DEPARTMENT OF THE INTERIOR

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SUMMARY

Historic and geologic records indicate that Cotopaxi has erupted often during the last few thousand years. From these records we can infer that the volcano almost certainly will erupt again in the future, although the time of the next eruption cannot yet be predicted. Future eruptions probably will be preceded by an increase in numbers of

small volcanic earthquakes and probably also by increased steaming and melting of snow and ice. A brief appraisal of volcanic hazards from Cotopaxi suggests that the chief hazards from future eruptions will consist of large mudflows and floods moving along the floors of valleys that head on the volcano, and ashfalls in areas generally west of the volcano. Pyroclastic flows and their associated ash clouds, and lava flows on and near the flanks of the volcano, also pose real hazards, but because they will affect areas not perma-

nently occupied by people, they are lesser ones. Measures that can be taken to reduce loss of life and property before and during an eruption include: 1. Evaluation of the probable kinds and distributions of hazards, especially ashfalls and mudflows; 2. Monitoring of Cotopaxi with tiltmeters and seismometers to detect swelling of the volcano and future increases in the numbers of earthquakes; 3. Informing the populace about potential hazards from eruptions, what plans have been and should be made to mitigate the effects of eruptions, and what people should do if an eruption occurs.

SUMARIO

Datos geológicas é históricas indican que el Volcán Cotopaxi ha erupcionado muchas veces durante los últimos mil años. A base de esto se puede inferir que este volcán seguramente entrará en erupción en el futuro; sin embargo, no se puede predecir todavia el instante de la próxima erupción. Nosotros creemos que futuras erupciones serán precedidas por un aumento de actividad sísmica, pequeños temblores volcánicos, y probablemente por un aumento de emisiones de vapor y deshielo de nieve y hielo. Una breve evaluación de los riesgos volcánicos del Cotopaxi sugiere que el mayor riesgo en futuras erupciones ha de consistir en grandes flujos de barro é inundaciones descendiéndose a lo largo de la parte baja de los valles que se inician en el volcán, y también en las caídas de cenizas sobre las regiones al oeste del volcán. Flujos piroclásticos, las nubes de cenizas asociadas y flujos de lava sobre las faldas del volcán, presentan un real, pero mucho menor, riesgo debido a que afectan regiones que no

están permanentemente ocupadas por gente. Las medidas que deben implementarse, con el objeto de reducir pérdidas de vida y propiedad, antes y durante una erupción son: 1. Evaluar los tipos probables y la distribución esperada de los riesgos, especialmente la caida de cenizas y los flujos de barro: 2. Vigilar el Volcán Cotopaxi mediante inclinómetros y sismómetros para detectar "hinchamientos" ó cambios de la topografiia alrededor del volcón, como también aumentos en el número de temblores volcanicos; 3. Informar a la población sobre el riesgo potencial de las erupciones, como también decirles los planes que se han realizado ó se van a llevar a cabo para mitigar los efectos de las erupciones, y lo que

INTRODUCTION

la gente deberia hacer si habrá una erupción.

This report presents the results of a brief investigation of potential volcanic hazards from Cotopaxi volcano. The study was undertaken at the request of the Government of Ecuador through the auspices of the Agency for International Development, U.S. Department of State (USAID). Cotopaxi is a compound stratovolcano located in the Province of Cotopaxi, central Ecuador, about 55 km south of Quito (See index map.) A nearly symmetrical cone, Cotopaxi is 5,897 m high and is composed of interbedded blocky andesite lava flows, pyroclastic debris, and mudflows. The summit area contains a central crater and the flanks are mantled with glaciers and snowfields. Slopes high on the cone are generally

between 30° and 40°. Cotopaxi is one of the most active volcanoes in Ecuador. It has erupted frequently during the last several centuries and produced lava flows, ash, pyroclastic flows, and very large mudflows. In the event that Cotopaxi erupts in the near future, the information on this map can be used to help prevent the loss of life and property. However, if loss of life and property from future eruptions is to be minimized, a more detailed evaluation of volcanic hazards

at Cotopaxi, as well as at other potentially dangerous volcanoes in Ecuador, should be

