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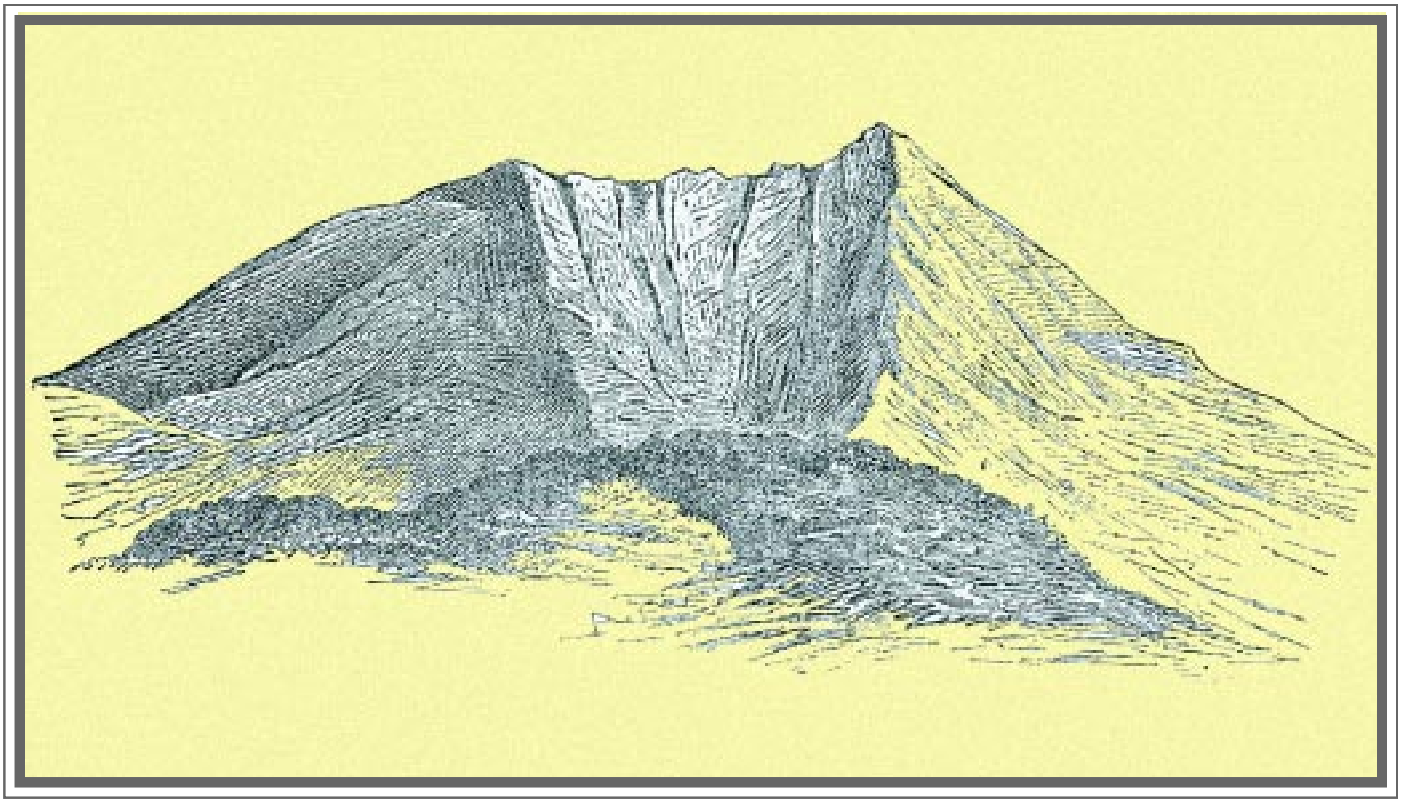
Lahar Hazards at Mombacho Volcano, Nicaragua



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Cover photograph

Lithograph showing the south side of Mombacho Volcano adapted from von Seebach (1892).

