.**

Cross-section, approximately east and west, through the northern part of the crater; summit plateau and basin of the Lac des Palmistes at the right. Profiles of 20 June, 1902, and March, 1903, constructed from photographs taken and observations made by the author for the American Museum of Natural History.

shifting its axis 30 *m* to the eastward. From about this time the upward movement predominated again. The whole mass of the new cone seemed to rise about 125 *m* and the apex of the spine stood as high as before, attaining the altitude of 1568 *m* [1]) by the end of March [2]).

[1]) Lacroix, Comptes Rendus, 6 April, 1903. Author's separate, pag. 3.

[2]) The author's personal observations of the mountain and its surroundings during this period extended from 17 February to 1 March inclusive, and from

On the eastern side of the island, these phenomena were repeated in the gorge of the Rabaka river, which was filled with ash in the same manner as that of the Wallibou. These two gorges form an almost straight line across the island between La Soufrière and the mountains called Morne Garou. The bed of ashes in the Rabaka presented from a distance the appearance of a glacier. The secondary eruptions formed little cones and craters on the surface of the ash bed, but such cones were rapidly washed away by the heavy rains. There was as much erosion in the bed of cinders filling the gorge of the Rabaka as there was in the Wallibou, and perhaps more. Where the gorge left the mountains, the bed of cinders seemed to be more than 30 *m* thick. On 27 May, 1902, the writer saw secondary eruptions occurring from the beds filling the Rabaka, and a visit to the locality a few days later showed that some of these had formed a lake. The dike of this lake at last reached the top of the wall of the gorge itself, and then the waters of the lake found their exit over the rim of the old gorge, cutting a ravine which soon became a gorge. In March, 1903, this new gorge was seen to be 15 *m* wide and 30 to 35 *m* deep.

Naturally the destination of all the cinders carried out from these gorges is the ocean. On the east side the cinders which have been washed off from the slopes of the mountain, the ravines and the gorges have been distributed along almost all the coast of the island, but particularly from Black Point on the south to Espagnol Point on the north, augmenting the sea beach some dozens of meters. Along the west coast, the circumstances were different. From the Wallibou on the south as far as the village of Morne Ronde, $2^1/_2$ *km* to the north without interruption, and for at least 3 *km* farther to the north, with interruptions, the old sea beach has disappeared for a breadth of 100 *m* in some places. This phenomenon was caused by the shaking of the mountain during the eruptions of May, 1902. The mouth of the Wallibou is one of the most important of the places which have suffered in this way. All along this part of the coast one can see the bluffs characteristic of land slides. Directly after the May, 1902, eruptions, they extended into the water without any shore line.

A simple calculation gives the result that not less than 5,500,000 cubic meters of ashes have been washed out of the Wallibou gorge itself, to say nothing of the thousands of cubic meters removed from the watershed of the river. The shore line of the river was extended not less than 100 *m* by the deposition of sediment between May, 1902, and March, 1903. The same extension happened at the mouth of the Rozeau and Larakai rivers, but in general along the

west coast one cannot find the new sediment except at the mouths of the rivers and of the ravines where there is some beach. The remaining coast is too precipitous.

The site of the village of Richmond, between the rivers Richmond and Wallibou, was covered with eight or ten meters of cinders and volcanic dust. Its position with reference to the Soufrière was like that of St. Pierre to Mont Pelé. The volcanic blast destroyed almost every vestige of the village. Bombs of medium size are to be found in the volcanic débris here, but in general the ash is rather fine in texture. The bark was removed from the trees on the side toward the crater, and the wood was charred, while the other side was almost uninjured. The Richmond estate on the terrace just above the village suffered total destruction from the eruption. The stone house of the proprietor, which had been only partly rebuilt after the damage done by the hurricane of 1898, was completely ruined. Directly after the eruptions, the bed of ashes covering the flat portion of the terrace, resembled perfectly the undulatory surface of freshly fallen snow. The storms of the rainy season did not permit this surface to remain long undisturbed. Channels of erosion appeared in every direction, and one saw develop under his eyes complete river systems. These systems of drainage were most perfectly developed upon the slopes of the ridges, and are a prominent feature of every photograph taken at that time.

The volcanic hurricane passed outward in all directions from the crater during the great eruptions. One finds everywhere upon the eastern, southern and western slopes of the volcano overturned trees with the trunks pointing away from the crater. Such trees are not to be confounded with the overturned trees on Morne Garou which were cast down by the hurricane of 1898. At the Soufrière there was no notch in the crater rim like the gorge of the Rivière Blanche at Mont Pelé of sufficient depth in proportion to the crater to direct the explosive force in one direction. The notch forming the head of the Larakai gorge on the west side of the crater was the lowest portion of the rim and was not more than 270 *m* lower than the highest portion. The bottom of this notch, however, was not less than 370 *m* above the bottom of the crater, so that the exploding cloud had already lost some of its force through expansion before it reached this part of the crater rim. The middle of the southern portion of the rim also was about as low. At the Soufrière the heavy dust-laden steam cloud swept down the eastern, southern and western slopes of the volcano propelled by the full force of the horizontally expanding portion of the steam cloud. The horizontal expansion was probably increased by the cushioning effect of the atmosphere and the preceding

eruption-cloud. The northern third of the crater is circled by the before-mentioned Somma ring rising 125 *m* higher than the highest portion (the northern) of the present crater. That part of the cloud, therefore which went toward the north was checked in its advance by having to surmount this obstacle. The result was that the devastation was not as great on that side of the mountain, and the cloud lost its momentum before reaching the Owia and Fancy estates at the extreme northern and northeastern end of the island, and they were not destroyed by the eruption. Parts of these estates, indeed, were not injured materially.

