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procure the sacred books of Buddhism. The translation is that of Dr. J. Legge—

"After travelling for seventeen days, a distance we may estimate of about 1500 li (from Tun-huang), the pilgrims reached the kingdom of Shen-shen, a country rugged and hilly, with a thin and barren soil. The clothes of the common people are coarse and like those woven in our land of Han, some wearing felt, and others serge or cloth of hair. The king professed our law, and there might be in the kingdom more than 4000 monks, who are all students of the hinayana (small vehicle of salvation). The common people of this and other kingdoms in this region, as well as the sramans (monks), all practice the rules of India, only the latter do so more exactly, and the former more loosely. Here the pilgrims stayed for about a month, and then proceeded on their journey, fifteen days' walking to the north-west bringing them to the country of Wu-e. In this there were more than 4000 monks, all students of the hinayana."

Hsian-Tsang (629-645 A.D.) passed through Lau-lan on his return from India, two centuries later than Fa-Heen, but his notice on this country is extremely meagre. We are merely told that, after leaving the walled but deserted town of Tche-mo-to-na, or Nimo, "he travelled 1000 li in a north-easterly direction, and reached Na-po-po, which is the same as Lau-lan."

RECENT VOLCANIC ERUPTIONS IN THE WEST INDIES.*

By Dr. TEMPEST ANDERSON.

It will be in the remembrance of every one present that in May, 1902, severe volcanic eruptions took place in St. Vincent and Martinique, both of which islands form part of the chain of the lesser Antilles in the West Indies. The Royal Society appointed a committee to investigate the eruptions, by whom I had the honour of being nominated along with Dr. J. S. Flett, Petrologist to the Geological Survey, to proceed to the scene of the eruptions and report to them. In our report, read before the Royal Society on November 20, we have already entered fully into the description and discussion of the phenomena observed; it will be better, therefore, in this paper to content myself with a *résumé* of the chief points, with special references to the geographical changes produced.

The islands of the lesser Antilles, from Saba on the north to Grenada on the south, form the summits of a chain of mountains about two-thirds submerged; for while their highest peaks reach eleva-

* Read at the Royal Geographical Society, January 12, 1903. Maps, p. 348. The descriptions of the plates will be found at the end of the paper.

tions of barely 5000 feet above sea-level, the depth of the Caribbean sea to the west is over 10,000 feet. They occupy the summit of a great fold of the Earth's crust, and are almost entirely volcanic, the chief exception being Antigua and a small portion of the eastern part of Guadeloupe, which, with Barbados, appears to form part of another fold more to the east, which is not volcanic. Other volcanoes occur on the mainland to the west of the Caribbean sea, one of which in Guatemala has also recently been in eruption. Earthquakes had taken place in the region surrounding the Caribbean sea during some months previously, and it has been concluded that the readjustments of the Earth's crust which gave rise to these have also been connected with the eruptions in St. Vincent and Martinique.

The island of St. Vincent is oval, the long diameter being nearly north and south. It is about 18 miles long and 11 miles wide. A mountain chain stretches along the main axis of the island, and reaches to a height varying from 2000 to 4000 feet, the highest point being just over 4000. It is entirely composed of volcanic materials, the beds dipping away from the central mass in all directions towards the sea. They consist chiefly of tuffs and agglomerates—in fact, fragmentary materials resembling those discharged from the Soufrière during the recent eruptions. Among them are many ejected blocks of enormous size, even as much as 20 or 30 feet in diameter, showing that some of the former eruptions must have been explosive like the late one, but on a grander scale. Lava-flows are comparatively few, but not entirely absent, and dykes are rare.

In the southern part of the island volcanic action has long been extinct or dormant, and we did not see any remains of craters, all such having apparently been removed by denudation. Towards the northern part of the island, however, is the great mass of the Soufrière mountain, in the summit of which is a crater of an almost circular form, about a mile in diameter. This, which is called the old crater, appears to have been the chief, if not the only, site of the recent eruption. On the north-east of the old crater, and only separated from it by a narrow ridge, is the so-called new crater, which was active in 1812. It is only about one-third of a mile in diameter, and it is doubtful whether it took any part in the last eruption. To the north of these craters, and partly encircling them, is an old crater-ring, which bears the same relation to them as Somma does to Vesuvius. The name Morne Garu was formerly applied indiscriminately to all this mountain range, but now has become restricted to a peak some distance to the south of the main crater, while the name Soufrière appears to be always given to the active cone.

To the south of the main craters, and between them and Morne Garu, a great depression or system of valleys extends right across the island. The eastern side of this is occupied by the Rabaka Dry river and

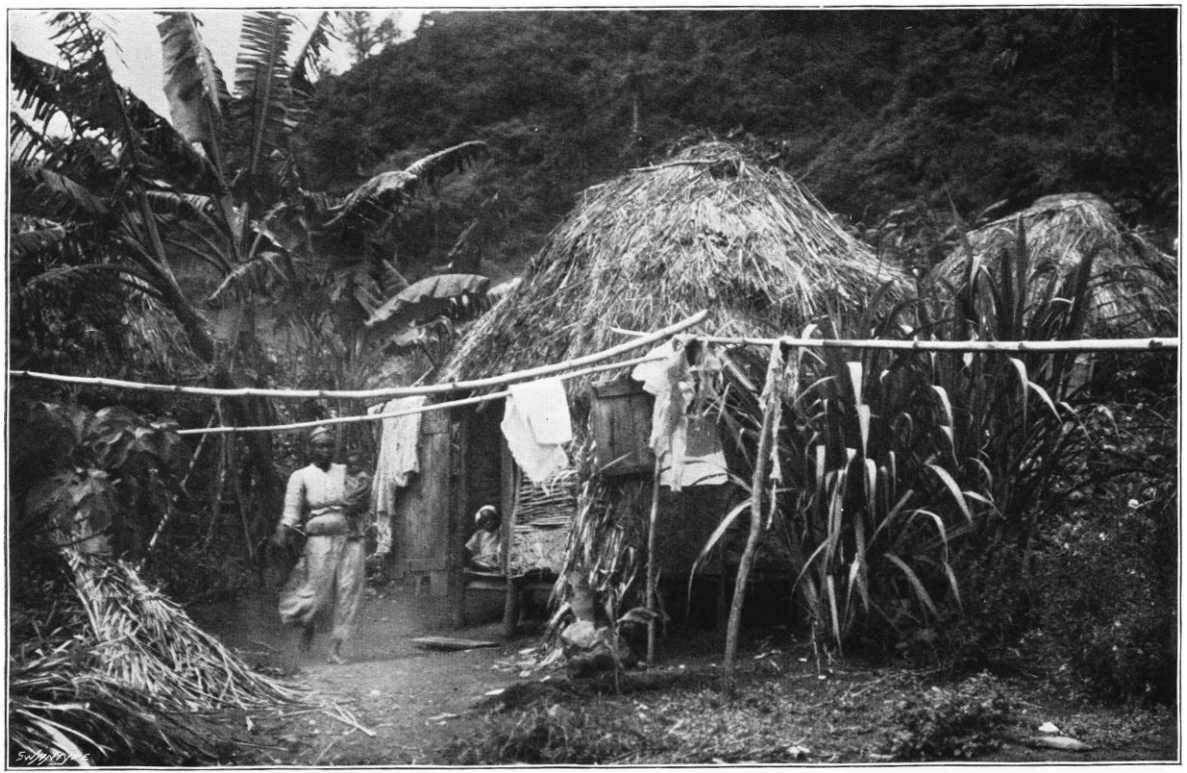


PLATE I.—TROPICAL VEGETATION. CHATEAU BELAIR, ST. VINCENT.