Volcanic-hazard zones shown on this map were prepared from examination of 1:50,000-scale topographic maps and stereo-aerial photographs and from results of a brief field investigation during December 1975 and January 1976. Because the locations of many boundaries shown on the map have not been checked in the field, the map shows a generalized distribution of hazards and may not be correct everywhere in

CURRENT ACTIVITY OF COTOPAXI VOLCANO

In 1975, Cotopaxi began to show activity of the kind that normally precedes a volcanic eruption. This activity was first noticed in July, and it continued, with varying intensity, at least until the spring of 1976. The activity observed consisted of (1) increased emission of steam from fumaroles; (2) melting of snow and ice near the crater rim, which produced new or larger bare spots on the volcano; and (3) small earthquakes. Records from three portable seismographs installed near Cotopaxi by Hall and personnel of the Observatorio Astronómico Nacional of Quito indicated that the level of seismic activity was low but was similar to that observed at presently quiet but recently active volcanoes in Central America (David Harlow, oral commun., 1976). In January 1976, the level of thermal and fumarolic activity of Cotopaxi was lower than during the previous several months, but some activity continues. It is not possible now to predict whether an eruption will occur in the near future; thus, we believe that visual and instrumental monitoring of the volcano should be continued. (See comments on monitoring in section entitled "Mitigation.")

FUTURE ACTIVITY

The long history of past eruptions of Cotopaxi (table 1) indicates that the volcano almost surely will erupt in the future. The historic record shows that: (1) Fifty eruptions have occurred since 1738 (only major eruptions are listed in table 1); (2) Twenty of those eruptions produced lava flows and mudflows, in addition to volcanic ash; (3) At least five eruptions resulted in significant loss of life and property. Deposits of volcanic ash and mudflows of prehistoric age around the volcano prove that the eruptions of historic time were not unusual. In fact, these older deposits show that eruptions similar to those described in written accounts have occurred repeatedly

during a period of many thousands of years. Some of the prehistoric eruptions produced ashfalls and mudflows much larger than those of historic time. Since 1742, eruptions have occurred at an average of about one per 10 years (table 1). These eruptions did not occur at regular time intervals but were clustered in episodes that were separated by quiet intervals of variable length. Unfortunately, the duration of quiet intervals cannot be predicted. At the present time (1976), Cotopaxi has been inactive for at least 34 and probably as many as 72 years. An eruptive episode may consist of many kinds of events, including weeks or months of various types and scales of activity. Future eruptive episodes probably will start with

Although the next eruption could occur with little or no warning, such a possibility seems unlikely. Future eruptions, especially large ones, will probably be preceded by increased frequency of small earthquakes, by increased fumarolic activity, or by increased melting of snow and ice over hot spots on the volcano. Most likely, all three of these phenomena would precede a large eruption.

small ash eruptions. However, an eruption generally does not follow a predictable

pattern or cycle; thus, kinds of future events cannot be predicted even after an eruption

VOLCANIC HAZARDS

Volcanic eruptions produce molten and solid rock materials that are either blown high into the atmosphere and then fall back to the earth's surface (ash and coarser airfall deposits), or flow directly out onto the ground surface (lava flows and pyroclastic flows). The severity and the location of hazards from a volcanic eruption depend chiefly on the explosiveness of the eruption, the kinds of materials thrown out, and their volume and extent. The kinds of events that constitute volcanic hazards and their origin and effects are described in the final section of this text. An eruption of Cotopaxi could result in airfall deposits, and one or more kinds of

flowage deposits; these are discussed in the following paragraphs. Airfall deposits