In May, 1902, the crests of the radial ridges of the mountain were covered with a skin some centimeters thick of fine slippery mud. This was composed of the finest dust from the eruptions, which with water formed a cement-like substance that kept its position on the nearly level crests of the ridges. Upon the slopes the mud from time to time became saturated with water beyond its point of equilibrium, when it descended the ravines in avalanches or mud-flows. The upper reaches of the mountain were covered with a bed of the same fine mud, which was at least 2 *m* thick in places. This formed an ooze which was extremely laborious to traverse. The eruption of September, 1902, covered the western slopes of the mountain with a hard compact coating of coarse sand, cinders and little bombs. Under this coating there could still be found, in March, 1903, the former layer of fine stiff mud.

## The cone.

The ancient cone is composed of several beds of cinders and flows of solid lava from prehistoric eruptions. Dikes are rare in the island, but two are to be seen in the north side of the crater wall, crossing the beds of cinders and lava from the bottom to the level of about 900 *m*. Measurement of width was not practicable, but the larger dike seemed to be about 15 *m* wide. Numerous avalanches from the walls of the crater occurred during all of the author's five ascensions of La Soufrière. Without doubt the upper part of the crater has enlarged much through the agency of these avalanches since the commencement of the eruptions, and will continue to enlarge thus until the re-establishment of vegetation checks the avalanches.

## The crater.

The crater is a great pot-shaped depression in the top of the mountain. It is about 1·5 *km* in diameter and in May, 1902, the

author estimated its visible depth at about 730 *m* below the highest point of the rim. The walls of the crater are for the most part vertical or almost vertical, whether they are of agglomerate or of lava. Below, on 31 May, 1902, as on the 3 and 10 of March, 1903, one could see a lake of mud, or of water thick with black sand. The lake was evidently in strong ebullition. Waves traversed the surface and steam rose in force. In March, 1903, it seemed as if the surface of the lake was about 60 *m* lower than on 31 May, 1902. That is to say, the crater had deepened during the eruptions of September and October, 1902. Before the eruption of 7 May, 1902, there was a large lake of clear water in the crater which was of renowned beauty. Its surface was almost 300 *m* below the edge of the crater, that is to say, it was 600 *m* above the level of the sea. Its depth was about 160 *m*. All this mass of water, more than 50,000.000 cubic meters, seems to have been thrown from the crater at one o'clock on the afternoon of 7 May, 1902, causing inundations in the gorge of the Rabaka, the Wallibou and other rivers.

An important question in May, 1902, was, „Had the crater of 1812 taken part in the new eruptions?" Without having had a perfect view of the crater, the author answered the question negatively at that season [1]), a decision which was confirmed afterward. The crater of 1812 was almost filled with the cinders of the eruption of 16 October, 1902. In March, 1903, there were fumaroles in the mass of rock forming the wall farthest from the great crater Perhaps they were the outlets of the heat of the cinders in the small crater, which were probably 75 *m* deep. There were fumaroles also at the head of the Larakai gorge at the west of the great crater, and at the head of the Rozeau valley at the edge of the crater. These were probably true fumaroles, connected with fissures.

On 3 March, 1903, the author saw small eruptions of the Soufrière which possessed the characters of the great eruptions and were very interesting. At the beginning the lake of mud was much agitated for some moments, then a stream of black mud was thrown up in pulsations. Trough this black and white mass rose with rumbling a strong column of steam, charged with brown and gray powder and showing beautiful convolutions resembling cauliflower. In the column one could see stones rising like rockets with trails or streamers of white steam following them. On these days (31 May, 1902, 3 and 10 March 1903), the stones fell again into the crater, but many rocks had been thrown out on to the slopes of the cone within a few days before

[1]) Bull. A. M N. H., Vol. XVI, p. 337.

the ascents were made They made depressions in the surface of the slopes. Often they became broken in falling. Such blocks had been heated to a high degree, but not to melting, like bombs. The great eruptions of this series on St. Vincent are those of 7 and 18 May, 3—4, 21 and 24 September, 16 October, 1902, and 23 - 30 March, 1903. All have been characterized by the expulsion of vast quantities of dust and lapilli, accompanied by numerous bombs and hot stones, but there has been no *flow* of lava. The quantity of steam was enormous in proportion to the lava, and reduced it to the condition of powder. This powder charged the steam, so as to form a highly mobile fluid, or rather a dense, heavy cloud having some of the properties of a fluid. The material of the ejecta is a hypersthene andesite more basic than that of Mont Pelé.

## Summary and Comparisons.

Two lessons stand out pre-eminently among those taught by the Caribbean eruptions of 1902 and 903: those regarding the action of dust-laden clouds of exploding steam, and the construction of a cumulo-volcano.

The eruptions of the Soufrière of St. Vincent were typical explosive outbursts of the ordinary type with a great amount of water vapor present. The overloading of the steam-cloud with fine dust caused the mixture to flow like a highly mobile fluid down the slopes of the volcano in all directions impelled at first by the explosion and afterward by the rapid expansion of the highly heated vapor, which gave the rolling cloud the high and destructive velocity of a hurricane. The content of hot dust and lapilli, incandescent on leaving the crater, maintained the temperature of the cloud to at least a scalding degree to a distance of fully 8·5 *km* from the crater. From the cloud advancing along the mountain slopes steam rose in masses carrying enormous quantities of fine dust with it. The column of steam and ejecta rising vertically from the crater possessed the cauliflower-like convolutions and other familiar characteristics of such columns. It rose far above the upper limit of the trade-winds and was carried toward the E. S. E. (contrary to the trades) at the rate of 48 *km* per hour by the currents of the atmosphere. The heavy outbursts from the Soufrière have been as numerous as those from Mont Pelé. They have been more violent in character and have thrown out more débris, although the erection of the cone at Pelé more than compensates for the latter. The intervals between the eruptions of the Soufrière have been periods of relative or entire calm.