PLATE II.—THE WALLIBU DISTRICT FROM THE SEA.

its tributaries, which drain into the sea on the windward coast north of George Town. The western, which is rather more extensive, is much eroded into deep valleys and ravines, often with almost precipitous sides, in which flow the rivers and torrents, which are often dry, and go by the names of Wallibu, Wallibu Dry river, Rozeau, Morne Ronde, and Larikai. The rocks of which this part of the mountain is composed are almost entirely tuffs and agglomerates formed of fragmentary material, similar to that ejected from the volcanoes during the recent eruption. We saw a few beds of lava, but they were chiefly exposed in the deeper parts of ravines, and were obviously of much older date than the more superficial portions. This great transverse valley, and especially its western portion, the valley of the Wallibu, received the greater part of the products of the eruption, amongst which we saw no lava, and do not believe any was erupted. A considerable number of ejected blocks * were noticed, but the great bulk of the material consisted of fine sand and ashes—in fact, lava blown to pieces by the sudden expansion of its imprisoned gases. The trade-wind blows steadily from the east or north-east, and a certain amount of the finer particles would be caught by the wind and deposited in the Wallibu valley. A considerable amount was also driven directly upwards so violently as to go through the whole thickness of the trade-wind and get caught by an upper current in the reverse direction, by which it was carried to the east as far as Barbados and the surrounding sea. A certain quantity fell on the north slopes of the volcano beyond the Somma ridge and along the east coast as far as to beyond George Town, but the greatest deposit which we saw, and in comparison with which all the others were trivial, was in the Rabaka and Wallibu valleys.

The tropical rains have cut deeply into the soft strata which form the cone of the Soufrière and the slopes at its foot, and have produced a series of branching valleys with steep or almost precipitous sides, and separated by the narrowest of ridges—in fact, often mere knife-edges. The whole, before the eruption, was clothed with the most luxuriant tropical vegetation. Into this series of valleys was discharged from the Soufrière a black cloud, so heavily laden with incandescent dust that it might most fitly be described as an incandescent avalanche. The mechanism of its production is discussed below, but its immediate geographical effect was to fill the Rabaka and Wallibu valleys and some of their tributaries to a depth in some places as great as 200 feet. The motion of the mass was sufficient to prevent any large amount of hot sand being deposited on the ridges, while the hollows received the greater part, and the whole was smoothed over by the blast, and lay in rolling masses like drifted snow. Thus in the course of a single

* The nature of these will form the subject of a special report to the Royal Society by my colleague, Dr. Flett.

day, or probably much less, the whole of the vegetation on this part of the mountain was utterly devastated, and the valleys were filled up with a deep new deposit of incandescent sand. This was the first and most obvious geographical alteration.

When we arrived on the scene a month later, secondary changes had taken place to a very marked extent. The wet season had set in in earnest, and as much as 5 inches of rain had been registered in one period of twenty-four hours. Denudation was taking place on a prodigious scale. The surface was everywhere scored with rain-furrows, which joined together in a sort of feather-pattern into larger streams, which had cut deep channels into the soft material; and these again united to form rivers, which in some cases had re-excavated the old channels, but in others had cut new and quite independent ones. The amount of denudation that had been accomplished in this short space of time seemed incredible to one accustomed to the leisurely rate of change in temperate climates. The Wallibu had excavated a new bed in the hot ash nearly 80 feet deep, and had left in places as many as five or six terraces to mark successive stages of its excavation, and the Rabaka on the east side had cut a corresponding gorge. Nor were the changes yet complete; we were fortunate in seeing them still in progress, and obtaining photographs of many of the most striking phenomena. When the weather was fine little change was to be seen, though the ash was still smoking, and hot enough in places even on the surface to burn the bare feet of our porters. Most of the river-beds were then also dry, but a brisk shower of rain changed all this. The water came down the rivers in torrents and undermined the steep banks. This started landslides of hot ash, which fell into the river, and explosions of steam on an enormous scale took place. Showers of hot mud were thrown up to a height of perhaps 150 feet like great geysirs, and great clouds of steam, laden with brown dust, rose to a height of many hundred feet, and were carried away to sea by the trade-winds. Nor was this all: the fallen ashes often dammed the streams, and when the water at last overcame the obstruction it descended no longer as water, but as a gush of boiling-hot mud, which made the river-bed temporarily impassable, and built up alluvial fans at the mouth of the river. One day when we ascended the Soufrière, we crossed dry river-beds without difficulty in the morning when the weather was fine, but on returning in the afternoon, heavy rains having fallen in the mean time, a small river was full of boiling mud, and we were only able to cross it by the aid of a bridge which our men constructed of trees killed by the eruption, and this we saw carried away by a great gush of boiling mud soon after we had got over.

The spots from which these explosions had taken place, when sufficiently cooled to be approached safely, were also interesting. They formed bowls or funnels from perhaps 10 feet to 30 feet in diameter,

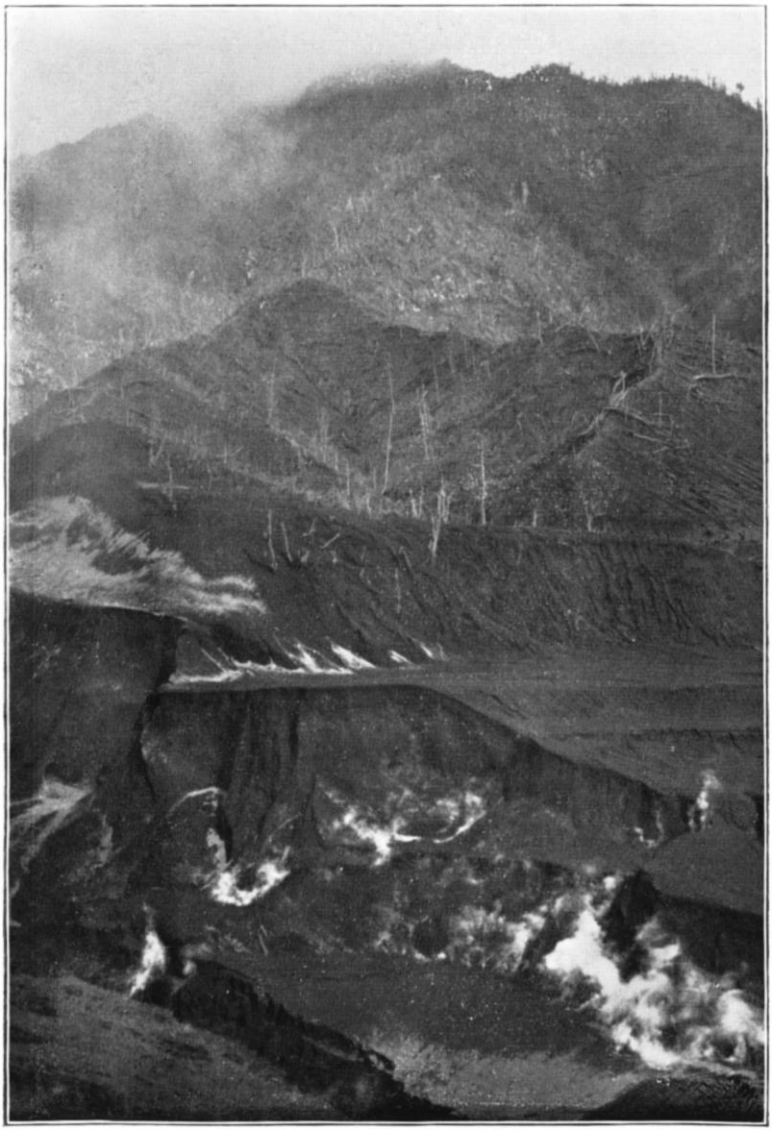


PLATE III.—IN THE WALLIBU VALLEY.

which, however, were seldom perfect, as one side had generally been removed by the stream as it cut its way deeper, and left the remains of the bowl standing as a depression in its bank. Surrounding the bowl was a low cone of *débris*, consisting of the stones and larger fragments which had been thrown up and fallen down around it, while the lighter sand was carried away by the wind. These new valleys, with their details—the terraces and steam-bowls and the associated fans and deltas—constitute another geographical change.