Lahar Hazards at Mombacho Volcano, Nicaragua

By J.W. Vallance, S.P. Schilling, and G. Devoli

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U.S. DEPARTMENT OF THE INTERIOR
Gale Norton, *Secretary*

U.S. GEOLOGICAL SURVEY
Charles G. Groat, *Director*

For additional information write to:

Scientist-in-Charge
U.S. Geological Survey
1300 SE Cardinal Court, Bldg. 10
Vancouver, WA 98683
(360) 993-8900
FAX: (360) 993-8980

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Lahar Hazards at Mombacho Volcano, Nicaragua

By J.W. Vallance, S.P. Schilling, and G. Devoli[1]

INTRODUCTION

Mombacho volcano, at 1350 m, is situated on the shores of Lake Nicaragua and about 12 km south of Granada, a city of about 90,000 inhabitants (figure 1). Many more people live a few kilometers southeast of Granada in ‘las Isletas de Granada and the nearby ‘Peninsula de Aseses. These areas are formed of deposits of a large debris avalanche (a fast moving avalanche of rock and debris) from Mombacho. Several smaller towns with population, in the range of 5,000 to 12,000 inhabitants are to the northwest and the southwest of Mombacho volcano. Though the volcano has apparently not been active in historical time [1] (numerals in brackets refer to end notes in the report), or about the last 500 years, it has the potential to produce landslides and debris flows (watery flows of mud, rock, and debris—also known as **lahars** when they occur on a volcano) that could inundate these nearby populated areas.

In late October and early November 1998, torrential rains of Hurricane Mitch caused numerous slope failures in Central America, the most catastrophic of which occurred at Casita volcano, Nicaragua on October 30, 1998. At Casita, five days of heavy rain triggered a 1.6-million-cubic-meter rock and debris avalanche that generated a 2- to 4-million-cubic-meter debris flow that swept down the steep slopes of the volcano, spread out across the volcano’s apron, destroyed two towns, and killed more than 2500 people [2]. The avalanche did not dam the upper drainages or impound water. Rather, it appears that the Casita debris flow evolved directly as the avalanche moved down slope [2].

On October 30, 1998 between 10:30 and 11:00 AM, residents south of Casita heard a roaring noise like helicopters or thunder. Some thought an earthquake was occurring. Three to five minutes thereafter, a wave of muddy debris 1.0-1.3 km wide and an average of 3.5 m deep destroyed all traces of two towns (figure 2). Observations by survivors record an enormous flood on the slopes of the volcano and a wall of mud on the volcano apron. A person on the volcano slopes saw a “black curtain of water with trees.” On the apron of the volcano where the flow spread out, survivors describe the flow as—“an infernal wave of mud, rocks, and trees,” or “enormous mass of mud.” [2]. The debris flow moved about 10 km from its source. It also generated floods that moved an additional 10 km downstream, destroying roads and bridges and inundating homes.

[1] Instituto Territoriales Nicaragüense Regionales (INETER), Nicaragua.

