WEST INDIAN VOLCANIC ERUPTIONS
AND
THE HAZARD TO HUMAN POPULATIONS

by

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ABSTRACT

The most destructive component of a typical West Indian volcanic eruption is the hot, high-density cloud consisting of lava fragments suspended in gas, which travels downward away from the eruptive vent. This phenomenon is called a pyroclast flow or glowing avalanche. A summary is given of the sequence of events at some of the world's better-described historic pyroclast flow eruptions, with special attention to precursory signs connected with this type of eruption, and the extent of destructive damage resulting from it.

Three eruptions emitting pyroclast flows have occurred during the present century in the Lesser Antilles, causing the loss of over thirty thousand human lives which could have been saved by timely evacuation. Several hundred thousand people in the Windward and Leeward Islands live within striking distance of volcanoes which have emitted large pyroclast flows in historic or recent prehistoric time, and the geological evidence suggests that similar eruptions will occur in the future. The local administrations on most of the volcanic islands have no plans for action in the event of an eruption, and the delay involved in formulating plans could be fatal. Therefore plans for the evacuation of each potentially dangerous area should be made now and revised at appropriate intervals.

Other types of volcanic activity which represent possible, although lesser hazards to human life are briefly discussed. These include large vertical (Vulcanian) eruptions, mudflows, and volcanically-generated tsunamis.

INTRODUCTION

The aim of this paper is to describe the types of volcanic activity which represent a hazard to human populations in the West Indies. The most dangerous type of activity is the pyroclast flow - alternatively called the glowing avalanche or nuée ardente - eruption. Special attention will be paid to precursory signs connected with this type of eruption, and to the extent of destructive damage resulting from it. In the Lesser Antilles, large centres of population have been overwhelmed by pyroclast flows, and many thousands of people have perished. The largest single disaster was that at St Pierre in Martinique, during the 1902 eruption of Montagne Pelée, when almost the entire city and human population of 28,000 were destroyed.

No practicable measures can be taken to divert pyroclast flows or stop the damage to property, but it is possible by evacuation to avoid the loss of human life. Several hundred thousand people in the Windward and Leeward Islands live within striking distance of volcanoes which have emitted pyroclast flows in historic or recent prehistoric time. The local administrations in most of the islands have no plans for action in the event of an eruption, and the delay involved in deciding what to do could prove to be fatal. Plans for the evacuation of potentially dangerous areas should be made now and revised at appropriate (say ten-yearly) intervals. Volcanic eruptions, although less frequent than hurricanes, can cause enormously more damage. Hurricane emergency plans exist in most islands: it is logical that similar provision should be made for action in the event of a volcanic eruption.

The duties of the vulcanologist are firstly to make the island administration aware of the possibility of destructive volcanic eruptions, and to define as clearly as possible the areas in each island which are likely to be desolated by pyroclast flows; secondly, to establish those particular events which suggest that a pyroclast flow is imminent. The first requirement, to define the potentially dangerous areas, is relatively simple to fulfil: it depends on a knowledge of the past activity and present topography of the volcano, plus an appreciation of the mechanics of pyroclast flow emission. Maps of the British Commonwealth islands showing areas in which damage from pyroclast flows may be expected in the event of a large eruption, have already been produced by staff of the Seismic Research Unit for restricted circulation to the appropriate authorities.

The second requirement, to identify those features which may be precursors of pyroclast flow emission, is more difficult to meet. The only data upon which predictions can be based are the accounts of historic pyroclast flow eruptions, and only fourteen suitably detailed accounts of this type of eruption, including four from the Lesser Antilles, have been found in the geological literature. The chronology of these eruptions will be summarised, following which an attempt will be made to generalise on the sequence of events leading up to the emission of large pyroclast flows.

EXAMPLES OF HISTORIC PYROCLAST FLOW ERUPTIONS

The sequences of events at the world's better-documented pyroclast flow eruptions are shown diagrammatically in Fig 1. Individual eruptions are listed vertically and the horizontal dimension represents the time scale. Various symbols represent the different types of activity.