The shore deposits deserve a separate mention. On the windward coast especially, the amount of sand brought down by the streams had been so great that for 2 or 3 miles a new beach had been formed by the mud carried along the coast by the waves, where formerly the sea reached the foot of the cliffs; but this will no doubt eventually be washed away again.

We looked carefully for signs of general upheaval or depression of land, but without finding any. The rise and fall of the tide amounts to only about 2 feet, and the sea has made very definite marks along the face of the cliffs where they happen to be composed of lava or hard tuff. We were satisfied that no alteration of level more than a few inches could have taken place, and our boatmen, who knew the place well, were of the same opinion. There was, however, one very remarkable instance of a local subsidence which deserves notice.

At the mouth of the Wallibu valley, on the leeward side, extending from Richmond village on the south to Morne Ronde on the north, a distance of above a mile, there was formerly a low foreshore, along which ran the main road. It was described to us as having been covered with palm trees and luxuriant tropical growth, and studded with numerous picturesque villages, which nestled in beautiful little bays. Similar places still exist just outside the devastated area at Chateau Belair, Rose Bank, Barruali, and Layu.* Behind the foreshore the land rose in steep bluffs composed of fragmentary volcanic deposits like the rest of the Wallibu district. On the day of the great eruption the whole of this foreshore subsided into deep water, and as submarine slopes here are very steep, it is probable that the earthquakes connected with the eruption set up landslides, with the above results. It is possible that there may have previously been a fault along the line of the foot of the bluff, which determined the actual slip, and if this be so it might account for hot water rising here, which gave the name of Hot-waters to one spot; but, whatever be the exact cause, this subsidence is a geographical change worth mention.

The next geographical change noted was that the crater has been somewhat enlarged, especially at its southern lip, but not to any conspicuous extent; it has lost its clothing of vegetation, but this will

* The last beyond the map.

soon be renewed, and its contained lake has been discharged, but it is already beginning to fill again. Any one who knew it before and visited it now would notice a considerable change, but, if he deferred his visit for a few years, would probably see no marked difference.

Another curious little secondary result deserves notice. Water will hold more mud in suspension when it is flowing down a steep slope. The water in the steeper upper parts of the valleys was charged with mud to the utmost, but where it descended on to more gentle slopes, and consequently moved more slowly, it could not carry so much, and deposited part, especially where it moved slowly at the side of the stream. We saw two places where dams had thus been formed across the mouths of small lateral valleys, and small lakes or large ponds had been produced. As the dams were only soft mud, these may only be temporary; but I have seen a permanent lake of several acres formed in this way in Iceland, by a bank of shingle brought down by a rapid glacial river. Dr. Flett thinks, and I agree that the explanation is feasible, that these lateral dams are the remains of the avalanche which filled the valley during the eruption, and that the centre part only has since been washed away.

A watercourse formerly existed which supplied all the plantations in the Carib country on the east or windward slope of the mountain with water taken from the Rabaka river high up. The river has now changed its course, and no water enters the conduit, which, moreover, in places is blocked up with ashes. This, however, can doubtless be remedied, but, as far as it goes, is a geographical change. The plantation buildings were not of sufficient size for their destruction to be of geographical importance, and the black population will, according to all previous experience, return after the cessation of the eruptions.

On the whole, the permanent geographical changes in St. Vincent are comparatively small. It remains to discuss the mechanism of the eruption; but this will be better considered along with that of Mont Pelée.

Turning now to the consideration of Martinique, I may remark that our instructions were to proceed first to St. Vincent and devote our chief attention to that island. This we did, but later on we went also to Martinique, for the purpose of making such an examination as would enable us to compare the phenomena of the two volcanoes.

There is remarkable similarity between the islands of St. Vincent and Martinique. Both are roughly oval in form, with the long axis almost north and south. The north-west portion of each is occupied by a volcano, the Soufrière and Mont Pelée, more strictly called Montagne Pelée, which have many points in common. Both volcanoes show a single or practically single vent, a remarkable absence of parasitic cones, and a scarcity of dykes. In both a transverse valley exists to the south of the volcanoes, and the main discharge of ejecta during

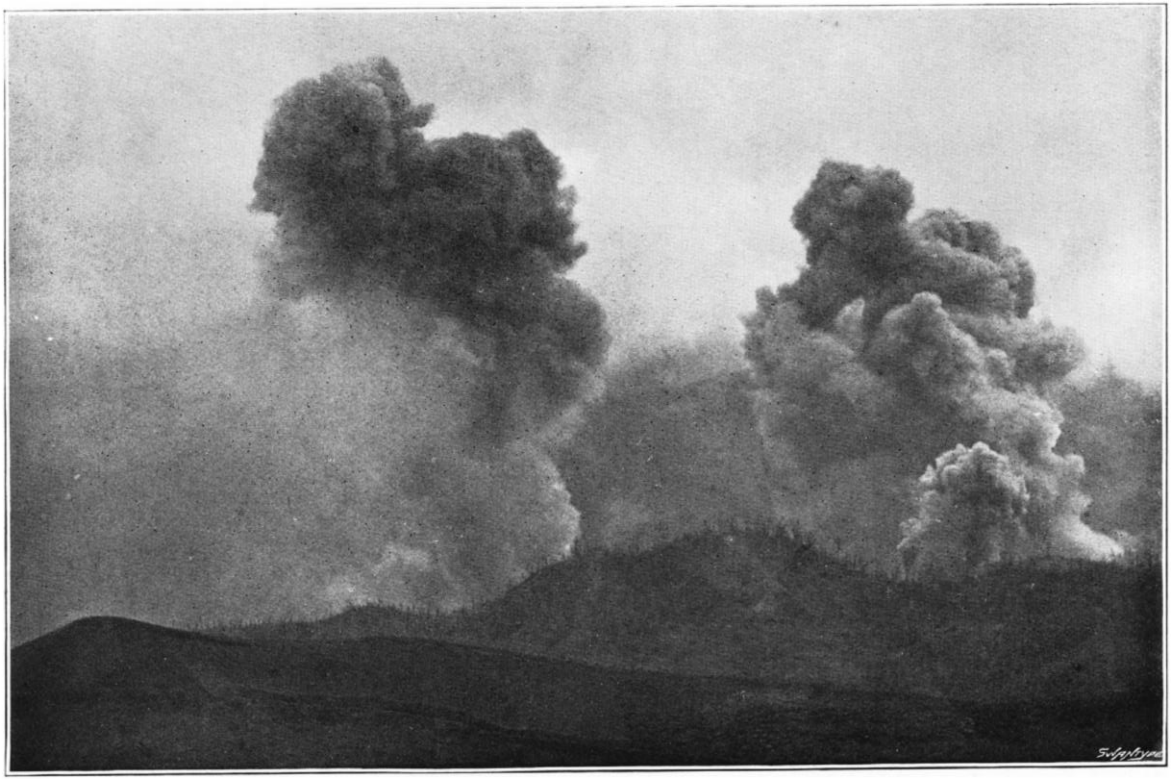


PLATE IV.—STEAM AND ASH EXPLOSIONS, WALLIBU.