At Mont Pelé the earlier exploding dust-laden steam clouds were not, like those of the Soufrière, free to expand and distribute their force radially in all directions. The great outbursts of 8, 19 and 20 May had their force concentrated and directed toward the southwest by the relations of the walls of the crater to the great V-shaped gash. Hence the „zone of annihilation", as distinguished from the area of more temporary devastation, of these eruptions was a narrow sector of a circle, the centre of which was the crater, while the eastern radius passed about 750 *m* east of St. Pierre and the western passed scarcely 500 *m* west of the mouth of the Rivière Blanche. From the beginning there was some radial dispersion of the dust-laden eruption clouds on the other slopes of the volcano, but this did not assume great importance until the eruption of 6 June, 1902. By this time the top of the new cone was on a level with the eastern part of the crater rim and the walls of the crater had lost much of their directive effect. The change was more marked in the eruption of 9 July, and when the great eruption of 30 August, 1902, occurred the point or points of exit were so high that the expansion of the dust-laden cloud was uninterrupted toward the east and southeast, as well as toward the southwest and west. The result was that the hamlet of Morne Balai, the western half of the village of Ajoupa-Bouillon and the whole of Morne Rouge were destroyed. Some of the houses in Morne Balai or Ajoupa-Bouillon were not set on fire by the eruption cloud and even the dry thatched roofs were unscorched; at Morne Rouge, however, many houses were burned. The configuration of the mountain slopes protected Le Précheur from entire destruction. There seems to be no evidence that this eruption cloud swept with violence over the site of St. Pierre. It seems probable that the cloud did not preserve a scalding or burning temperature for more than six or seven kilometers from the crater, even in the southern section of a circle drawn with such a radius. The concentration, however, of the May, 1902, eruptions maintained the incandescence of their clouds to a much greater distance from the crater. Persons were burned by the steam of those outbreaks who were about 10 *km* in a direct line from the crater.

The construction of a cumulo-volcano has been seen in the erection of the new cone and its wonderful spine at Mont Pelé. The elevation of the cone seems to be due to the exudation of extremely viscous lava, in the same manner as foam rises from an open bottle of champagne. Some of this lava is pumiceous in texture, while the rest is densely vitreous or partly lithoidal. The material has been too rigid to flow on reaching the surface and it has risen until equilibrium has been established between the ascensional forces and the weight

of the mass, the ascensional forces being assisted in maintaining the cone by friction, by the rigidity of the partly cooled mass and by the expansion of the cone to a greater cross-section than that of the deepseated conduit. A rough estimate of the mass of the cone makes it 175,000,000 $m^3$. If the specific gravity of the cone as a whole is only 1·5, its weight would be 257,500,000,000 $kg$, an indication of the enormus power which has been exerted here. The formation of the cone would seem to be a function of extreme viscosity of the lava combined with abundant supply of water and a comparatively mild continued activity. The eruptions of the Soufrière have been too violent, the periods of rest too complete and the viscosity of the more basic lava too low to permit of the formation of a lava cone with or without a spine within the crater of the St. Vincent volcano.

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## Abbreviations.

Am. Geol. = American Geologist.
Am. Jour. Sci. = American Journal of Science.
Am. Mus. Jour. = American Museum Journal.
Am. Nat. = American Naturalist.
Bull. Am. Mus. Nat. Hist. = Bulletin of the American Museum of Natural History.
N. Am. Rev. = North American Review.
Nat. Geog. Mag. = National Geographic Magazine.
Pop. Sci. Monthly = Popular Science Monthly.
Sci. Am. = Scientific American.
Sci. Am. Suppl. = Scientific American Supplement.

# Explanation of Plate II.

Fig. 1. **Mont Pelé.** View from the southwest, 22 May, 1902, from the deck of the U. S. tug „Potomac".

Fig. 2. **St. Pierre.** The ruined city as it appeared on 19 February, 1903. The renewed vegetation is in evidence on the bluffs which were protected from the volcanic hurricane.

Photographs made for the American Museum by E. O. Hovey,

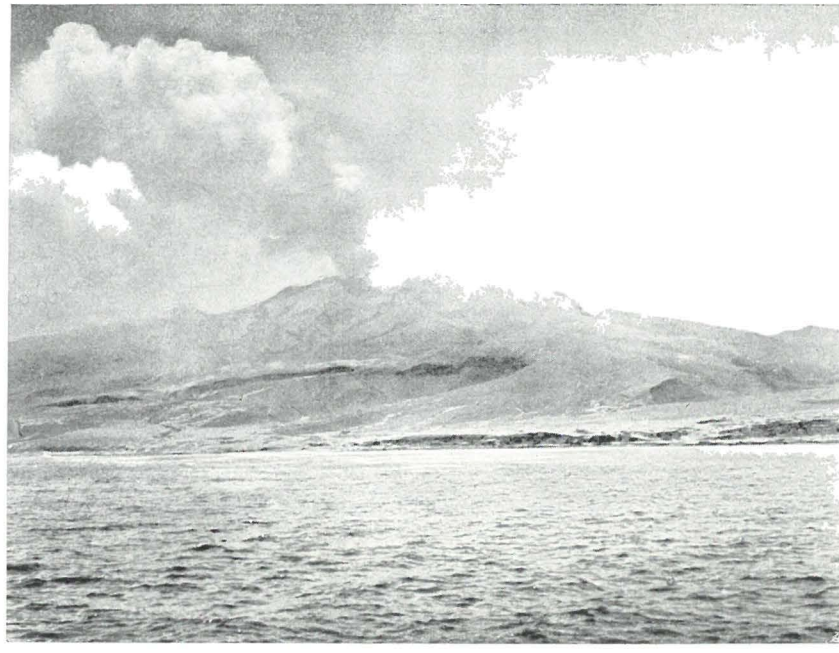


Fig. 1.

Fig. 2.

# Explanation of Plate III.

Fig. 1. **St. Pierre.** A view in the eastern part of the „Quartier du Centre“ 21 May, 1902.