Volcanic ash from Cotopaxi could be carried by wind in any direction, but it is most likely to be carried in a westerly or northwesterly direction, and somewhat less likely to the north or southwest (table 2). Present wind data for the Cotopaxi area (V. Lasso, oral commun., 1976) indicate that during summer months (June, July, August, and part of September) winds above an altitude of 10,000 m blow mostly from east to west at about 50-60 km/h with a variable component to the southwest. Winds at or below 10,000 m blow mostly toward the northwest at 25–40 km/h. Records for other months (September-June) indicate that winds at all elevations blow generally toward the northwest at 5-15 km/h with an occasional component to the south. Not only do the predominant winds blow toward areas that are west and northwest of the volcano, but people and agricultural land are also concentrated there; consequently, most damage from future ashfalls would be expected to occur in those areas. Old deposits of ash and coarser airfall material that are present west of the volcano suggest that most future airfall deposits will be no more than a few centimeters thick at a distance of about 15 km. They would, of course, be thicker closer to the volcano and perhaps as thick as a meter on its lower slopes. Ash thicknesses from most eruptions

would be expected to decrease to less than 1 cm at the distance of Quito (55 km), even if the wind were blowing in that direction. A large-volume eruption, however, could deposit a layer as much as a meter thick at a distance of 15 km, and several cm thick at the distance of Quito.

Close to the volcano the immediate effect of an airfall would include injury to people and animals from the impact of relatively large fragments, and damage to structures from the weight of the ash—both effects were reported from eruptions during the period 1742-1768 (table 1). Major loss of life due to ashfall, however, would not be likely except from a very large eruption. An ashfall could produce darkness, confusion, and panic downwind from the volcano, especially in the Machachi and Mulaló-Latacunga areas. Evacuation or other movements of people and animals may be difficult or impossible during an ashfall. Water-supply systems for drinking water and irrigation would be affected, and agricultural machinery could be damaged in the zone of maximum ashfall hazard west of Cotopaxi.

²A possible eruption in 1942 (Hantke and Parodi, 1966) is omitted because it has not been verified by any other source, and several

families queried in the Lasso area, 20 km west-southwest of Cotopaxi, do not remember any activity that year.

3Hantke and Parodi (1966).

*Ash presumed to be from Cotopaxi; source not precisely known

5Wolf (1878). 6Whymper (1892).

Long-term effects of a volcanic-ash deposit would probably include serious damage or destruction of crops downwind from the volcano and death of some livestock. Consequently, there probably would be a need to provide relief foodstuffs for people living in parts of the broad valley lying west of Cotopaxi. The abrasiveness of the ash, and the corrosiveness of the acid compounds that cling to it, could also be expected to harm machinery brought into an ashfall area for relief and cleanup.

Lava flows

Lava flows are not expected to present a direct hazard to people near Cotopaxi, because they move slowly and probably would be restricted to the flanks of the volcano. Lava flows from Cotopaxi evidently have not entered areas that are now populated. The main hazards that result from lava flows would be mudflows and floods caused by melting of snow and ice on the cone.

Hot pyroclastic flows

Hot pyroclastic flows probably will not be a serious direct hazard except to areas on the immediate flanks of the volcano. It is unlikely that future pyroclastic flows and associated hot ash clouds and lateral blasts will reach beyond a roughly circular area that extends slightly beyond the flanks of Cotopaxi. Because Cotopaxi is sheathed by ice and snow, hot pyroclastic flows traveling down its flanks could be expected to produce such large volumes of melt water that the hot rock debris in the pyroclastic flows would quickly form mudflows. Judging from descriptions by eyewitnesses, the catastrophic eruption of Cotopaxi that caused tremendous mudflows in 1877 evidently produced hot pyroclastic flows, rather than molten lava flows, and the pyroclastic flows in turn produced the devastating mudflows. Thus, we expect that future hot pyroclastic flows from Cotopaxi will also become mudflows before reaching the populated valley floors near the volcano.

If pyroclastic flows did reach the base of the volcano, we believe that resulting mudflows could spread out over the "severe" and "lesser" flowage-hazard zones described in the following section, but that the hot pyroclastic flows would not extend farther than a few km from the flanks of the volcano.