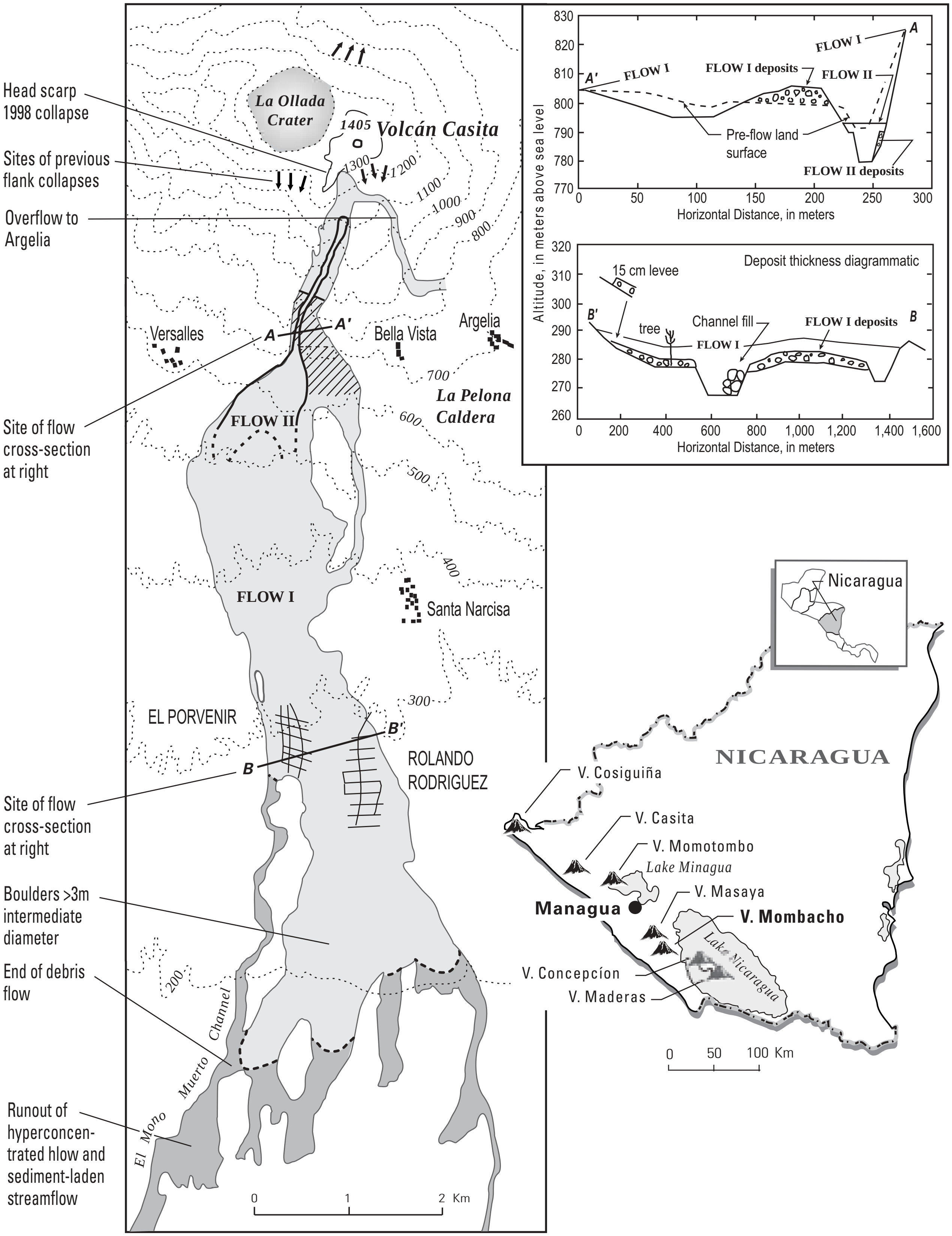

Figure 1. Locations of major cities and significant Quaternary volcanoes in Nicaragua including Mombacho volcano and schematic map showing the areal extent of and two cross-sections for the Casita, Nicaragua debris flow of 1998 adapted from Scott *et al*. (in press).

No large debris flows occurred at Mombacho volcano during Hurricane Mitch, but historical accounts indicate that such events have occurred there in the past. In 1570, an intense rainstorm caused an avalanche and debris flow on the south side of the volcano that inundated a town named Mombacho, killed more than 400 people, and obliterated the town [1]. The town of Mombacho no longer exists and its exact location is not known, but it was apparently high on the volcano or very near the open crater to the south (plate 1). The following account records this event.

> *Cuatro leguas de esta ciudad [Granada] estaba un pueblo de indios que se llamaba Mombacho, junto á un volcán pequeño que el año de 70, con un tormenta muy grande de viento y agua que hizo un noche reventó, y un lado del cayó todo la gente que había en él no escapó sino un solo vecino de la Ciudad de Granada que se llamaba Caravallo, y dos indias viejas; quedando seis ó siete españoloes con todos los demás indios enterrados. Por el otro lado salió tan gran tempestad de agua y piedra que en más de seis leguas por aquella parte hizo grande daño en los cacaotales y estancias de ganados (Lopez de Velasco 1970:87) [1].*

[English translation]

> *Four leagues (22,288 meters) away from this city [Granada] there used to be a village of natives called Mombacho, near a small volcano that blew out in the year 70, during a very strong storm at night with rain and wind. One side of it*