Fig. 2. **St. Pierre.** The valley of the Rivière Roxelane in the northern part of the city as it appeared 22 May, 1902. The Savannah or Boulevard was at the right, the Jardin des Plantes was partly in the gorge at the rear.

Photographs made for the American Museum by E. O. Hovey.

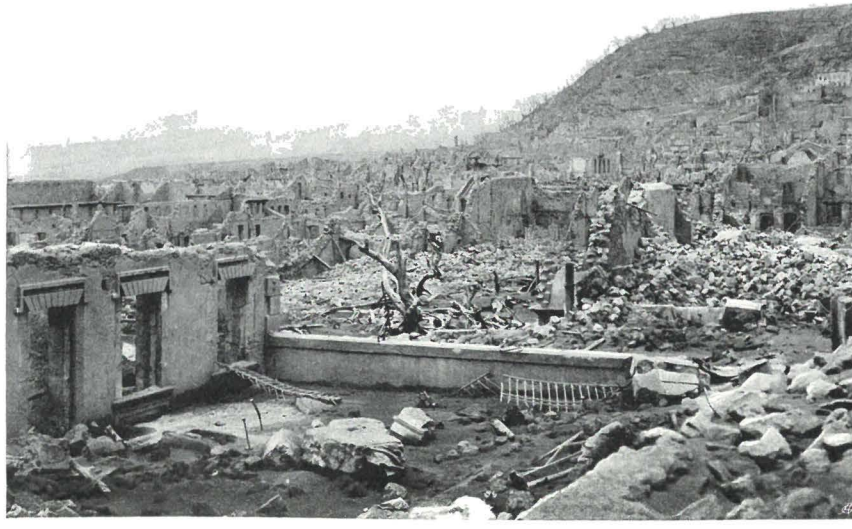


Fig. 1.

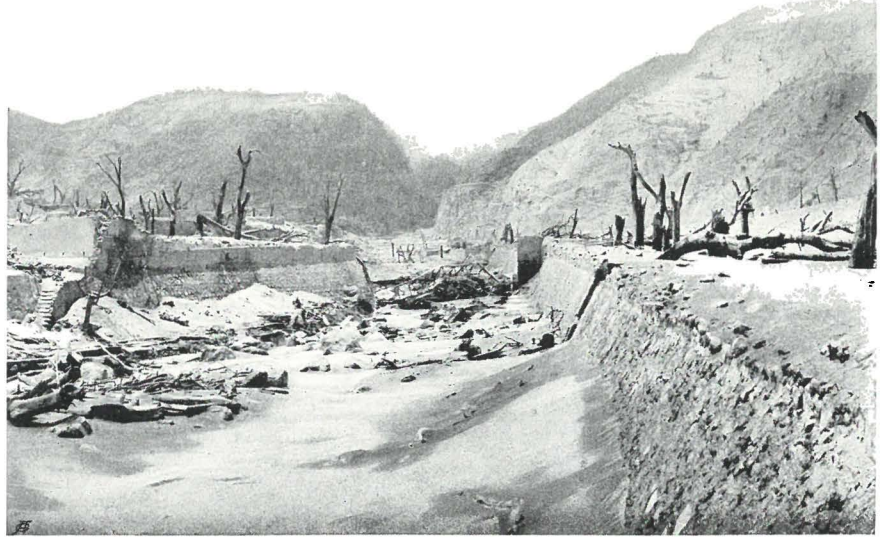


Fig. 2.

# Explanation of Plate IV.

Fig. 1. **Mont Pelé.** A dust-laden steam-cloud or „dust-flow". The bottom of the cloud traversed the gorge of the Rivière Blanche nearly to Morne Saint Martin.

Photographed 6 July, 1902, for the American Museum by E. O. Hovey

Fig. 2. **Mont Pelé.** A similar dust-flow photographed from a positio nearly at right angles to the preceding. July (?), 1902.

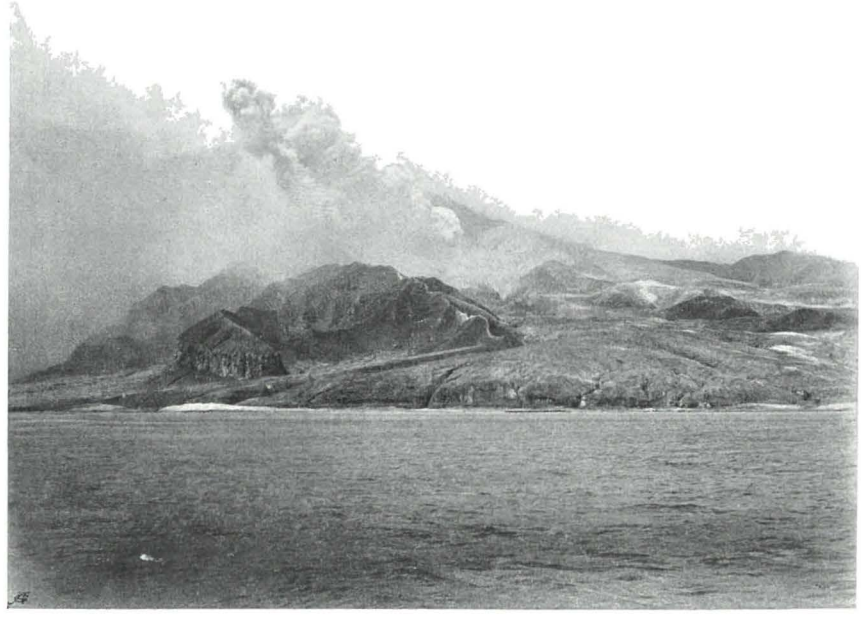


Fig. 1.