Mudflows and floods

Mudflows and floods can be expected to be major hazards from future eruptions of Cotopaxi. These events are generally restricted to drainage basins that head on the volcano, and the effects expected in each of the three major drainage basins that lead from the volcano are discussed separately. Areas subject to eruption-caused mudflows and floods from Cotopaxi have been

divided on the map into two hazard zones: a zone of "severe hazard" and a "lesser-

The severe-hazard zone includes areas that have frequently been affected by small and large mudflows and floods in the historic and geologic past. Areas within this zone are judged to be very dangerous places during future eruptions of Cotopaxi. The zone includes most stream channels, terraces a few meters high adjacent to those channels, and some areas that are several meters or more above present channel floors. Within the zone, the channel floors will be the most hazardous places during eruptions; almost everywhere, safety increases as height above those channels increases. The lesser-hazard zone includes areas that apparently have been covered by mudflows during recent prehistoric time but that probably have not been covered by mudflows during or since the 1877 eruption. This area can be affected by only the largest mudflows that can be expected from future eruptions. Thus, the zone is safe from all but very large and infrequent mudflows and floods.

Topographically high areas that lie outside these two hazard zones have not, to our knowledge, been covered by mudflows within the last few thousand years. Thus, we believe that these areas will not be affected by mudflows or floods during eruptions in the foreseeable future.

Drainage basin southwest of Cotopaxi Several valleys that lead west from the volcano will be subject to mudflows and floods from future activity of Cotopaxi. They include the Río Cutuchi west of Cotopaxi and all of the valleys that lie south of the Cutuchi to and including the Río Aláquez. A zone of severe hazard extends across much of the valley floor between the Río Cutuchi and Río Saquimala, and includes the broad area west of Mulaló, the town of San Felipe, and the westernmost part of Latacunga. All the valley floors and low terraces of major rivers flowing from the west side of Cotopaxi are also included in this area of

relatively frequent mudflow and flood hazards. Very large mudflows could also be expected to spread across the zone of lesser hazard in the future. Virtually all of the valley floors of the Río Cutuchi and Río Saguimala, the town of Lasso, and much of Latacunga fall within this zone. In the valley of the Río Cutuchi, from the Cerrito del Callo south to Latacunga, mudflows would endanger the Pan American Highway, the railroad, all bridges across rivers that head on the volcano,

South of Latacunga, the Río Cutuchi is confined within a canyon, and most mudflows and floods probably will be restricted to the narrow canyon floor. All land and structures within the canyon, however, such as highways, railroads, pipelines, and bridges, could be affected by future mudflows as well as by floods. We have not determined what communities downvalley from Latacunga would be affected, or whether the canyon is narrow enough in any place to cause a very large mudflow to overflow the canyon walls. Towns such as Saquisilí, Poaló, Pujilí, Aláquez, Guaytacama, most of Mulaló, and the easternmost part of Latacunga stand on high ground, and should be safe from future mudflows and floods.

Drainage basin east of Cotopaxi Two river valleys, the Río Tambo and the Río Tamboyacu, will be affected by

mudflows and floods that originate on the east and southeast sides of Cotopaxi. These two rivers join and drain eventually into the Río Napo. The zones of severe hazard and of lesser hazard closely follow the two rivers, because both rivers flow in steep-sided and deep canyons. Damage should be relatively slight in those areas because of the expected restricted distribution of mudflows and floods, and because the areas are sparsely populated.

Drainage basin north of Cotopaxi

In the past, mudflows and floods that originated on the north and northeast sides of Cotopaxi combined at the base of the volcano to flow northward, mostly along the valley of the Río Pita. The zone of severe hazard there is limited to the vailey of the Río Pita itself except near the towns of Sangolquí and San Rafael. Near San Rafael, the confining river valley walls are low, and mudflows of moderate size could spread out over the adjacent ground to a width of a kilometer or so and remain outside the confines of the Río Pita channel for a distance of 3-4 km.