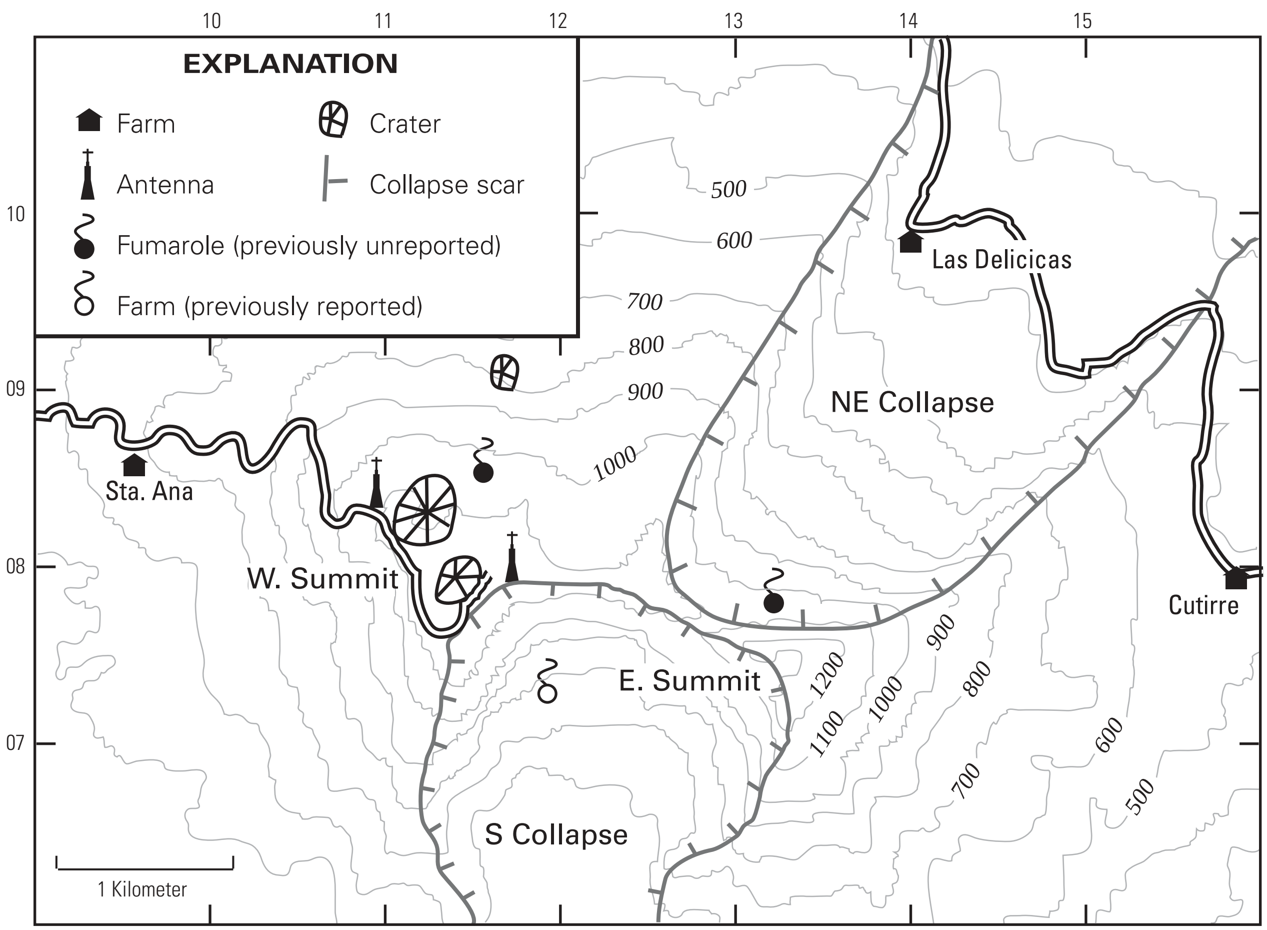

Figure 2. Topographic map showing the edifice of Mombacho volcano and the debris-avalanche scarps to the north and south adapted from van Wyk de Vries and Francis (1997).

fell(*) over and all the people who had been on it there did not escape except for a neighbor of the city of Granada called Caravallo, and two old native women that were spared; six or seven Spaniards and all others natives were buried by it. Such a great quantity of water and stone came out from the other side that it caused great damage over more than six leagues (33,412 meters) in that part of the cacaotales (cacao plantation grounds) and over the livestock areas (Lopez de Velasco 1770:87) [1].

*Translator's Note: No indication of what fell over. (Something or maybe "one side fell down" in the first instance. "Blew out or burst"=("reventó"). Comment: In general text difficult to follow. Missing and incorrect words.