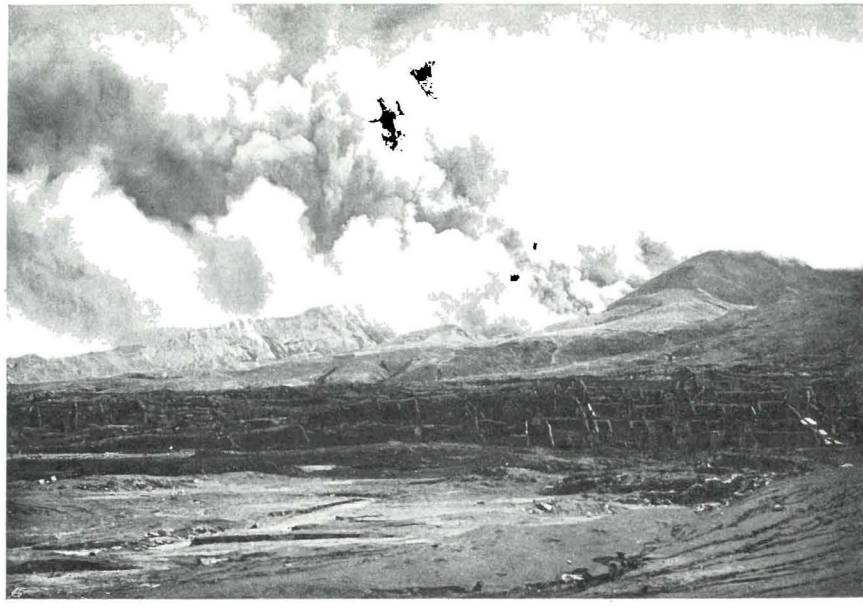


Fig. 2.

# Explanation of Plate V.

Fig. 1. **Mont Pelé.** The ash-filled gorge of the Rivière Blanche, viewed from Morne Saint Martin, 20 February, 1903. Before the eruptions began the upper portion of this gorge was 100—150 *m* deep. The view shows the opposite side of the spine from that in Plate I.

Fig. 2. **Mont Pelé.** The surface of the ash-filled gorge of the Rivière Blanche, showing the great blocks which have been brought down from the new cone with the dust-flows.

Photographs made 20 February, 1903, for the American Museum by E. O. Hovey.

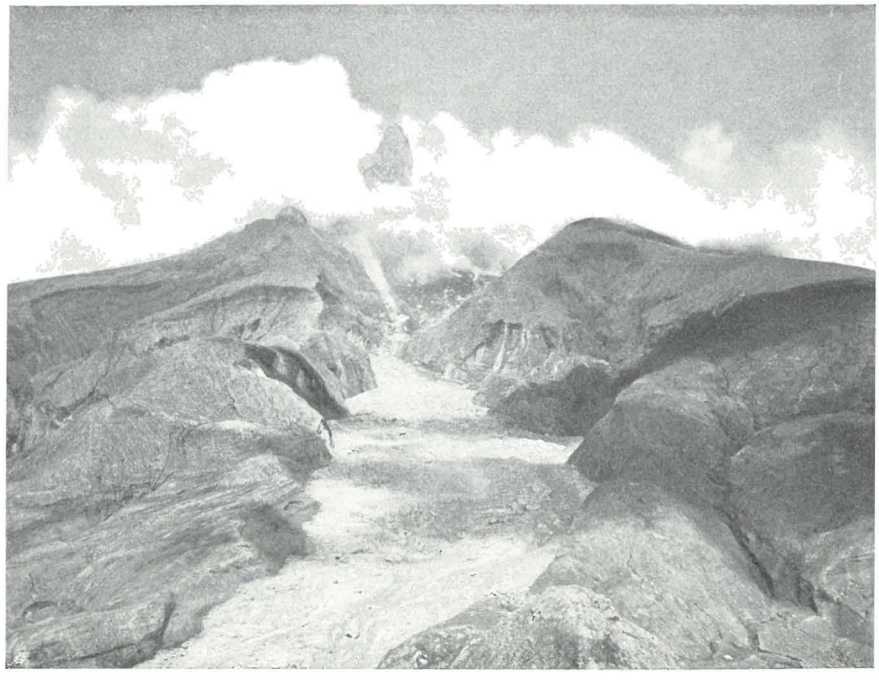


Fig. 1.

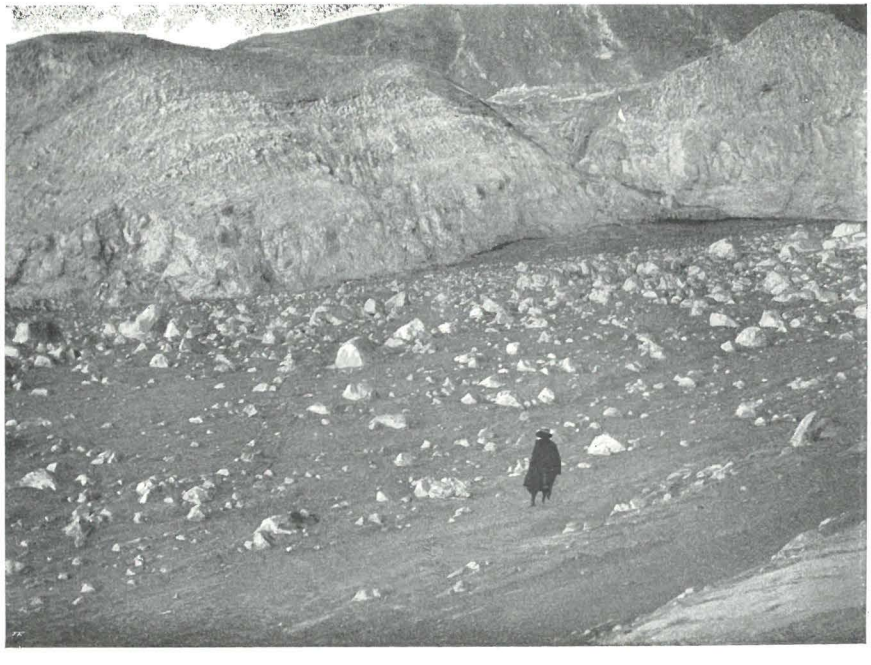


**Fig. 2.**

# Explanation of Plate VI.

Fig. 1. Ejected block which fell upon the divide between Rivière Sèche and Rivière Blanche, about 2 *km* from the crater. The material is a fresh, vitreous hypersthene andesite.