PLATE V.—ROZEAU DRY RIVER FLOWING WITH BOILING MUD.

the recent eruptions, which have often been nearly synchronous, has been into this depression, and especially into its westerly portion. In both islands the recent eruptions have been characterized by paroxysmal discharges of incandescent ashes, with comparatively few larger fragments and a complete absence of lava.

There are, however, a few points of difference. The eruptions of St. Vincent have been altogether on a much larger scale than those in Martinique. The area devastated was considerably larger, the amount of ashes ejected probably ten times as great, and if the loss of life was not so large, this is accounted for by the absence of a populous city at the foot of the mountain. If such a city had existed at the mouth of the Wallibu river in St. Vincent in the position corresponding with that of St. Pierre, there can be no doubt that it would have been as completely destroyed as that unfortunate city. While both volcanoes show practically a single vent, this is much more marked in the case of St. Vincent, where excepting the new crater, which is really part of the old or main one, there is not a single parasitic cone. We saw no fumaroles, no hot springs, nor any trace of radial cracks and fissures.

On Mont Pelée, it is true, the main activity is confined to a restricted area about the summit of the mountain, and the top of the great fissure which extends or extended from this down in the direction of the Rivière Blanche; and there are no parasitic cones comparable, for instance, to those which are so numerous on Etna; but there are many fumaroles, which Prof. Lacroix and his colleagues speak of as emitting gases hot enough to melt lead, though not copper wire. A telegraph cable has been three times broken at about the same place, and the broken ends on one occasion, at any rate, showed marks of fusion of the insulating medium. There are also several hot springs. Judging from these and other indications, it is most probable that radial cracks entered deeply through the substance of the mountain, and penetrated even the submarine portion of its cone.

Flows of mud have also played a much more conspicuous part on Mont Pelée than in St. Vincent. Quite early in the eruption a great flow of this kind came down the Rivière Blanche and overwhelmed the Usine Guérin, which stood near its mouth, so that now nothing remains visible but the upper part of the chimney stack. It is probable that some at least of these mud-flows may have been due to the discharge of the small crater lake which existed before the eruption, or to heavy rains, the water in either case behaving in a manner comparable to what we saw in the Wallibu; but, at any rate, they occupy a more prominent part in the descriptions of these eruptions than in those of the Soufrière.

Not only has the amount of erupted material been much less, but its distribution has been much more local than in St. Vincent, and this is

accounted for by the great fissure at the top of the valley of the Rivière Blanche, which communicated with the main pipe of the volcano, and out of which the eruptions took place. This fissure, which was mentioned as existing in the eruption of 1851, pointed almost directly towards St. Pierre, and as the erupted material flowed out almost like a fluid, it was directed straight down on the doomed city. The lowest portion of the lip of the crater of the Soufrière was much broader and more even, so the incandescent avalanche which descended from it was spread much more widely.

The latest accounts from Prof. Lacroix indicate that the recent small eruptions of Mont Pelée have filled up the highest parts of the fissure and formed a cone, which covers up most of the former crater. In any further eruption, therefore, the avalanche of incandescent sand will not be confined to the district of the Rivière Blanche, but may descend on any side of the mountain.

Coming now to more strictly geographical details, it is wonderful how small have been the changes produced, smaller than even those in St. Vincent.

The north end of St. Pierre is completely buried in dust or levelled with the ground, so that nothing remains visible of the ruins of the houses except in certain protected situations, and the plateau rising to the north of the town towards the foot of the mountain is also covered. It is difficult to state the exact depth, but it is certainly inconsiderable in comparison with the 200 feet in the Rabaka, or even the 80 feet in the Wallibu. Further to the south, in the centre of the city of St. Pierre, the amount of ashes was much less; a great deal has been already washed away, but I doubt if it ever was more than 2 or 3 feet thick on an average, and on Morne d'Orange, at the south end, it was quite insignificant—only a few inches. The destruction of St. Pierre itself by the incandescent avalanche, and the hot blast and attendant conflagration, is an event of intense human interest as being attended by the sudden death of over 30,000 persons, but from the point of view of the physical geographer can hardly be called considerable, neither can the carrying away of a few small bridges, nor the formation of a small mud delta at the mouth of the Rivière Blanche.

It remains now to discuss the nature of these peculiar eruptions. They belong to a type which have hitherto been imperfectly, if at all, described, and we were fortunate enough to witness at a distance, at least as close as was safe, one of the characteristic eruptions of Mont Pelée, and thereby to confirm the views which we had previously formed by observation of the effects of those of the Soufrière.

On arrival at Fort de France we found that the devastated area to the north of the island was still almost entirely unoccupied. The greater part of the inhabitants of St. Pierre and the neighbourhood had been killed by the eruption, and the few survivors were only returning

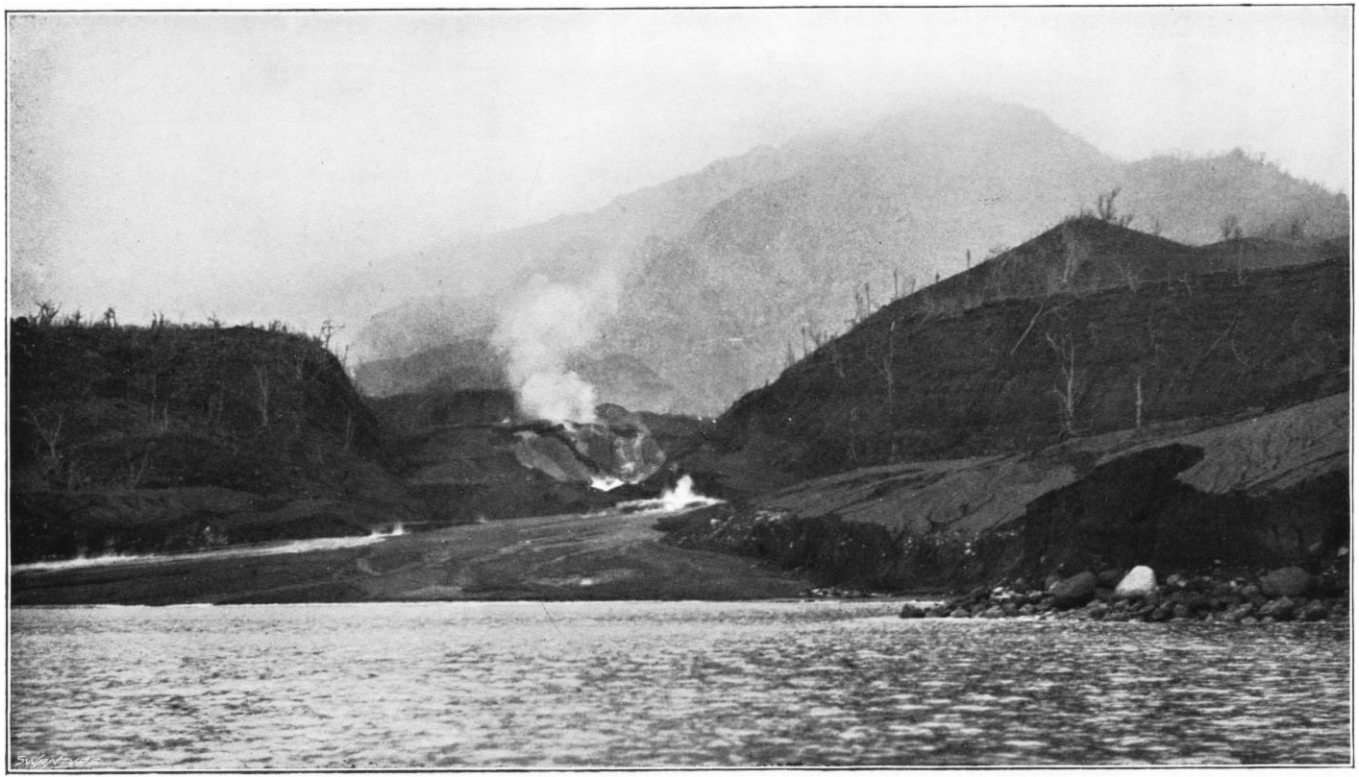


PLATE VI.—THE MOUTH OF THE WALLIBU FROM THE SEA.