Many have suggested that an earthquake caused 1570 debris flow as in the following 19th century account:

A causa de un terremoto, collapse la pared sur del volcán [Mombacho], provocando un alud de barro y piedras. El pueblo indígena de Mombacho queda sepultado muriendo sus 400 habitantes (Incer n.d.).

[English translation]

Due to an earthquake, the South face of the volcano [Mombacho] collapsed, causing an avalanche of mud and stone. The native village of Mombacho was buried, 400 of its inhabitants dying (Incer n.d.).

The account below, however suggests that the earthquake happened the night before the debris flow rather than on the same stormy night:

Before the landslide took place:

…solía temblar mucho y muy a llenado la tierra en aquella comarca [Grandada], y las noche antes que se reventa, dicen que temblaban y se meneaban las sabanas y prados circunvecinos, como se menea el agua e el mar poco ante que vea la calma, y que en las casas de Granada no quedaron aquella noche tejas en los tejados, y que muchas paredes y casas se cayeron; ya no tiembla tanto por allí la tierra ni tan á menudo (Dos Religiosos 1965) [1].

[English translation]

*…There used to be many earthquakes and a lot of dirt in that area [Granada], and during the night before it **blew out**, it is said that, there were earthquakes and that the savannas and meadows trembled liking the movements to those of the sea water before it reaches its calm. It is also said that, on the houses of Granada there were no tiles left on the roofs, and that many walls and houses fell down; there are no more earthquakes in that area or not so frequently (Two religious persons 1965) [1].*

Taken together the accounts above suggest that the 1570 debris flow at Mombacho was remarkably similar to the 1998 debris flow at Casita. In each case, an intense rainstorm triggered a land-slide, which in turn generated a debris flow, and the debris flow destroyed population centers near the volcano. Also like Casita, Mombacho is a deeply dissected volcano, with numerous areas of rock that has been weakened by hydrothermal alteration.

In prehistoric time, Mombacho has erupted explosively to form widespread ash-fall deposits (called **tephra**), and huge debris avalanches. The volcano has also erupted numerous **lava flows**. Although the volcano has erupted numerous times during the past, the chronology of its activity is poorly known [1]. On at least three occasions huge debris avalanches have occurred at the volcano. These debris-avalanche deposits extend about 10 km from the summit to the southeast, northeast and south (plate 1). Each covers 20 to 30 km^2. The oldest of these edifice failures was to the southeast and produced an unnamed group of isletas, the partly inundated hummocks that are characteristic of debris avalanche deposits. This avalanche also dammed Laguna de Pichicha. Its failure scarp has been filled in by subsequent volcanism and is now no longer recognizable as such. A prominent scarp open to the north-northeast (figure 2) is the source of the debris avalanche that formed Las Isletas de Granada, Isla Guanabana and Peninsula de Aseses. The youngest debris avalanche came from the south crater of Mombacho volcano (figure 2). It now occupies a lobe up to 6 km wide that is marked at its distal southern margin by Río El Pital and is characterized by numerous lakes that fill closed depressions on its surface (plate 1). If such eruptions were to occur now, many people and costly infrastructure would be at risk. In the aftermath of a voluminous eruption of ash, or pyroclastic debris, volcanic debris flows would certainly occur during the rainy seasons.

This report describes the hazards of landslides and lahars in general, and discusses potential hazards from future landslides and lahars at Mombacho volcano in particular. The report also shows, in the accompanying lahar-hazard-zonation map, which areas are likely to be at risk from future landslides and lahars at Mombacho.

DEBRIS AVALANCHES, LANDSLIDES, AND LAHARS

Slope failure on a volcano can generate a rapidly moving **landslide** called a **debris avalanche**. Small-volume debris avalanches typically travel only a few kilometers from their source, but large-volume debris avalanches can travel tens of kilometers from a volcano. Debris avalanches destroy everything in their paths and can leave deposits of 10 meters thick or more on valley floors.