Photographed 20 February, 1903.

Fig. 2. Mont Pelé from the French commission's observatory at Morne des Cadets 9 *km* S. 10° E. from the crater.

Photographed 1 April, 1903.

Photographs made for the American Museum by E. O. Hovey.

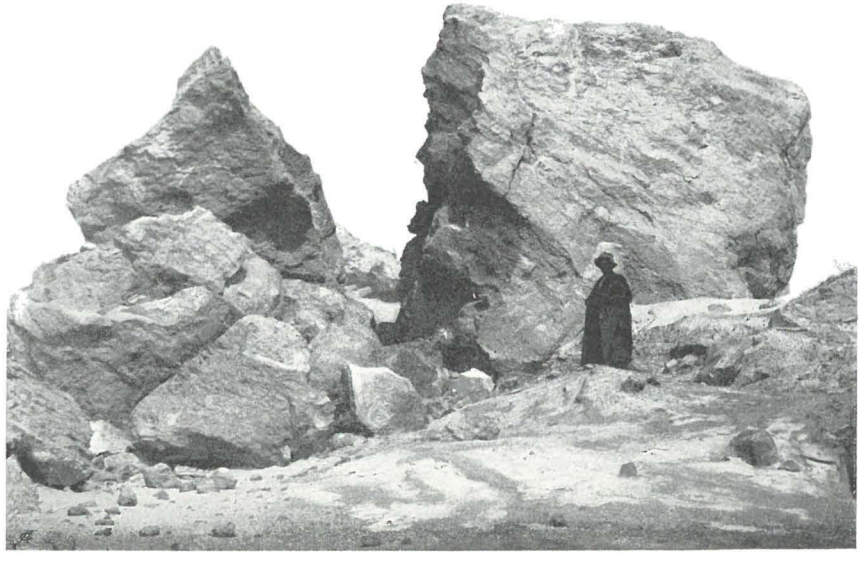


Fig. 1.

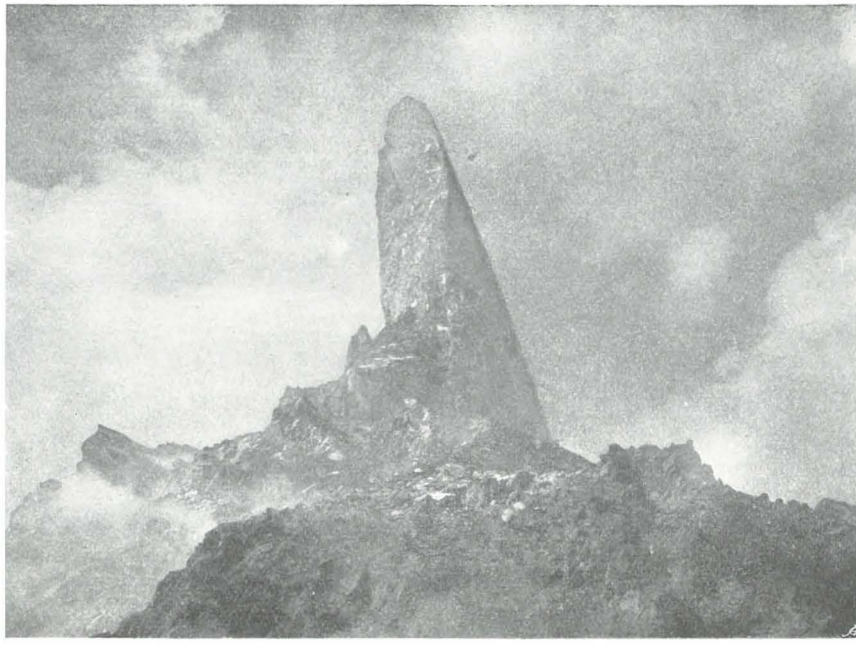
Fig. 2.

# Explanation of Plate VII.

Fig. 1. **Mont Pelé.** The spine, or obelisk, from the crater-rim beside the V-shaped gash. Most of the material in view is of solid (i. e. non-fragmentary) lava. The apex is about 500 *m* above the point of observation.

Fig. 2. **Mont Pelé.** The top of the spine, or obelisk, from the crater-rim, looking about N. 30° W.

Photographs made 26 March, 1903, for the American Museum by E. O. Hovey.



Fig, 1.

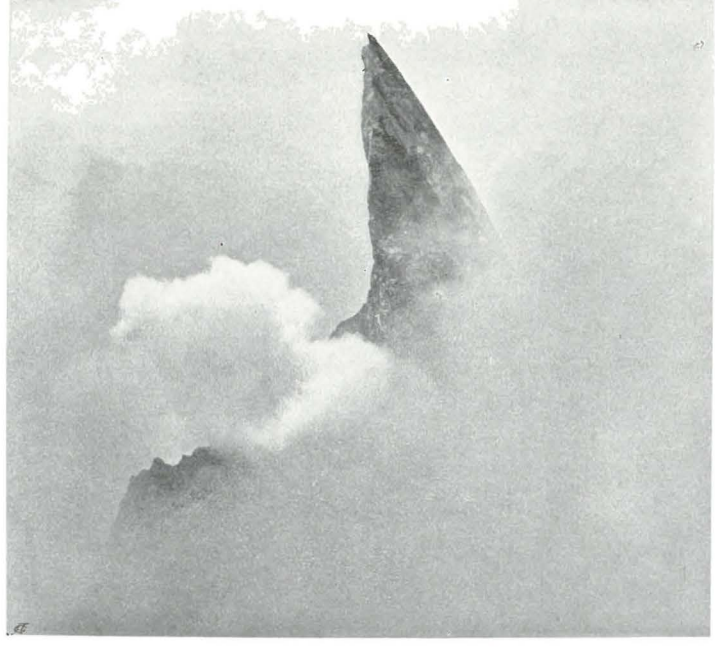


Fig. 2.

