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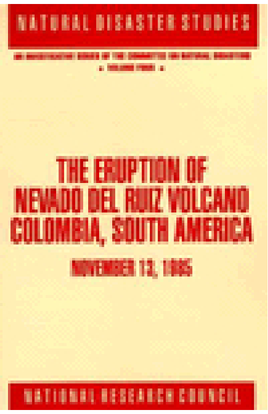

The Eruption of Nevado Del Ruiz Volcano Colombia, South America, November 13, 1985

Committee on Natural Disasters, Division of Natural Hazard Mitigation, National Research Council

ISBN: 0-309-57227-4, 128 pages, 6 x 9, (1991)

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THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

Natural Disaster Studies
Volume Four

The Eruption of Nevado Del Ruiz Volcano Colombia, South America November 13, 1985

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For:

Committee on Natural Disasters
Division of Natural Hazard Mitigation
Commission on Engineering and Technical Systems
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1991

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Library of Congress Catalog Card Number 91-60824
International Standard Book Number 0-309-04477-4

A limited number of copies of this monograph are available from:
Committee on Natural Disasters
National Research Council, HA 258
2101 Constitution Avenue, N.W.
Washington, DC 20418
202/334-3312

Additional copies are available for sale from: National Academy Press 2101 Constitution Avenue, N.W. Washington, DC 20418 202/334-3313 1-800-624-6242

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Acknowledgments

We are indebted to many people and organizations in the Republic of Colombia, who graciously allowed us to interrupt their schedules to facilitate our field work. Of major importance to the success of our effort was the information and assistance provided by the Instituto Nacional de Investigaciones Geológico-Mineras (INGEOMINAS), whose director, Alfonso Lopez Reyna, hosted our team and provided it access to agency personnel, documents, and disaster sites. In particular, Francisco Zambrano Ortiz, Technical Director of INGEOMINAS, coordinated our contacts with agency personnel familiar with the events surrounding the eruption of Nevado del Ruiz; Pablo Caro and Carlos Ulloa, INGEOMINAS geologists, accompanied our team in the field and assisted in the completion of its geotechnical reconnaissance; and Dario Mosquera of INGEOMINAS facilitated the social science aspects of the team's work by providing contacts with other agencies and organizations.

Several Colombian agencies were particularly helpful in providing us information, and, in many instances, personally guided us around the Armero disaster area. General Guillermo de la Cruz Amaya, the Director of the Colombian Civil Defense organization, granted us a protracted and informative interview and also extended the services of regional and local civil defense personnel to assist us in our information gathering. Among these was Colonel Rafael Perdomo Silva, who provided the social scientist members of the team their initial tour of the Armero site and the nearby refugee camps, and recounted the events surrounding the warning and emergency activities in the weeks around the eruption day. Civil defense authorities in Mariquita and Honda also assisted by arranging visits with various local officials and refugee camp personnel near the disaster site.

Among the local officials, the mayor of Honda and her staff provided many interesting insights into impacts to communities beyond Armero. Both staff members and disaster survivors at the camps spoke willingly and candidly about their experiences with the prolonged temporary housing situation. The social scientists appreciated speaking with several local Red Cross officials, staff, and volunteers at the camps.

The social scientists on the team would also like to thank Diego Silva and German Naranjo of the Red Cross, who accompanied them to the disaster sites, for their invaluable guidance and insights. For three full days, these young men tirelessly fielded questions and related their firsthand experiences, thereby greatly enhancing our understanding of this disaster and the plight of its victims.

Preface

On November 13, 1985, catastrophic mudflows swept down the slopes of the erupting Nevado del Ruiz volcano in Colombia, South America, destroying structures in their paths. Various estimates of deaths ranged as high as 24,000 area residents. Though the nature and extent of risk posed by the mudflows to local communities was well documented and extensive efforts had been made to communicate this information to those at risk, the affected communities were caught largely unaware by the mudflows.