The first four eruptions, at the top of the diagram (Fig 1), are from the Lesser Antillean islands of St Vincent and Martinique. Other eruptions summarised in the diagram include that of Mt Lamington, Papua, in 1951 - one of the most carefully and completely described of all historic pyroclast flow eruptions; the eruption of Bezymianny, Kamchatka in 1956, which was unusual in that the first climax involved only vertical (Vulcanian-type) explosions, whilst the grand climax and emission of pyroclast flows came rather late; the disastrous eruption of Agung, Bali in 1963; and the 1948 eruption of Hibok-Hibok, Philippines, in which the most severe pyroclast flows came extremely late in the eruption.

SUMMARY OF THE TYPICAL COURSE OF EVENTS ASSOCIATED WITH PYROCLAST FLOW EMISSION

Earthquakes

The examples given in Fig 1 suggest that if premonitory signs occur far in advance of an eruption, these are likely to take the form of felt or instrumentally recorded local earthquakes which may begin as much as 400 days before the first volcanic explosions (e.g. St Vincent 1902). Relatively little is known about the pattern of seismic activity before most of the eruptions quoted in Fig 1, because no seismographs were operating in the areas concerned. Experience in recent years from other active volcanoes, e.g. Kilauea, Hawaii (Richter et al., 1964, p. D5), suggests that swarms of microtremors generally do occur beneath a volcano before an eruption, even if no more than the usual number of felt earthquakes are reported locally. The occurrence of such an earthquake swarm probably means that magma is migrating at depth, and that the likelihood of an eruption is very much greater than during seismically quiet periods. The earthquake foci may rise progressively towards the earth's surface and the frequency of local earthquakes and rate of energy release will probably increase towards the date of the eruption.

The only eruption in Fig 1 for which there is a detailed account of preceding seismic activity is that of Bezymianny in 1956. Here the frequency and total energy-release of local earthquakes built up over a 21-day period, and for the last 10 days before the eruption, more than 100 earthquakes per day were recorded instrumentally. Three days before the eruption, the larger shocks caused ground displacements of over 1000μ at 45 km distance from the volcano, and by the day of the eruption the energy released in the form of earthquakes had reached an estimated 10^{20} ergs per day.

When an earthquake-swarm begins beneath a volcano, scientific investigators should institute a special watch on the volcano and local authorities should prepare themselves for further developments. It is unlikely, however, that a volcanic eruption will follow immediately, and not all swarms of shallow earthquakes beneath a volcano end in an eruption.

Soufrieres

The occurrence of a marked increase in the flow rate and temperature at steam vents and hot springs around a volcano, like the occurrence of a local earthquake crisis, indicates that the probability of an eruption in the early future is much greater than usual. An increase in activity was reported at the Montagne Pelée soufrieres more than a year before the 1902 eruption and five months before the eruption of 1929. At the eruptions of Merapi in 1930, 1932, 1939 and 1942, however, Neumann van Padang (1963) reported specifically that no general increase in fumarole temperatures was detected prior to eruption. Thus the heat flow from soufrieres does not necessarily increase before an eruption.

Earth Tilt

Tilting of the flanks of the volcano was reported at Manam 1959 both before and during the eruption, and at Komagatake 1929 it was discovered after the eruption that tilting had occurred. At Kilauea volcano, Hawaii (Eaton, 1959), it has been demonstrated that earth tilt measurements can be used as a means of volcanic prediction. No measurements are reported for the other eruptions listed in Fig 1.

Volcanic explosions preceding the destructive climax of an eruption.

It is common for eruptions which ultimately produce large pyroclast flows to begin with relatively mild explosions, accompanied usually by the vertical emission of pyroclasts. This is followed typically by increasingly violent activity terminating in large vertical (Vulcanian-type) and pyroclast flow explosions. This period of increase may at the shortest last 12 hours (e.g. Komagatake 1929), or at the longest several months including, possibly, one or more quiescent intervals.

In the St Vincent eruptions, illustrated in the top two lines of Fig 1, the destructive climax of pyroclast flow emission followed in 1812 on the fourth and in 1902 on the second day after the initial volcanic explosions. In Martinique there was a longer interval than in St Vincent between the first explosions and the beginning of pyroclast flow emission (14 and 74 days respectively for the 1902 and 1929 eruptions).

It is worth noting that for all four Lesser Antillean eruptions, if evacuation of the flanks of the volcano had been completed within 24 hours of the beginning of volcanic explosions, no human lives would have been lost. The same applies for the eruptions of Mt Lamington 1951, Agung 1963, and Merapi 1930, in each of which more than 1,000 persons were killed. It is especially important to note that at Agung, where the eruption followed a dormancy of 120 years, volcanologists had recommended evacuation of the region four days before the eruptive climax, but many of the people had not moved voluntarily and had not been compelled to do so by the authorities.