Very large mudflows could spill out of the Río Pita canyon into other river valleys; thus, the zone of lesser hazard has been extended into the valleys of the Río San Pedro and the Río Santa Clara. The first potential spillover point would allow mud to flow westward between Rumiñahui and Pasochoa into the upper Río San Pedro. The amounts of debris would not be expected to be large and should be mostly confined to land immediately adjacent to the river. Effects along the river and adjacent lowland would be expected to extend as far as its junction with the Río Pita. A second spillover point would allow mud to enter the Río Santa Clara valley and follow that river from its upper reaches down to its junction with the Río Pita. In prehistoric time, mudflows that flowed northward from Cotopaxi apparently followed paths that led northeast from the position of the present Río Pita and passed east of Cerro Ilaló. The Río Pita now flows in a canyon so deep that it seems likely that mudflows no larger than those of historic and recent prehistoric time could not leave the

canyon to pass east of Cerro Ilaló. Existing and future developments along the Río Pita (and the Río San Pedro below its confluence with the Río Pita) for water and power supplies for Quito and other communities would be endangered by mudflows of small to moderate size. Very large mudflows would, in addition, endanger similar developments on the Río Santa Clara and the upper Río San Pedro.

MITIGATION

Volcanic eruptions cannot be prevented or stopped. Diversion or other control of mudflows, lava flows, and other products of eruptions is expensive, and its effectiveness is limited. In general, reduction of loss of life and property requires that the products of eruptions be avoided where possible and that plans be made to lessen the effects when and where they cannot be avoided. Measures to reduce loss of life and property can be taken before, during, and after eruptions.

Certain actions, to be effective, must be taken well before an eruption occurs. Areas of potentially high hazard during an eruption should be identified from the map, along with kinds of events that can be expected to affect them. Plans can then be made for dealing with various kinds of eruptive events and different degrees of severity, and for evacuation or other measures for the various areas that would be affected. Long-term plans should discourage high-value investments as well as permanent occupation in areas of the greatest hazard.

Monitoring with instruments before an eruption provides the best evidence as to whether or not a volcano is approaching an eruption, and may help determine how soon an eruption might occur. Such monitoring, along with visual observations and earthquakes that can be felt, may provide warning and increase the sense of urgency necessary to take actions that can decrease the loss of life and property. Historically, instrumental observations of small earthquakes and of ground tilt have been the best ways to evaluate the condition of a volcano. It should also be possible to develop a system to record the passage of mudflows down the flanks of the volcano that will trigger warning devices in communities downstream. When an eruption appears to be imminent, planning and communication are ex-

tremely important. Local government officials, business and other groups, and private citizens should be informed of the situation. Instructions should include information relative to the kinds of events that might occur, their probable range in severity, the expected effects of those events, and what people should do if an eruption does occur. All people should be aware of official plans to cope with an eruption, and what warnings, if any, can be expected. They should also be informed of the kinds of eruptive events that would require action on their own initiative, and be instructed to prepare their own plans, including possible evacuation. Some actions to reduce losses in zones of severe hazard when an eruption appears

this must be done before mudflows occur, but may be possible after a minor ash eruption begins. Heavy ashfall, however, probably would halt such movements because of reduced visibility, difficulty in breathing, and the effects of ash on

1. Remove livestock and other movable valuable items to a safe place. To be effective,

2. Encourage people in highly endangered areas to live outside those areas temporarily, even though they continue to work in them.

3. Evaluate the probable effects of ash and mudflows on water systems and plan to

protect drinking water. 4. Insure that planned evacuation routes remain clear. respond to both mild and severe eruptive events.

5. Insure that individuals know what to do when an eruption occurs, and how to

During an eruption of the volcano, a visual watch is extremely important. Eruptions

6. Warn people against panic from darkness that may occur during an ashfall. 7. Practice operation of a warning system; practice evacuation if possible. 8. Instruct people to store extra food and water.

do not occur at a predictable rate or intensity; thus, minor eruptions of ash may, and often do, continue for days or weeks before a major eruptive event occurs. A visual watch, along with "rumblings" of earth and earthquakes that can be felt, may provide the only short-term warning that a major event is occurring during an extended eruptive

During ashfalls, people can lessen the severity of the effects by actions such as: . Remaining indoors rather than fleeing. Remaining in a building is usually desirable if the location is outside areas that could be affected by mudflows.