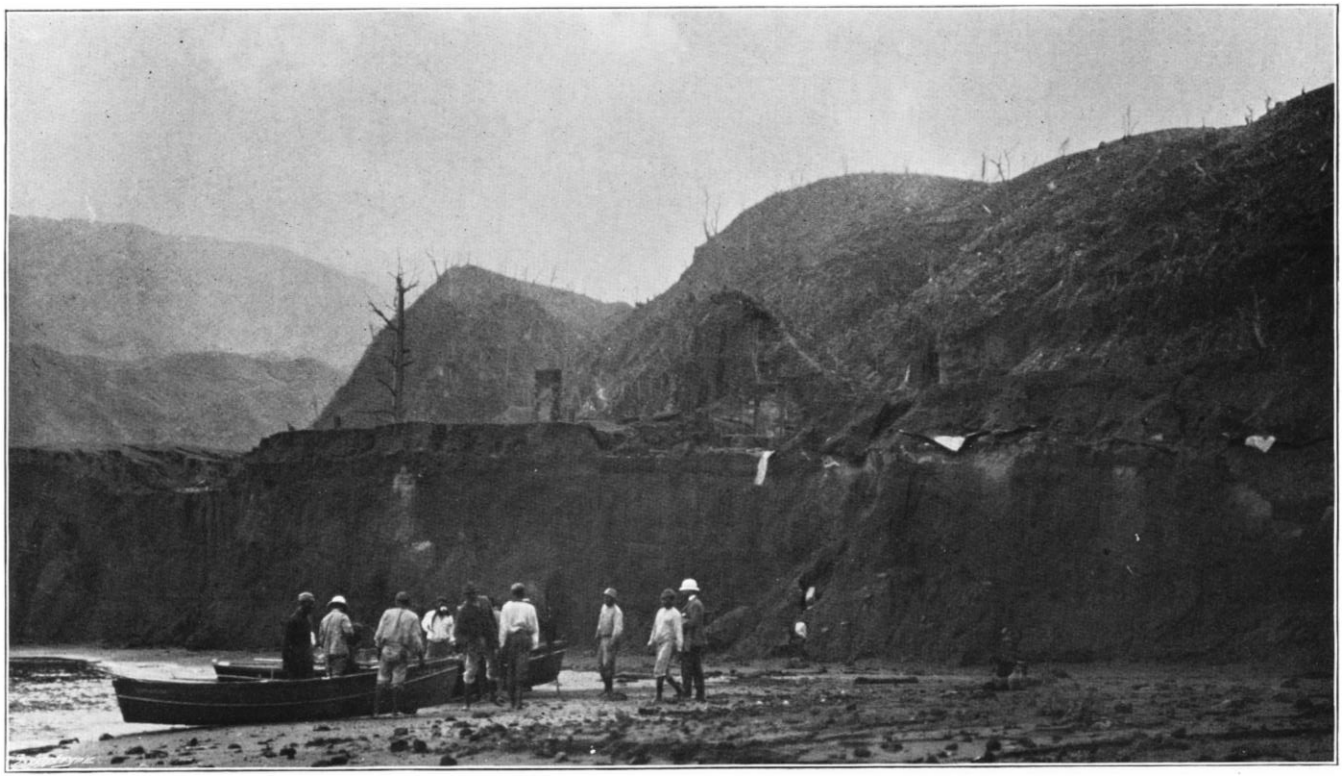


PLATE VII.—THE SITE OF THE WALLIBU SUBSIDENCE.

by slow degrees. It was therefore impracticable to make our base of operations on land near the scene of eruption. Fort de France was too far away to be available, except at a ruinous expenditure of time and money in going to and fro. It was therefore determined to engage a sloop, provision it, and live on board, moving by day to any point where landing was desirable, and retiring at night to some safe anchorage within reasonable distance. We devoted our first day to an examination of the ruins of St. Pierre, and in the evening we moved about 2 miles south along the coast and spent the night at anchor off Carbet, just at the limit of the area of devastation, at a spot commanding a full view of the mountain. Next morning we returned to St. Pierre, and moored the sloop to one of the buoys at the north end of the town. Dr. Flett landed and further examined the ruins, while I remained on board and took photographs of the magnificent cauliflower masses of dust and steam which were frequently ejected from the great triangular fissure above mentioned. Later in the afternoon we sailed further north along the coast, still taking photographs of Mont Pelée, which was clearer that day than we ever saw it before or after, and showed to great perfection the deeply eroded valleys with which its slopes are scored. They much resemble those in corresponding position on the slopes of the Soufrière in St. Vincent, and appear to be formed in the same way in strata of similar composition, viz. fragmentary ejecta from the volcano which had consolidated to form soft tuffs, and had subsequently been eroded into their present forms by ordinary atmospheric agencies.

I have ventured thus to write in narrative form as leading up to the occurrences of that memorable evening. We returned and sailed slowly south past the base of the volcano, witnessing and photographing many small explosions and their cauliflower clouds of dust, and thus twice crossing the track of the eruption which took place later. We anchored as before off Carbet, and watched the sun set behind the clouds of ashes ejected by the volcano. When approaching the horizon and thus viewed, the sun appeared a sickly yellowish-green, and so pale that it could be looked at with the naked eye without discomfort. Later on, after sunset, the gorgeous after-glow appeared, and the thin clouds in the western sky were lit up with most brilliant red, beginning perhaps 30° or 40° from the horizon, while the part below still remained yellowish-green. Later still, as the sun sank further below the horizon, the yellowish-green area sank also, and only the reds remained, till they too sank out of sight, and gave place to the light of a brilliant three-days-old moon. We had sat on deck absorbed in watching this superb spectacle, and were just going to begin supper, when one of us, looking towards Pelée, said, "That cloud is different to the others. It's quite black, and I'm sure it's coming this way." A few moments' examination confirmed this, and, the captain's attention being called to it