At three of the fourteen eruptions illustrated in Fig 1, on the other hand, pyroclast flows were emitted within 24 hours of the beginning of the eruption, and in all three instances no other, earlier sign of impending activity in the form of increased solfataric activity or felt earthquakes had been noticed. It is reassuring to observe that none of the "short notice" pyroclast flow eruptions was very large or very destructive. However, there is not sufficient evidence to justify a conclusion that early pyroclast flows will always be mild ones,especially since in several other eruptions, the first pyroclast flow, although later in the cycle, was the most violent (e.g. Soufriere of St Vincent, Mt Pelée and Mt Lamington in Fig 1).

Looking now at the other extreme on the time scale, it is important also to consider for how long after the beginning of an eruption destructive pyroclast flows are likely to be emitted. Hibok-Hibok volcano is an exception in this respect: the most destructive pyroclast flow was erupted more than three years after the beginning of the 1948 eruption. Moreover, this event took place 28 months after the beginning of dome growth, whereas in most other eruptions the beginning of growth of a new dome marks the end of the eruption of major pyroclast flows (e.g. Pelée 1902; Merapi 1930; Bezymianny 1955) Of the eruptions shown in Fig 1, only Manam 1956 and Hibok-Hibok 1958 produced large pyroclast flows more than 160 days after the beginning of explosive volcanic activity.

PHYSICAL PROPERTIES AND PHYSIOLOGICAL EFFECTS OF PYROCLAST FLOWS

A pyroclast flow is essentially a suspension of solids in gas. It is usually very hot, the temperature at the moment of emission from the crater being probably over 1000° C. In the Montagne Pelée eruption of 1902, the pyroclast flow which destroyed St Pierre melted bottle glass, and must therefore have been at a temperature of over 650° C, when it reached the city.

The bulk of a pyroclast flow is denser than the surrounding air and therefore remains close to the ground, flowing preferentially down river valleys and other topographic depressions. The flow emerges principally over the lowest part of the crater rim, although if the eruption is large enough, it is liable to flow in all directions from the crater. The high gas content and continuous evolution of gas leads to the auto-expansion of the flow and a capacity for self propulsion at high speed. Speeds of up to 60 m.p.h. were reported at Pelée 1902, Lopevi 1960 and Agung 1963.

In the West Indies, pyroclast flows usually carry along boulders including many which are one foot across, and a few which are as large as 20 feet across. Elsewhere, and occasionally in the West Indies, the coarsest fraction may be only of sand grade. There is always a relatively high proportion of very fine dust.

The distance travelled by a pyroclast flow depends mainly on the volume emitted in one explosion, i.e. on the size of the eruption. It is common for the larger pyroclast flows in an eruption to travel 5-10 km from the crater. The maximum distance travelled from the crater by historic pyroclast flows is 30 km, at Bezymianny in 1956; trees were snapped and set on fire at this distance. Prehistoric pyroclast flows at Crater Lake, Oregon, have been traced to straight-line distances of 35 miles from their source (Williams, 1942, p.79). The thickness of deposits from a single flow is likely to be variable, but may locally exceed 100 feet, especially in former valley floors. It is greatest where deceleration is highest, i.e. where the mean topographic slope decreases.

The combination of high velocity and high density provides a pyroclast flow with tremendous kinetic energy. It is normal for all vegetation including forests to be razed, and sometimes even the tree stumps are removed and the land scoured of unconsolidated soil or ash layers. At the Pelée 1902 eruption, in the city of St Pierre, massive buildings in stone were demolished, and ships in the harbour were totally stripped of their superstructure.

The physiological effects upon man and animals are usually lethal: the principal cause of death appears to be asphyxiation from breathing a mixture of steam laden with hot dust. In addition to internal burns in the mouth and respiratory system, severe external burns may occur on parts of the body not protected by clothing. At St Pierre in Martinique many people were dismembered by flying debris, but at other historic eruptions this was not reported to be common.

EVACUATION

The question of when to recommend that a population should be evacuated, and when to recommend that it should return, is likely to be a difficult one, in which the desire to protect human life must be offset against the possibility that evacuation may prove to have been an unnecessary disruption of the island's economy. The latter consideration becomes more important in those islands where the capital or other major centres of population and employment lie within the danger-zone.