Lahars, also called mudflows and debris flows, are masses of mud, rock, and water that look much like flowing concrete. They occur when water mobilizes large volumes of loose mud, rock, and volcanic debris. Commonly, landslides and debris avalanches will incorporate enough water to form lahars. Lahars, like floods, inundate floodplains and structures in low-lying areas. They can travel many tens of kilometers down valleys at speeds of tens of kilometers per hour. Lahars destroy or damage everything in their paths through burial or impact. Lahars follow river valleys and leave deposits of muddy sand and gravel that can be several meters thick. They are particularly hazardous because they travel farther from a volcano than any other hazardous phenomenon except tephra, and they affect stream valleys where human settlement is usually greatest. In some instances, lahars clog channels or block tributaries so that water collects behind the blockage. The impounded water can spill over the blockage and generate floods that move down valley. Breaching of such blockages can occur within hours, months, or even years after impoundment.

Like floods, lahars range greatly in size. The smallest lahars occur most frequently (perhaps every few years), whereas the largest recur on the order of centuries to millennia. The amount of water and loose volcanic debris entrained determines lahar size. Eruptions can deposit millions of cubic meters of sediment into channels that when mixed with water during subsequent rains causes lahars.

Landslides and lahars can cause problems long after the original eruptive or other disturbance. Once lahars fill stream channels with sediment, the streams begin to erode new paths. The new stream channels can be highly unstable and shift rapidly as sediment is eroded and moved farther down valley. Also, because stream channels are clogged with sediment, they have less ability to convey water and thus are more susceptible to smaller-magnitude floods.

FUTURE LANDSLIDES AND LAHARS AT MOMBACHO VOLCANO

Like neighboring volcanoes, Mombacho can erupt explosively to produce widespread tephra falls, though the lack of historical volcanism of this type suggests that the probability of explosive eruptions at Mombacho is less than at active Nicaraguan volcanoes like Masaya, Cerro Negro, Telica, and San Cristóbal. The ash and loose debris produced by an eruption would surely cause lahars when mixed with water from rains during the rainy season. Small volcanic earthquakes, steam explosions and deformation of the crater area would be likely to precede explosive eruptions at Mombacho volcano

Because eruptions are likely to be infrequent at Mombacho, landslides and debris flows during torrential rainstorms are the most likely threats to nearby people and infrastructure [1]. These phenomena, like those at Casita and at Mombacho in 1541, are most apt to occur during unusually intense rain. They are especially likely after long periods of rain toward the end of the rainy season.

LAHAR-HAZARD-ZONATION MAP

Potentially hazardous areas around Mombacho volcano are delineated as lahar-hazard zones. The accompanying lahar-hazard-zonation map (plate 1) shows areas that could be affected by future lahars at or near Mombacho volcano. Individual lahars typically affect only one or a few drainages. The location and size of an affected area will depend on local conditions, such as the intensity and duration of rainfall,l the volume of material involved, and the character of an eruption, if any.

Lahar-hazard zones are subdivided further on the basis of their relative degree of hazard. Hazard-zone boundaries derive from three main factors. First, there are the magnitudes of lahars known to have occurred at the volcano, as inferred from historical accounts and prehistoric deposits. Second, an empirical model calibrates lahar-inundation limits on the basis of lahars of known volume that have occurred at other volcanoes. Third, we apply our experience and judgment derived from past experience with events of a similar nature at other volcanoes.

Although sharp boundaries delineate each hazard zone, the limit of the hazard does not end abruptly at the boundaries. Rather, the hazard decreases gradually with increasing distance from the volcano and decreases rapidly with increasing elevation above valley floors. Areas immediately beyond distal hazard zones are not free of risk because the hazard limits can only approximately be located, especially in areas of low relief. Many uncertainties about the source, size, and mobility of future lahars preclude precise location of the hazard-zone boundaries.

Users of our hazard map should be aware that we have not simulated all hazardous landslide and lahar scenarios. The edifice of Mombacho volcano is steep, incised, and partly affected by hydrothermal weakening of the rock. For this report, we selected prominent channels directed toward populous areas in order to define the most significant zones of inundation from lahars of various volumes. Other channels for which we have not modeled lahar inundation are not necessarily devoid of lahar hazard. Landslides and lahars from other unmapped channels could also threaten life and property.

An automated empirical technique calibrated with data from other volcanoes [3] estimates potential areas of inundation from lahars of various volumes. For each channel analyzed, we define four nested hazard zones that depict anticipated inundation by hypothetical “design” lahars having different volumes. The largest design lahar reflects our estimate of the largest probable lahar generated on the steep slopes of Mombacho volcano (plate 1) [3]. The intermediate and smallest design lahars are more typical lahar volumes. Lahars of the largest size have occurred historically at Mombacho and would be likely after an eruption or during severe rainstorms.