2. Using moist cloths over nose and mouth to reduce intake of ash. 3. Filtering water for use if stored water is not available. 4. Shoveling ash off roofs of weak structures. 5. Shaking vegetation to reduce breakage of limbs or stems because of the weight of

accumulated ash. If an eruption results in mudflows, people must move as quickly as possible out of the severe- and lesser-hazard zones to ground that is high enough to be safe, or at least as safe as is feasible. If a mudflow is seen to develop, only a few minutes or a few tens of minutes would be available to move to safety. For example, during the 1877 eruption of Cotopaxi, mudflows originating at the summit of the volcano were reported to have reached Latacunga only 30 minutes after the eruptive event that produced them (average velocity=70 km/h). Mudflows flowing south from Mulaló reached the bridge over the Río Pastaza at the foot of Tunguragua (a distance of at least 80 km) in less than 3 hours (Wolf, 1878). If heavy ashfall or cloudy weather obscures the volcano, the roar of a mudflow as it moves downvalley may provide at least a few minutes for escape. People living in hazard zones should know the location of safe areas, and the safest routes to each them. It should be emphasized that, in general, safety increases with every step as height above a river channel increases, and also as horizontal distance from that channel

increases, even within a single hazard zone. Remedial actions after an eruption, though important, are beyond the scope of this report; plans for such actions should be prepared after appropriate studies. Relief measures in most areas affected are relatively straightforward and include provision of food, rehabilitation of water, sewer, and communication facilities, care of injured and dead, and prevention of disease.

Airfall ash tends to be much more widespread than mudflow deposits; although the effects are less suddenly catastrophic, they can extend over a longer period of time. Ashfall can cause loss of crops over a very large area. Unless it is feasible to flush the ash from pastures, death of livestock may result from physical and chemical effects of ash that is eaten with plants during and after an eruption. Immediate as well as longer term loss of food, livestock, and seed can seriously impair the ability of people to feed themselves, and may result in the need for aid from outside the affected area for a considerable period of time.

Loss of homes, other buildings, and equipment must be expected from an eruption, but such losses will depend on their location and the severity of the eruption. DESCRIPTIONS OF VOLCANIC HAZARDS TYPICAL OF COTOPAXI AND SIMILAR VOLCANOES IN THE HIGH ANDES OF ECUADOR

Highly explosive eruptions throw molten and solid rock particles of dust to boulder size high into the atmosphere. Large fragments fall back rapidly onto the volcano's flanks, but relatively small particles fall slowly and can be carried great distances by winds. The falling particles form a progressively thinning blanket that reaches from the volcano to distances of hundreds of kilometers. The effects are most severe next to the volcano, and decrease in severity rapidly with increasing distance. Airfall deposits may be thick enough to bury or collapse structures near a volcano. Most damage, however, comes from thinner deposits that may cover vast areas far from the erupting volcano. Dust-sized abrasive particles, and the gases that accompany them, can cause difficult breathing and result in darkness during daylight hours; these effects may disrupt normal transportation and communication and lead to panic. Ash particles

results can include severe crop damage over large areas. Death of livestock also can result from starvation because of the blanketing of pastureland, and from poisoning of Flowage deposits

The principal flowage deposits produced by volcanoes are lava flows, hot pyroclastic flows of rock fragments and gas, mudflows, and floods.

Lava flows usually issue quietly from volcanoes as coherent streams of hot molten

also coat equipment and vegetation with a fine deposit that may carry acidic gases

(mainly of sulfur compounds, but sometimes chlorine and fluorine) along with it. Where

particles fall, water supplies commonly become temporarily acidic and turbid, and

darkness may cause electrical power-supply systems to be overloaded. Longer term

rock and move slowly downhill from their source. Lava flows generally move more slowly than a person can walk, perhaps a few meters per hour, and commonly do not reach much beyond the flanks of a volcano like Cotopaxi. Such flows do not seriously threaten people because they are local in extent and can be avoided. However, nonmovable property in the path of a lava flow generally cannot be protected from destruction. Thus, lava flows are relatively unimportant as a direct threat to people, but if they flow out onto snow and ice, they can cause large mudflows and floods. The resulting mudflows and floods can travel far down valleys that head at the volcano. Pyroclastic flows