we all, passengers and crew, heaved up the anchor as quickly as possible, and set all sail. The black cloud had meanwhile rolled down the side of the mountain on to the sea, and came quickly towards us. We had not moved a moment too soon. The upper slopes of the mountain cleared somewhat, and some big red-hot stones were thrown out; then I saw the triangular crack become red, and out of it poured a surging mass of incandescent material, reminding me of nothing so much as a big snow-avalanche in the Alps, but at a vastly different temperature. It was perfectly well defined, did not at all tend to rise like the previous cauliflowers, but flowed rapidly down the valley in the side of the mountain which had clearly been the track of previous eruptions, till in certainly less than two minutes it reached the sea, and was there lost to view behind the remains of the first black cloud, with which it appeared to coalesce. There and on the slopes of the mountain were doubtless deposited the greater part of the incandescent ash, while the steam and gases, with a certain portion of still entangled stones and ash, came forward in our direction as a black cloud, but with much greater rapidity than before. The sailors were now alarmed, nay, panic-stricken, got out the oars and pulled for their lives. Meanwhile the cloud came nearer and nearer; it was well defined, black, and opaque, formed of surging masses of the cauliflower type, each lobe rolling forward, but not all with one uniform rotation; bright scintillations appeared, some in the cloud itself, and some like little flashes of light vertically between the cloud and the sea on which it rested. These were clearly the phenomena described by the survivors in the St. Vincent eruption as "fire on the sea," occurring in the black cloud which overwhelmed the windward side of that island. We examined them carefully, and are quite clear that they were electric discharges. The scintillations in the body of the cloud became less numerous and more defined, and gradually took the form of vivid flashes of forked lightning darting from one part of the cloud to another. The cloud rapidly gained on us. When it had got within perhaps half a mile or a mile—for it is difficult to estimate distances at sea and in a bad light—we could see small material falling out of it in sheets and festoons into the sea, while the onward motion seemed to be chiefly confined to the upper part, which then came over our heads and spread out in advance and around us, but left a layer of clear air in our immediate neighbourhood. It was ablaze all the time with electric discharges.

As soon as it got overhead stones began to fall on deck, some as big as a walnut, and we were relieved to find that they had parted with their heat and were quite cold. Then came small ashes and some little rain. Eventually we gained the harbour of Fort de France unhurt, and the proposed ascent of Mont Pelée next day, for which men had already been engaged, was abandoned. The cloud was also noticed at Fort de France. It was described as like those in the previous eruptions, but

PLATE VIII.—A BEACH OUTSIDE THE DEVASTATED AREA.

PLATE IX.—RIDGES ON THE SOUFRIÈRE.

PLATE X.—LOT 14. A DEVASTATED PLANTATION.

two unbiassed observers, who had seen it and that of May, declared this was the larger of the two.

Our limited time was now coming to an end, but on leaving for Dominica two days later we were able, from the deck of a steamer, to make some examination of the slopes of the mountain down which we had seen the incandescent avalanche descend. The whole district from just beyond St. Pierre to near Prêcheur, a distance of about 4 miles, was covered with a deposit of light grey ash of varying thickness, perhaps averaging a few inches, but evidently much deeper in the valleys of the Rivière Blanche and Rivière Seche, which descend from the mountain about 2 miles beyond St. Pierre, and drain the slopes below the large fissure out of which we saw the eruption descend. The water of these rivers was boiling as it fell into the sea—in fact, it was reproducing on a small scale the phenomena of boiling mud which are described above in the cases of the Wallibu and Rabaka rivers in St. Vincent, though how far up the mountain these Wallibu effects extend, and where they give place to true volcanic discharges, it is difficult to describe as yet; we must wait further observations by M. Lacroix and his colleagues.

Returning now to the mechanism of the hot blast and the source of the power which propelled it, both my colleague and I are convinced of the inadequacy of previous explanations, such as electricity, vortices, or explosions in passages pointing laterally and downwards, or explosions confined and directed down by the weight of the air above. Such passages into the mountain, which, to be effective, would require to be caverns closed above, and not mere open ravines, do not exist in the case of the Soufrière, and we are not aware that they have been observed in Mont Pelée; and as to the weight of the air, this did not prevent the explosions in the pipe of the Soufrière from projecting sand and ashes right through the whole thickness of the trade-winds till they were caught by the anti-trade current above and carried to Barbados. Moreover, the black cloud, as we saw it emerge from Mont Pelée, seemed to balance itself at the top of the mountain, start slowly to descend, and gather speed in its course, and the second incandescent discharge followed the same rule. We believe that the motive power for the descent was gravity, as in the case of any ordinary avalanche.

The accepted mechanism of a volcanic eruption is that a molten magma rises in the volcano chimney. It consists of fusible silicates and other more or less refractory minerals, sometimes already partly crystallized, and the whole highly charged with water and gases, which are kept absorbed in the liquid, partly by the immense pressure to which they are subjected. When the mass rises nearer the surface and the pressure is diminished, the water and gases expand into vapour and blow a certain portion of the more or less solidified materials to powder, or, short of this, form pumice stone, which is really solidified froth,

and they are violently discharged from the crater. When the greater part of the steam and gases has been discharged, the lava, still rising, finds a vent either over the lip of the crater, or often through a lateral fissure, and flows quietly down the side of the mountain.

It is quite recognized that these phenomena may occur in various relative proportions. The explosive phase may predominate, in which case only sand, pumice, and fragmentary material are discharged, with perhaps ejected blocks torn from the sides of the chimney, and in this case an ordinary ash or cinder cone is built up. On the other hand, the magma may contain little vapour, and the lava may be discharged quietly and spread out widely as a sheet over the surrounding country. The Snake river basalts in Western North America are of this class, and though they cover an area larger than England and France combined, no eruptive cones or craters have been found on them, and it is supposed that none ever existed, but that the lava welled out quietly through fissures. Such fissures I have seen in Iceland, studded with a row of quite small craters only. We believe that in these Pelean eruptions an intermediate phase occurs. The lava which rises in the chimney is charged with steam and gases, which explode as usual, but some of the explosions happen to have only just sufficient force to blow the mass to atoms and lift the greater part of it over the lip of the crater without distributing the whole widely in the air. The mixture of solid particles and incandescent gas behaves like a heavy liquid, and before these particles have time to subside the whole rolls down the side of the mountain under the influence of gravity, and consequently gathers speed and momentum as it goes. The heavy solid particles are gradually deposited, and the remaining steam and gases, thus relieved of their burden, are free to ascend, as was the case with the black cloud which rose over our heads on July 9.

We had concluded, from our examination of the Soufrière, that something of this sort most occur, but the explanation was obvious when we saw the eruption of Mont Pelée. Dr. Flett remembers my saying while the eruption continued, "That's an avalanche," and among my notes made while in the Indies are the following: "The cloud of incandescent material, as we saw it welling out of the great fissure, reminded us of nothing so much as a snow-avalanche as seen in the Alps. It rolled rapidly from the mountain-side in well-defined billows, giving the impression of a vast volume of separate small particles mixed with a certain quantity of air or vapour, and, as in the case of Alpine avalanches, entangling more air in its progress, and setting up a blast sufficient to overturn large objects in its course."

This effect of avalanches in compressing the air before them and setting up a powerful blast, the effects of which extend beyond the area covered by the fallen material, has long been recognized. Plate 13 shows a group of large trees overthrown by the blast of the great

PLATE XI.—THE MAIN STREET OF ST. PIERRE.