Large lahars are less likely to occur than small lahars. Thus, the nested lahar-hazard inundation zones show that the likelihood of lahar inundation decreases as distance from the volcano and elevation above the valley floors increases. Lahars of all designated sizes could form on the volcano’s slopes if unusually intense rainstorms occur. The largest design lahar (plate 1) is based on the size of the largest lahar that occurred during Hurricane Mitch at Casita. Even during an intense storm like Hurricane Mitch, a lahar as large as the one at Casita volcano may not occur. Smaller lahars may occasionally result from heavy rains that normally occur each year during the rainy season of May to November. In general, lahar-hazard zones extend 5 to 10 kilometers from the summit crater (plate 1). Local topography plays a large role in controlling lahar travel distance.

HAZARD FORECASTS AND WARNINGS

It is difficult, if not impossible, to predict the precise occurrence of landslides and lahars triggered by earthquakes or torrential rains. However, generally hazardous conditions that favor formation of landslides and lahars can be recognized. Forecasts for very heavy rainfall, which commonly trigger flood warnings, can serve as indicators of conditions favorable for landslides and lahars. When Mombacho volcano erupts again, it is likely to disperse tephra on its flanks. Subsequent erosion of that tephra can generate lahars similar to or larger than those that have occurred in historical time. In this case, the eruption of the volcano can serve as a warning that conditions are favorable for lahar formation, and the distribution of tephra fall can indicate which flanks are more likely to be affected. However, government officials and the public need realize that potentially lethal events can occur in the lahar hazard zones with little or no warning.

PROTECTING COMMUNITIES AND CITIZENS FROM LAHAR HAZARDS

Communities and citizens must plan ahead to mitigate the effects of future landslides and lahars from Mombacho volcano. Long-term mitigation efforts might include using information about lahar and other volcano hazards contained in plate 1 when making decisions about land use and siting of critical facilities and development. Future development should avoid areas judged to have an unacceptably high risk.

Depending on the distance from the volcano, the hazard zones depicted on the map are areas that will be affected within a few minutes to about one hour after the onset of a lahar. Within 10 kilometers of the volcano lahars may happen too quickly to provide effective warning. Therefore, citizens must learn to recognize for themselves hazardous conditions that favor formation of landslides and lahars.

Because landslides and lahars can occur without warning, suitable emergency plans for dealing with them should be made in advance. Although it is uncertain when landslides and lahars will occur again at Mombacho volcano, public officials need to consider issues such as public education, communications, and evacuations as part of a response plan. Emergency plans already developed for floods may apply to some extent, but may need modifications. For inhabitants in low-lying areas a map showing the shortest route to high ground would be helpful.

Knowledge and advance planning are the most important items for dealing with landslide and lahar hazards. Especially important is a plan of action based on the knowledge of relatively safe areas around homes, schools, and workplaces. Lahars pose the biggest threat to people living or recreating along channels that drain Mombacho volcano. The best strategy for avoiding a lahar is to move to the highest possible ground. A safe height above river channels depends on many factors including the size of the lahar, distance from the volcano, and shape of the valley. Landslides and lahars from Mombacho volcano will happen again, and the best way to cope with these events is through advance planning in order to mitigate their effects.

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END NOTES

[1] Information about the 1570 debris flow that destroyed the town of Mombacho derives from Feldman (1993). Other geologic data upon which this report is based come chiefly from the work of van Wyk de Vries and Francis (1997).

[2] Information about the Casita flow derives from Sheridan *et al*. (1999), Kerle and Van Wyk de Vries (2001), Kerle (in press), and Scott et al. (in press).

[3] We constructed lahar-hazard zones by choosing design-lahar volumes of 1,000,000; 2,000,000; 4,000,000, and 8,000,000 cubic meters. We then modeled a lahar for each volume using the repeatable empirical model and digital cartographic technique described in Iverson *et al*. (1998). The model requires the choice of a reasonable range of volumes for each volcano. It then uses these volumes to compute average cross-sectional areas and areas of inundation for each modeled lahar. The GIS based computer program, LAHARZ (Iverson *et al*., 1998) then calculates the extent of inundation downstream in each drainage that heads on the volcano.

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