Pyroclastic flows often result from explosive eruption of molten and solid rock fragments along with gas, from collapse of spines or domes, or from laterally directed explosion of hot rock debris from a dome. The resulting suspension of fragments in hot gases can travel rapidly (often more than 100 km/h) down the volcano's flanks. Pyroclastic flows can reach temperatures of several hundred degrees Celsius. Most commonly, they extend less than 10 kilometers beyond a volcano's flanks, but they can travel much greater distances from extremely large eruptions. Pyroclastic flows generally follow valleys, but they may be mobile enough to overtop hills or ridges in their

Pyroclastic flows can bury and incinerate whatever they encounter; they are very dangerous because they can occur suddenly without warning and travel at high speeds. They also can melt large volumes of snow and ice, or become mixed with water in streams to produce mudflows and floods. The resulting mudflows and floods are likely to extend far beyond the limits of the pyroclastic flows. Mudflows Mudflows consist of rock debris that contains enough water to flow downslope.

Volcanic mudflows may be produced by heavy rains, but large ones often result from

melting of snow or ice by lava flows or hot pyroclastic flows. Such mudflows can occur

suddenly, can travel at speeds of 30-60 km/h, and can reach temporary depths as great as 100 meters while flowing down narrow valleys. Deposits left after passage of a mudflow are usually less than a few tens of meters thick. Mudflows are mostly confined to valley bottoms beyond the vicinity of the volcano, but they can reach distances of hundreds of kilometers, burying or sweeping away everything that lies in their paths. Floods are commonly produced during a volcanic eruption by melting of snow or ice. Mudflows caused by eruption may grade into muddy floods by incorporating river water as they move down valleys. Eruption-caused floods may occur suddenly and can be of

Damages from floods caused by eruptions are similar to the well-known effects of floods of other origins. **ACKNOWLEDGMENTS**

large volume. Floods caused by an eruption may occur at the same time as floods due to

precipitation and thus result in floods far larger than normal.

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TABLE 2.—Indicated average velocity of the eruption cloud and distribution

of ashfall from past eruptions of Cotopaxi

		Indicated	, 4
Event reported	Time	average velocity of eruption	Distribution of ashfall
		cloud	
	April	4, 1768	
Eruption began-	5:00 a. m.		Ash fell as far north as
Darkness began in Latacunga due to falling ash.	6:00 a. m.	34 km/h to SW	Pasto, Colombia, and to the southwest as far as Guayaquil.
Darkness began in Quito due to falling ash.	11:00 a.m.	9 km/h to N	
	June	26, 1877	
First eruption began (observed surface winds during the day were toward the west).	6:30 a. m.		Light ashfall to the north in Ibarra; ashfall in Quito exceeded that in Latacunga; ash fell in Guayaquil 230 km to the southwest but did
Ashfall began in Quito.	8:00 a. m.	37 km/h to N	not fall south of Ambato.
Ashfall began in Guayaquil.	9:00 a. m.	95 km/h to SW	
Main eruption be- gan.	10:00 a. m.		
Ashfall from main eruption began in Quito.	1:30 p. m.	16 km/h to N	