These events prompted the Committee on Natural Disasters, a standing committee of the National Research Council, to send an interdisciplinary research team to Colombia following the disaster. The study team's mission was to analyze the disaster's many aspects, specifically, the extent, constitution, and behavior of the mudflows; the nature of damage to structures; the status of the area's disaster warning system; and the extent of the area's disaster preparedness, emergency response actions, and disaster relief efforts—both at the time of the disaster and in the first few months following the event. The study team's field observations and its recommendations for improving the existing warning system were made in January and February 1986 (see Appendix B).

Chapters 1 through 3 of the present volume contain the study team's geological and geotechnical observations. They describe the physical setting, the volcano's geologic history, and the main characteristics of the 1985 mudflows, including areal extent and estimated flow velocities. Also described are the performance of structures located within or near the vicinity of the flows.

Chapters 4 through 8 describe preeruption awareness and emergency preparedness, disaster warnings given for the 1985 eruption, disaster impacts, disaster recovery, and posteruption preparedness for another disaster.

The primary purpose of this report was to compile the data that are considered perishable—the data that would be lost over a short period of time due to the recovery effort and other natural processes. The observations recorded here extend only through the study period—the first few months of 1986; they do not include events that have transpired since that date.

The reader should be aware of the substantial body of additional literature available on the Ruiz disaster and the preceding events. In cooperation with the Colombian government, and, more specifically, the Instituto Nacional de Investigaciones Geológico-Mineras (INGEOMINAS), scientists from the U.S. Geological Survey (USGS), United Nations Disaster Relief Office (UNDRO), University of Rhode Island, Georgia State University, Louisiana State University, Dartmouth College, University of Madrid, Canadian Department of Energy, Mines, and Resources, National Volcanological Group of Italy, and University of Grenoble have also conducted detailed studies on various aspects of the volcanic eruptions and the resultant disaster. It is hoped that the present volume will provide a useful summary of disaster events and issues to those wishing to learn from the tragic experience of Ruiz area residents.

Contents

The Eruption of Nevado Del Ruiz Volcano Colombia, South America

November 13, 1985

Executive Summary

A relatively small eruption of Nevado del Ruiz volcano, located in the Central Cordillera of Colombia, South America, took place on November 13, 1985. The materials ejected during the eruption melted part of the glacial ice cap at the summit of the volcano, releasing a series of lahars (volcanic mudflows and debris flows). The lahars descended through steep, well-defined, and relatively narrow river canyons, reaching speeds of up to 45 km/hr.

Major flows descended the eastern side of the volcano through the valleys of the Azufrado, Lagunillas, and Gualírivers. The flow through two of these channels, the Azufrado and Lagunillas rivers, merged approximately halfway down the mountainside to form a large flow that continued along the Lagunillas River valley. This flow disgorged through a narrow canyon onto a gently sloping alluvial fan and adjacent floodplain that extend along the eastern front of the mountains.

The lahar flow devastated the city of Armero, built on the alluvial fan approximately 2.0–2.5 km downstream from the mouth of the Lagunillas River canyon. Estimates varied and claimed that between 20,000 and 24,000 people perished at Armero, most of them crushed or buried in their homes. Another lahar flow descended the western slope of the volcano through the narrow canyon of the Chinchina River, destroying 400 houses and causing as many as 1,800 deaths near the town of Chinchina.

The risk of an eruption like that which occurred on November 13, 1985 was well recognized prior to the event. Extensive effort went into defining the risks and the areas subject to disaster and to promoting emergency preparedness for evacuation and disaster relief. Although many did much to prepare, it seems clear that the risk under which Armero lived its last days was never recognized by local city officials. Additionally, the official warning system in place the night of the disaster failed to get word to the citizens of Armero, most of whom were in bed for the evening after ashfall and other volcanic events of the day were thought to have ceased. An estimated 5,000 people did survive and were displaced by the disaster.