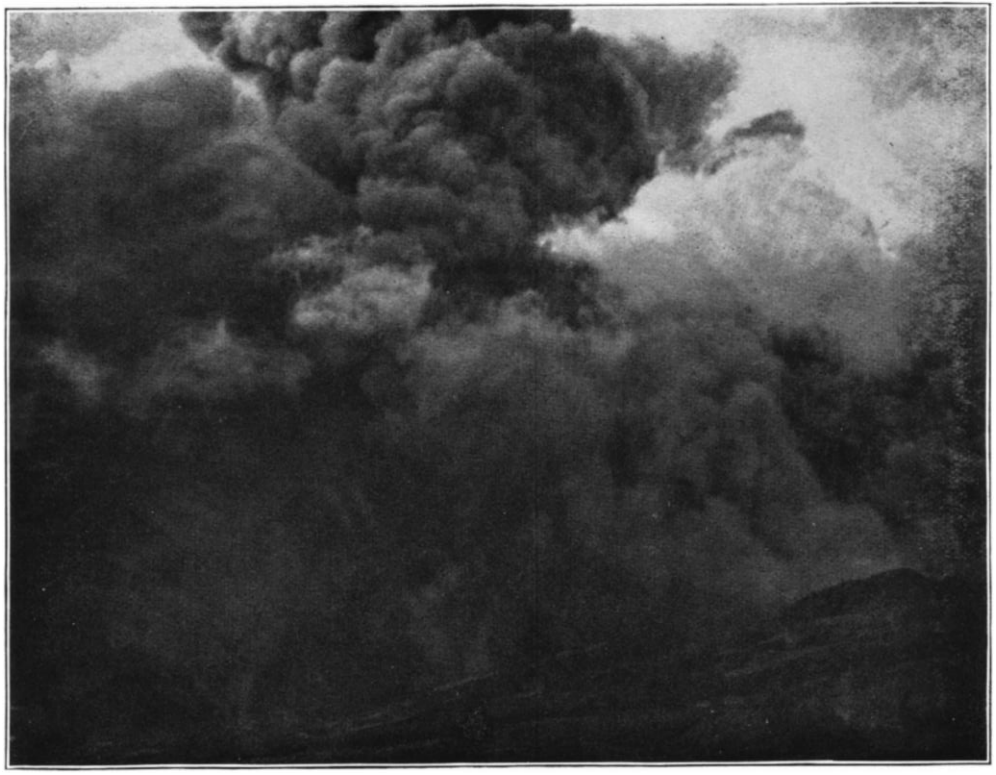


PLATE XII.—MONT PELÉE IN ERUPTION.

PLATE XIII.—TREES OVERTHROWN BY THE BLAST OF AN AVALANCHE.

avalanche from the Altels on the Gemmi pass in 1895; all lay prostrate in directions radiating away from the place where the avalanche came down

The only difficulty which we felt as to the sufficiency of the above explanation was the fact that these discharges descended slopes of 10° and 12°, which are less than the angle of repose for such material—for instance, not so steep as the side of an ordinary railway embankment; but we thought that the entangled gases and steam might be sufficient to account for the extra mobility of the mass. When we brought this explanation before the Royal Society, it was accepted as satisfactory by the physicists present. Prof. Sylvanus Thompson, F.R.S., mentioned as confirmatory his having noticed that small particles of silica, when heated to redness, move about the crucible like a liquid; and Dr. Edward Divers, F.R.S., in a letter to *Nature*,* not only confirms this statement, but points out that the liquid-like behaviour of powders at a red heat is most marked in cases where gases or vapours are being given off in minute quantities by the incandescent particles, which are thus kept surrounded each by a thin envelope of mobile gas, and this exactly meets the case of the volcanic particles in question.

DESCRIPTION OF DR. TEMPEST ANDERSON'S PLATES.

These plates are all from photographs taken by Dr. Tempest Anderson.

PLATE I.

Tropical Vegetation. Chateau Belair, St. Vincent.

This view, taken about 2 miles beyond the southern boundary of the devastated area, shows the luxuriant character of the tropical vegetation which formerly covered the whole district. The hut is of the usual type occupied by negroes, the descendants of liberated slaves. It consists of wooden uprights, walls of wattles, now generally giving place to boards, and a "trash" roof.

PLATE II.

The Wallibu District from the Sea.

In the distance is Morne Garu; in the middle distance the hot sand deposited by the eruption. The rolling, rounded character of the surface is shown, also the furrows and gullies already cut by the rain. The foreshore which formerly existed here has sunk into deep water, and the waves are cutting into the bluffs behind, and have exposed a section of the new ash resting on the old beds of fragmentary volcanic material. A new beach is in process of formation.

PLATE III.

In the Wallibu Valley.

In the distance are the slopes of Morne Garu, with trees killed by the eruption; in the foreground terraces of hot sand, marking the level to which the valley was originally filled, and some of the successive stages of its re-excavation. The hot sand is still steaming wherever water comes in contact with it.

* *Nature*, December 11, 1902, p. 126.

PLATE IV.

Steam and Ash Explosions, Wallibu.

This photograph was taken from above Chateau Belair, a distance of about 2 miles across the bay. In the foreground are the two ridges which saved the village during the eruption. Beyond them are seen the great clouds of steam and ash or sand, which were only visible after rain. The Soufrière mountain would be visible were it not concealed by the clouds.

PLATE V.

Rozeau Dry River flowing with Boiling Mud.

In the background are beds of new hot sand only a few feet thick, and already much washed into furrows by the rain, which is even cutting into the old banks. In the foreground, extending to just below the bridge, is a gush of hot mud as described on p. 268.

PLATE VI.

The Mouth of the Wallibu from the Sea.

Morne Garu is seen in the distance, and in the foreground the new alluvial fan of sand brought down by the river; in the middle distance is a small steam explosion.

PLATE VII.

The Site of the Wallibu Subsidence.

The low cliffs in the middle distance consist of old tuffs with a capping of several feet of fresh sand, the product of this eruption. On the top are seen the ruins of the Wallibu factory, and at the foot was formerly a foreshore, perhaps 200 yards wide, on which were the high-road and a number of negro huts standing among luxuriant vegetation. The whole subsided on the day of the eruption. The new beach in the foreground has been formed since that time (in about a month) of material washed from the cliffs and brought down by the rivers. The Soufrière is seen in the extreme distance to the left.

PLATE VIII.

A Beach outside the Devastated Area.

This is introduced for the purpose of comparison, to show the sort of place that existed before the eruption on the site of the last photograph.

PLATE IX.

Ridges on the Soufrière.

This plate shows the ridges of tuff on the lower slopes of the mountain on the windward side above Lot 14. Those on the leeward side are similar. Higher up the slopes become steeper, the ridges narrower, and the gullies between them deeper. The whole was formerly covered with luxuriant vegetation, of which a few charred remnants are seen. In the distance are the hills above George Town, and in front of them the Rabaka Dry River, with one of its branches in the foreground to the right.

PLATE X.

Lot 14. A Devastated Plantation.

This was the highest plantation on the windward side along the old Carib track which led to the summit of the Soufrière. The trees are charred and stripped of their leaves. The factory is unroofed, the machinery wrecked, and the waterwheel damaged. Much sand is about.

PLATE XI.

The Main Street of St. Pierre.

This photograph shows the condition of St. Pierre on July 8, about two months after the main eruption. The iron beam and masonry columns is all that remains of one of the principal shops. In the distance is part of the north tower of the cathedral still standing; the main part of the building is destroyed.

PLATE XII.

Mont Pelée in Eruption.

This photograph, taken on the afternoon of July 9, gives an excellent idea of the great black cloud which so nearly overtook us later in the evening, and which I was unable to photograph from absence of light.

PLATE XIII.

Trees overthrown by the Blast of an Avalanche.

A great avalanche descended from the Altels mountain on the Gemmi pass, in Switzerland, in September, 1895. At the end of an unusually long hot summer, a large portion of the Altels glacier and snow-field slid down bodily, and carried with it a quantity of stones and *débris*. The avalanche covered an area of above a square kilometre, and killed several men and above 100 cattle. The Altels is beyond the right of the plate, and the trees which were outside the area covered by the avalanche itself were overthrown by the blast of air which accompanied it. They all point radially away from the Altels. A few to the left were protected by the hillock, and escaped.