The decision to evacuate will be taken by the local Administration, but its judgement will presumably be strongly influenced by the advice from the vulcanologist. He in turn must relate the course of events in progress both to all that is known of the past of the particular volcano, and to existing experience and theory of volcanic eruptions in general.

OTHER TYPES OF VOLCANIC ACTIVITY WHICH CONSTITUTE A HAZARD TO HUMAN POPULATIONS

Pyroclast flows are by far the most dangerous feature of West Indian eruptions, but significant damage may also be caused by two other types of volcanic activity, namely Vulcanian eruptions and mudflows. Major catastrophes may also be caused indirectly by large submarine eruptions which produce tsunami.

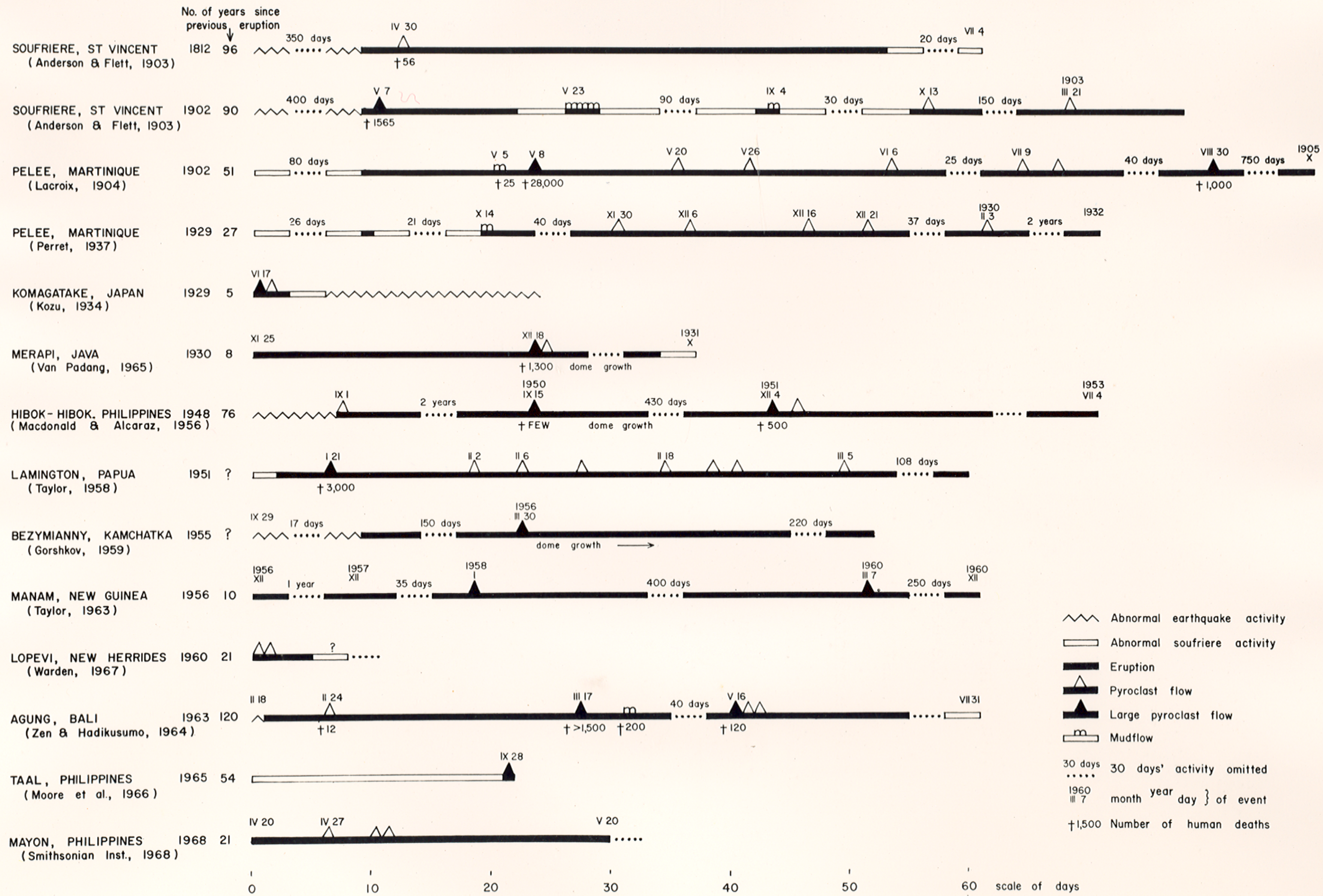
Vulcanian eruptions consist of large vertical explosions in which pyroclasts are carried to heights of many thousand feet before falling back on and beyond the flanks of the volcano. Areas close to and especially downwind of the active crater are most vulnerable. Pebbles and larger fragments may strike and kill people, whilst larger pyroclasts can puncture house roofs, and if hot enough may also cause fires. Thick deposits of fine ash, which are especially likely in the sector downwind of the volcano, may also cause roofs to collapse. At Komagatake in 1929, for instance, house roofs as far as 11 km downwind of the volcano collapsed under the weight of pyroclast fall deposits over one metre thick, in which the largest lumps measured up to 10 cm in diameter; whilst at 6.5 km distance, blocks of greater than 40 cm with red hot cores set many houses on fire. At the Soufriere of St Vincent in 1902, blocks of up to 25 cm in diameter fell at a distance of 8 km from the crater, and up to 5 cm at a distance of 20 km from the crater.