# Explanation of Plate VIII.

Fig. 1. **The Soufrière, St. Vincent.** The volcano from the southwest 7 March, 1903. The abrupt shoreline is due to landslides which occurred during the eruptions of May, 1902. In the foreground is the mouth of the Wallibou river. The amount of filling here, due to fresh ashes washed down by the river since the eruptions, is indicated by the fact that in May, 1902, the shoreline was at the extreme right of the area shown in the photograph.

Fig. 2. **The Soufrière, St. Vincent.** A puff from the volcano, 3 March, 1903.

Photographs made for the American Museum by E. O. Hovey.

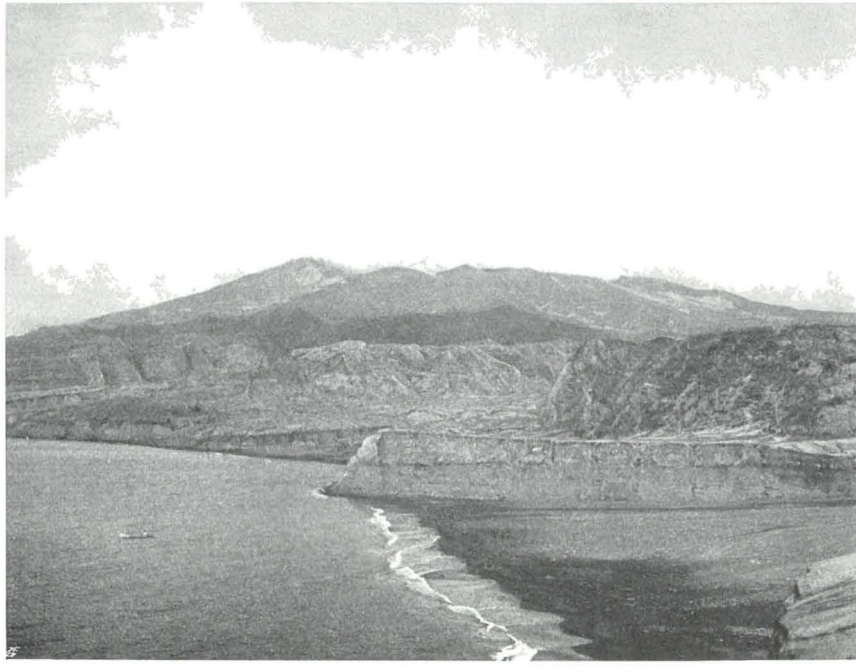


Fig. 1.

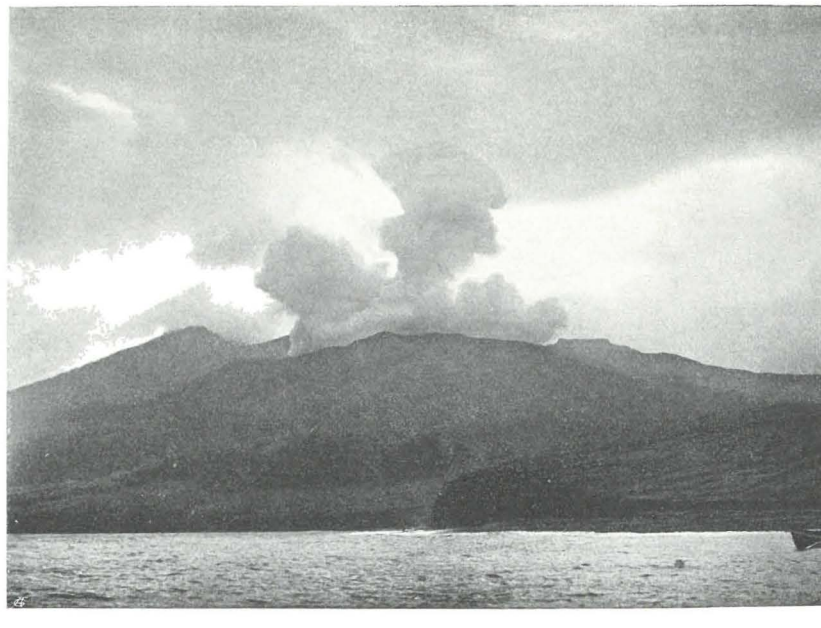


Fig. 2.

# Explanation of Plate IX.

Fig. 1. **St. Vincent.** The ash-filled gorge of the Wallibou river on 30 May, 1902. The little pond in the foreground was formed by a temporary dam thrown across the stream by a secondary eruption from the bed of ash. Within half an hour the waters had flowed over the dam and cut their way down to the level prevailing before the dam was formed.

Fig. 2. **St. Vincent.** The same area as the preceding, showing erosion effected during one rainy season.

Photographs made 7 March, 1903, for American Museum by E. O. Hovey.

Fig. 1.