In opening the meeting, the PRESIDENT made the following remarks: The meeting is probably aware that the Royal Society commissioned two scientific gentlemen, Dr. Tempest Anderson and Dr. Flett, to proceed to the West Indies and investigate the causes and effects of the recent volcanic eruptions in St. Vincent and Martinique. They have already reported to the Royal Society, but Dr. Tempest Anderson has been so good as to prepare a paper for us, mainly treating the subject from a geographical point of view, with regard to the geographical effects of the eruptions. I will now ask Dr. Tempest Anderson to address the meeting.

After the reading of the paper, the following discussion took place:—

Dr. FLETT: Dr. Tempest Anderson has asked me to say a few words to you regarding the map of the Caribbean region, and regarding the nature of the geographical changes which have taken place in St. Vincent and Martinique. Some of you have already seen this map. It shows the chain of volcanoes of the Antilles, and those which are at present in eruption. We had in Guatemala, in April, a very powerful earthquake, and since we have had volcanic eruptions which have devastated a considerable part of that country. The photographs Dr. Tempest Anderson has shown will explain the nature of the geographical changes which had taken place in St. Vincent before we got there. But you must remember that, since we left, important eruptions have taken place, and changes are going on in that country at an almost unexampled rate. Vast quantities of material are poured out of the volcanoes in the course of a few hours, and then with great rapidity the tropical rains wash them into the sea. There has been considerable devastation since we were there, and the whole north end of Martinique has, by the order of the governor, been recently evacuated. French scientific men are now resident in

MAPS TO ILLUSTRATE THE PAPER BY Dr TEMPEST ANDERSON.

NDIES.

rt of the

ST VINCENT.

f Miles.

2 3 4

or 2·37 miles = 1 inch.

Heights in feet.

15′ 61°10′ 5′

Quashie Pt or C. Rolle
Campobello B.
Porter Pt
Owia B.
Cow and Calves
Grand Baleine
Owia
Myrtle Bay
De Volet Pt
Windsor Forest
Espagnol Pt
Azier Bay
Sandy Bay
Victoria
Trois Loups B.
Larikai Pt
Soufrière Mt
Larikai B.
Crater of 1812
Robin Rock Pt
Morne Ronde Pt
Crater 1930 Flowing
Turema Pt
Rozeau Dry R.
Morne Ronde Village
Walliba Dry R.
Turema
Orange Hill
Walliba
Chateau Belair Bay
Waterloo
Lot 14
Richmond
Kukunjore
Rabaka
Rabaka Dry R.
Sea view Cottage
Petit Bordel
Rose Bank
Dark Head
Morne Caru
Richmond Pk
Langley Park Estate
Chateau Belair
Mt Brisbane
Mt Bentinck Estate
Georgetown
Rosehall
Cumberland
Black Pt
Wallilabu
Three Rivers
Colonarie
Barnwalli
Belleisle
Colonarie R. and Point
Belle Vue
Peter's Hope
Sans Souci

15′ 61°10′ 5′

20′ 13° 15

85° 80° 75° 70° 65° 60°

WEST INDIES AND CENTRAL AMERICA.

Scale of Miles

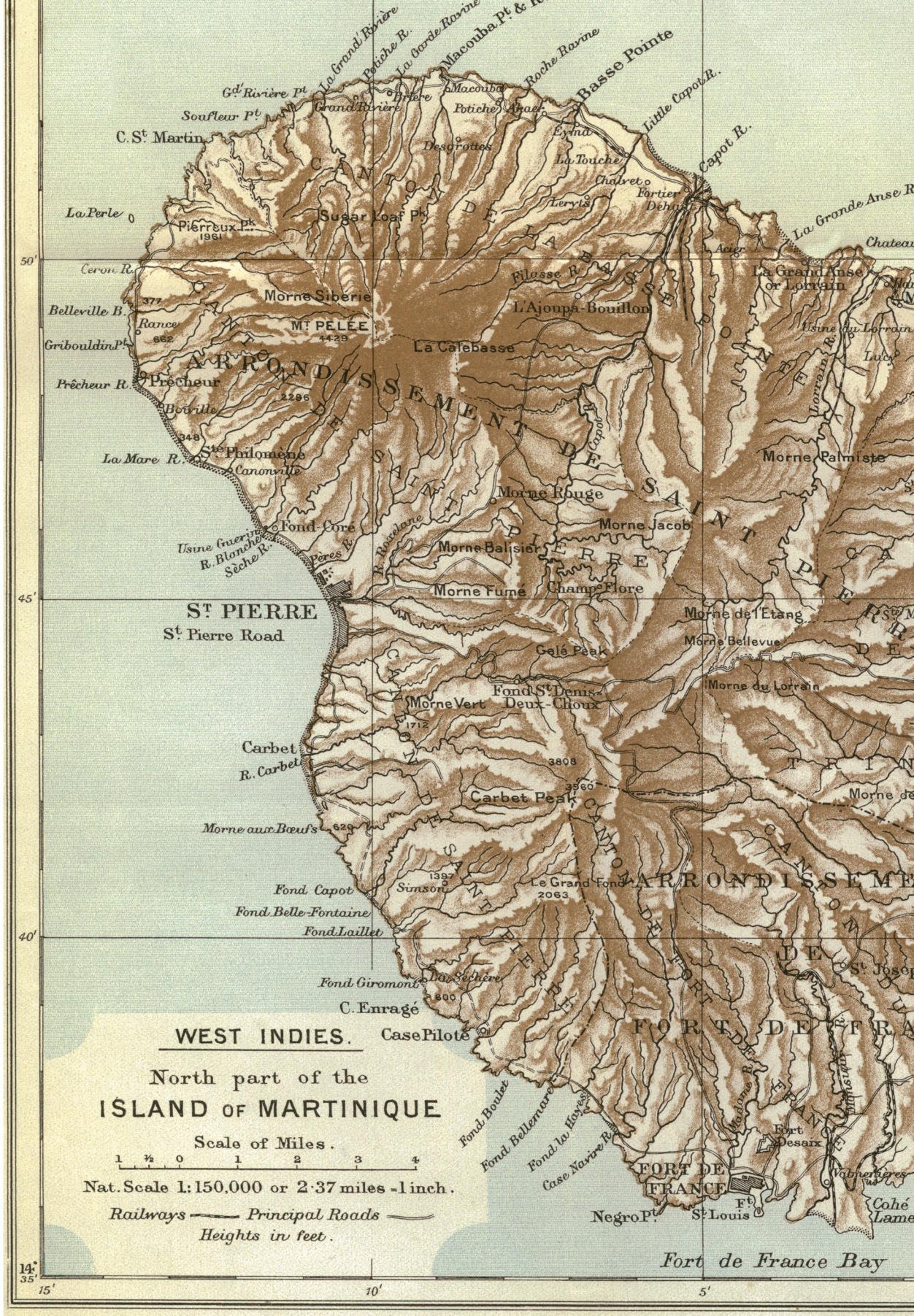
100 50 0 100 200 300

Natural Scale 1:20,000,000 or 316 miles = 1 inch.

Soundings in fathoms.

FLORIDA
C. Sable
Havana
Tropic of Cancer
C. S. Antonio
Ile of Pinos
CUBA
Santiago
GREAT BAHAMA ISLANDS
ATLANTIC OCEAN
Kingston
JAMAICA
REP. DOMINGO
Port au Prince
S. Domingo
Rasalind Bank
CARIBBEAN SEA
Porto Rico
Virgin Is
Anguilla
Barbuda
Antigua
Guadeloupe
Dominica
Martinique
Ste Lucia
St Vincent
Barbados
Grenada
Curaçao
LESSER ANTILLES
of Honduras
NDURAS
NICARAGUA

25° 20° 15°



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