The continuation of sporadic volcanic activity recorded since the November 13, 1985 eruption, combined with the extensive ice cap still remaining around the summit, could result in future lahars with equally devastating consequences for the large population still living in proximity to the volcano.

The study team characterized the magnitude and extent of the flows, catalogued much of the damage, and analyzed the nature of the geologic processes that led to both the initiation of the lahars and the extensive damage resulting from them. In addition, the team interviewed many survivors and participants in the emergency preparedness and recovery efforts. The lessons learned can be summarized as follows:

- The Nevado del Ruiz volcano continues to present a threat to the region from the formation of additional and potentially larger lahars to other volcanic-related phenomena such as ash fallout. Longer-term research to continuously assess the Ruiz hazard is needed.
- Special care must be given to properly educate as well as warn those members of the community who will be required to take action during an emergency situation to effectively communicate the potential risk.
- Risk communication and warnings are taken more seriously when accompanied by materials that provide adequate information, specifically about both the nature of the hazard and the steps that must be taken to mitigate the effect of the hazard. These factors are particularly important for hazards that have not manifested themselves in the lifetimes of the people who face them.
- The recovery efforts in many ways had characteristics similar to other disaster recovery efforts. The study and analysis of these efforts would have been enhanced had collection of socioeconomic data been undertaken prior to the event.
- A need to warn quickly and effectively must be emphasized.

1

Physical Setting and Geologic History

SITE LOCATION

The Nevado del Ruiz volcano, one of the highest peaks in the Central Cordillera of Colombia, is located approximately 120 km west of Bogota (4°50–55' N, 75°16–20'W). The Ruiz volcano belongs to a 50-km-long chain of seven volcanos aligned north-south along the Central Cordillera.

MORPHOLOGY AND PHYSICAL ENVIRONMENT

The summit of the Nevado del Ruiz volcano is located at about 5,400 m above sea level and remains covered year-round by a 10-to 30-m-thick ice cap that extends over an area of approximately 19 km^2 (INGEOMINAS, personal communication) with an estimated total ice volume of 337 million m^3 (Figure 1.1).

The upper part of the volcano, above an average elevation of 4,000 m, exhibits relatively steep slopes with inclinations ranging from 20 to 30 degrees. This part of the volcano consists of recent volcanic deposits. The break in slope at about 4,000 m elevation marks the contact between the recent volcanic units and the older basal volcano. Below this elevation the slope becomes flatter (approximately 10 degrees) and extends almost symmetrically to the floodplains of the north-bound Magdalena River on the east and the Cauca River on the west (Figure 1.2).

The slopes of the volcano are thus generally steep and are drained by narrow, relatively deep, "V"-shaped river valleys. Drainage towards the Cauca River, west of the volcano, takes place along the Claro, Molinos, and Chinchina rivers. Drainage towards the Magdalena River, east of the volcano, follows the Gualí, Azufrado, Lagunillas, and Recio rivers.

Figure 1.1
The summit region of Nevado del Ruiz volcano subsequent to the November 13, 1985 eruption. Note vapor cloud issuing from the summit crater and the tephra blanket overlying the glacial ice cap. (Photograph by D. Herd, USGS.)

Figure 1.2
Regional map showing the location of towns and rivers referenced in this report. Numbers below physical locations indicate approximate elevations in meters. North is at the top of map.

A three-dimensional schematic diagram of the terrain and main population centers of the volcano's eastern flank, where most of the destruction occurred and where the reconnaissance team's field observations were made, is shown in Figure 1.3. The foothills at the base of the eastern side of the volcano are at an approximate elevation of 400–700 m, 45 km east of the summit.

A gently sloping floodplain extends 20 km east from the foothills to the bank of the north-bound Magdalena River. The floodplain stretches north-south along the Magdalena River for over 70 km. Within the floodplain a low ridge of sedimentary rocks runs parallel to the Magdalena River in a north-south direction, approximately 5 km west of the river. The ridge-top elevation is approximately 400 m above sea level, or about 100–150 m above the level of the Magdalena River.