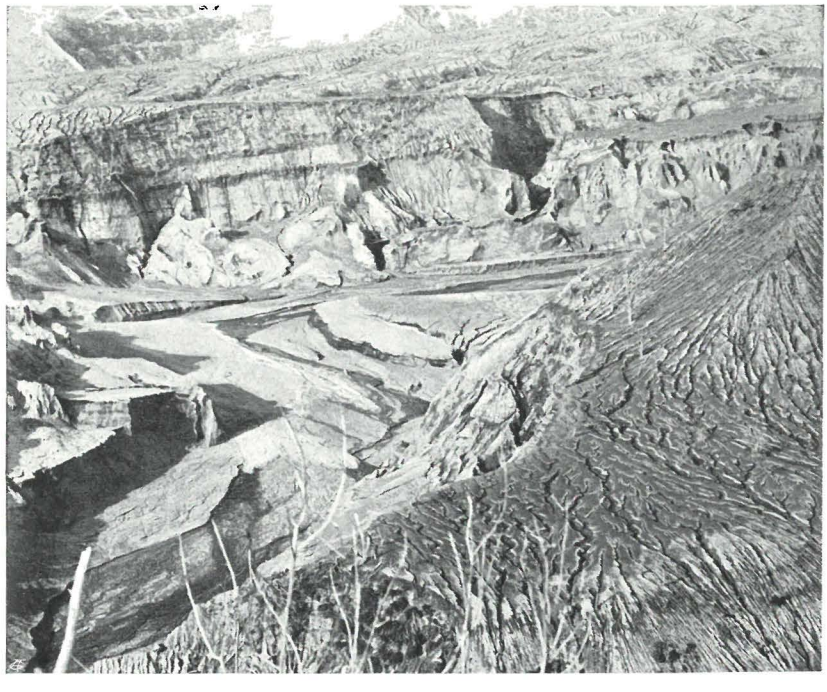


Fig. 2.

# Explanation of Plate X.

Fig. 1. **St. Vincent.** Ash-filled Rabaka valley. Cone formed during secondary eruption. The scale is given by the figure of the man standing on the side of the small cone.

Photographed 7 June, 1902.

Fig. 2. **The Soufrière, St. Vincent.** The mud coating 1 to 3 *m* thick on the upper slopes of the volcano. This was composed of fine dust mingled with water. Saturation by water produced mud flows or mud torrents from time to time.

Photographed 31 Mai, 1902.

Photographs made for the American Museum by E. O. Hovey.

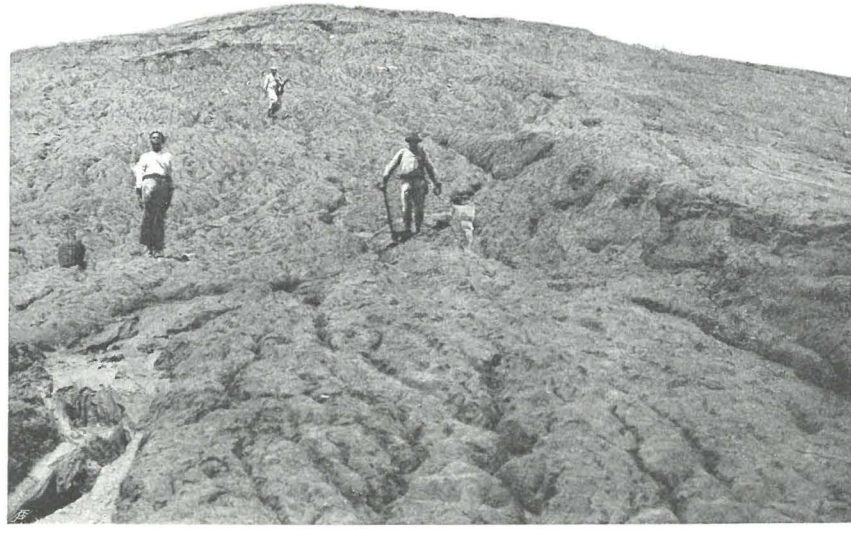


Fig. 1.

Fig. 2.

# Explanation of Plate XI.

Fig. 1. **The Soufrière, St. Vincent.** The Half-way Ridge (480 *m*) on 10 March, 1903. Shows the rough, cindery coat deposited 3—4 September, 1902, upon the fine, slimy coating left by the eruptions of May, 1902.

Fig. 2. **St. Vincent.** Devastation on windward (east) side of the Soufrière, due to the eruptions of May, 1902
Photographed 4 June, 1902.

Photographs made for the American Museum by E. O. Hovey.

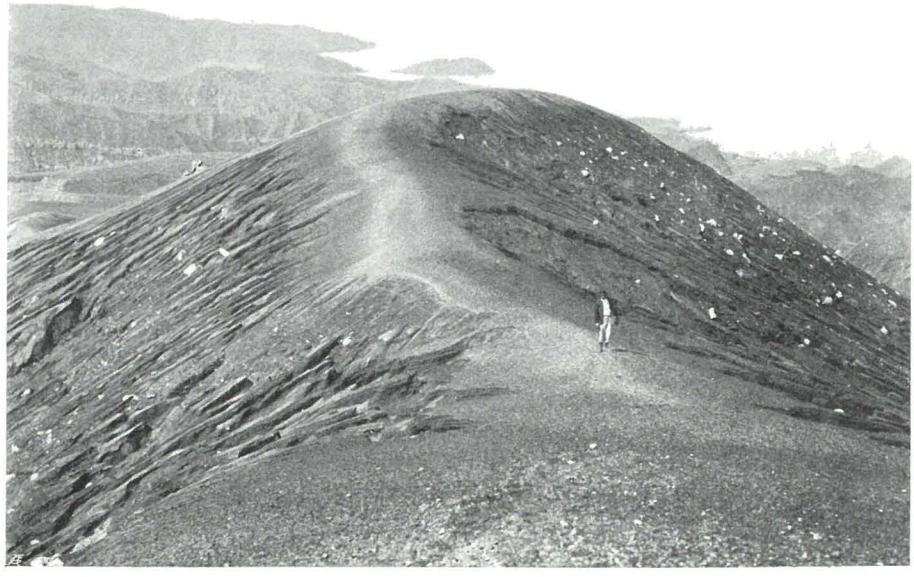


Fig. 1.

Fig. 2.