Damage and danger to life may also result from mudflows, which are a special hazard at volcanoes with large crater lakes (e.g. the St Vincent Soufriere in the West Indies). The water, mixed with ancient deposits from the lake floor plus new pyroclastic material, is likely to be blown out during the first strong explosions at the beginning of an eruption. Mudflows are a solid plus liquid mixture and travel down the major valleys of the volcano, especially those which head up to the lowest part of the crater rim. The distribution pattern of mudflows is therefore comparable with that of pyroclast flows. "Secondary" mudflows develop when torrential rain falls on slopes covered by unconsolidated volcanic ash, and may be a hazard during periods of heavy rain both during and for several years after an eruption.

Tsunami or giant sea waves are produced by the sudden displacement of a large volume of sea water and one of the possible causes of this is a large volcanic eruption below or at the sea surface. The most dramatic and disastrous example in the historic record is the eruption of Krakatoa, off Java, in 1883. An eruption of this island volcano began on 20 May 1883, and reached its climax between 26 and 28 August in the same year, when massive quantities of fresh magma were erupted, after which two thirds of the pre-existing island (a volume of about 4 cubic miles) collapsed below sea level. A giant sea wave, which in some bays reached a height of 120 feet, swept the adjacent coasts of Java and Sumatra, drowning 36,000 people. This is the largest recorded human disaster resulting from a volcanic eruption.

In the eastern Caribbean, four submarine volcanoes have been reported active in historic time, and there are probably numerous others in the region which have erupted in historic or recent prehistoric time, but which have not been identified. A very small sea wave was generated by a submarine explosion at Kick-'em-Jenny volcano, north of Grenada island, on 25 October 1965. Although no large submarine eruption has occurred in the past 200 years in the West Indies,a future eruption of this type remains a possibility. Many people in the Lesser Antilles live and work at elevations not more than sixty feet above sea level, and a wave of this height could drown many thousands. If a submarine volcano were threatening to become violently active, it might be wise to move people and transportable property from low-lying coastal areas in adjacent islands.

FIG I. DIAGRAMMATIC SUMMARY OF EVENTS AT THE WORLD'S BETTER-DESCRIBED PYROCLAST FLOW ERUPTIONS



APPENDIX

LIST OF POTENTIALLY DANGEROUS VOLCANOES IN THE WEST INDIES WITH DATES OF RECENT VIOLENT ERUPTIONS

ISLAND	VOLCANO	VIOLENT ERUPTIONS
Saba	The Mountain	?
St Eustatius	The Quill	?
St Kitts	Mt Misery	2158 ±94 B.C.
Nevis	Nevis Peak	?
Montserrat	Soufriere Hills	A.D.1646 ±54
Guadeloupe	La Soufriere	A.D.1400 ±150
Dominica	Morne au Diable	?
	Morne Diablotins	?
	Valley of Desolation	26,900 ±900 B.C.
	Morne Patates	?
Martinique	Mt Pelée	A.D.1902; A.D.1929
St Lucia	Qualibou	37,550 ±1,500 B.C.
St Vincent	The Soufriere	A.D.1718; A.D.1812; A.D.1902
Grenada	Mt St Catherine	?

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