	Only major eruptions and smaller ones	s corroborated by Wolf - are listed
Major eruptive episodes ²	Eruptive products	Effects and location of eruptive products
1532–1534		
15 November 1532 ^{3*}	Heavy ashfall	No report of effects available.
October-November 1533 ^{3*}	Ashfall	Do.
June–July 1534 ^{1,3*}	do	Do.
742–1768		
15–19 June 1742 ^{1,3}	Ashfall, mudflows	Considerable loss of property, probable loss of life.
9 December 1742 ¹	Ashfall, extensive mudflows	Widespread destruction of property in the valley of the Río Cutuchi.
		Hundreds of people and animals killed, buildings in lower parts of Latacunga totally dest
April 1743 ^{1,4}	Probable lava flow, ashfall, mudflows	Ashfall destroyed crops in the valley of the R10 Cutuchi.
30 November–2 December 1744 ^{1,4}	Ashfall, extensive mudflows (Probably produced	Mudflows more extensive than those from 1742 eruption. Mudflows flowed north in the Va
	by pyroclastic flow)	los Chillos, to San Rafael, to the southwest to Latacunga, and east to the Río Napo.
10 February 1766 ¹	Lava flows, ashfall, mudflows	Lower parts of Latacunga destroyed by mudflows and the crops in the valley of the Río C
4 A. et 17601	Lava flows, ashfall, mudflows	destroyed by ashfall and mudflows. Widespread fall of ash and bombs in valley west of Cotopaxi; ash carried northeast to
4 April 1768 ¹	Lava flows, ashfall, mudflows	Colombia, and southwest to Guayaquil. Earthquakes preceded eruption. Reported ash
		ness (meters), and distance (kilometers), from volcano summit:
		thickness (m) distance (km)
		Near volcano 0.9
		Mulaló
		Tanicuchi-Cienega 0.3 25
		Toacaso 0.15 30
		Quito 0.03 50
		Mudflows more extensive than those from the 1766 eruption flowed north to Valle de los
		and Tumbaco and west and south to Latacunga. Lower parts of Latacunga were destroy
		mudflows. Ashfall and mudflows resulted in considerable loss of human and animal li
		destruction of property and agricultural lands in drainages north and west of Cotopax
803		destruction of property and agricultural tartee in distinguishment and more of exercise
4 January 1803 ^{3,5}	Lava flows, ashfall, mudflows	Destruction of property.
353–1886		2 soud and on property.
$13-15$ September $1853^{3,5}$ (ash eruptions		This eruption produced the Manzanahuaico lava flow (3 km long with a volume of 27×10^6 m
continued through 1856)	Lava flows, ashfall, mudflows	the Pucahuaico lava flow, both on the west side of Cotopaxi.
1863 ^{3,5}	Small lava flows, ashfall	No effects reported.
21–26 September 1866 ^{3,5}	do	Do.
21 April–31 May 1877 ^{3,5}	Small lava flow at summit crater, ashfall	Do.
25 June–2 September 1877 ^{4,5}	Pyroclastic flows, lava flows, ashfall,	Pyroclastic flows probably descended all flanks of the cone, melted snow and ice, and pro-
20 dune=2 deptember 1077	extensive mudflows.	massive mudflows on all sides of Cotopaxi. Mudflows flowed north via Rio Pita to Sangolo
	Cheristre madients	the Río Guayllabamba, reaching the Pacific Ocean in 18 hours. Mudflows flowed
		southwest and south along the Río Cutuchi to Latacunga, Baños, and Puyo. Mudflows
		east down the Río Tambo to the Río Napo. Ash fell principally to the north and nor
		(Machachi, Quito), to the west, and to the southwest, reaching Guayaquil. Mudflows
		extensive destruction of works of man and agricultural lands along the Río Pita to the no
		the Río Cutuchi to the south. Hundreds of humans and thousands of cattle died. The lower
		of Latacunga were destroyed. Ash on lower slopes of Cotopaxi reached 1 m in thickn
23–24 August 1878 ⁷	Pyroclastic flows, ashfall	No effects reported.
26 February–19 June 1879 ⁷	Lava flows, ashfall	Ash fell in Quito, Latacunga, Ambato, and eastward into the Oriente.
3 July 1880 ^{6,7}	Ashfall	Ash deposited north-northwest and southwest of Cotopaxi.
January–March 1882 ⁷	do	No effects reported.
August and December 1883 ³	Lava flows, mudflows	Do.
23 July 1885 ³	do	Do.
903–1904		
26 September and December 1903 ³	Lava flows, mudflows	No effects reported.
	do	Do.
January–December 1904 ³		

CONTOUR INTERVAL 40 METERS

1 .5 0 1 2 3 4 5 6 7 8 9 10 KILOMETERS