The average mean annual temperature on the plain is about 25°C and the annual rainfall is approximately 180 cm. Annual precipitation in the highlands is estimated at 300–400 cm.

On the east side of the volcano, several towns have been built on the floodplain directly east of the foothills at elevations ranging from 400–500 m above sea level. The two largest towns are Armero, on the Lagunillas River, and Mariquita, 25 km north of Armero on the Gualí River.

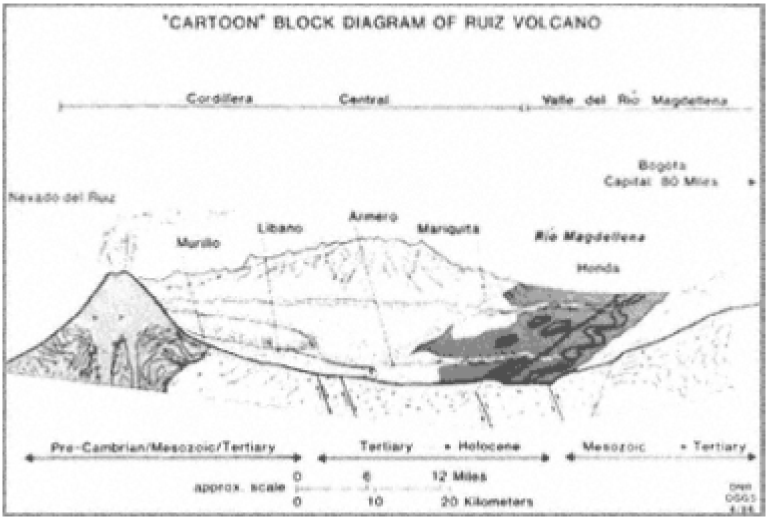


Figure 1.3
A diagrammatic three-dimensional view of the region east of Nevado del Ruiz showing the generalized geologic setting.

In addition, two relatively large cities are located on the western bank of the Magdalena River approximately 20 km east of the foothills. These cities are Ambalema, located at the junction of the Recio and the Magdalena rivers, approximately 63 km southeast of the volcano, and Honda, at the junction of the Gualí and Magdalena rivers, approximately 75 km northeast of the volcano. These cities, as well as other smaller towns between the foothills and the Magdalena River, are vulnerable to lahars generated in the volcanic highlands.

There are two other relatively large cities in the highlands on the eastern flank of the volcano. These two cities, located directly east of the summit between the Recio and Lagunillas rivers, are Líbano and Murillo. The largest city, Líbano, is located approximately 29 km east of the summit, at 1,590 m above sea level. Murillo is situated 16 km east of the summit at 2,900 m above sea level. Both cities, which are located at higher elevations than Armero, were unaffected by the lahars, which were constrained in narrow, well-defined river valleys. A discussion of the regional geology, tectonic setting, and prehistoric activity of the volcano can be found in Appendix A.

HISTORIC ERUPTIONS AND LAHARS IN THE RUIZ AREA

A review of the recorded activity of the Nevado del Ruiz volcano indicates the occurrence of two major historic events: the volcanic eruption of March 12, 1595, and the lahar flows of February 19, 1845. Minor lahar flows in 1828 have also been reported. A brief description of these events follows.

Volcanic Eruption of March 12, 1595

A description of this event is given by Fray Pedro Simon (1625). The text describes a volcanic eruption that started between 8:00 a.m. and 11:00 a.m. on March 12, 1595, with three thunderous explosions that were heard at distances of more than 100 km from the summit. The hot ash ejected was so profuse that it completely darkened the area around the volcano. Ash, lapilli, and pumaceous bombs covered a substantial area around the volcano—as far as 40–50 km from the summit.

Large mudflows developed along both the Gualí and Lagunillas rivers and both rivers were overwhelmed by a viscous mass of mud and ash with a strong sulfur odor. The land flooded by this mud was reportedly burned and fish died in both rivers. The largest flows apparently descended down the Lagunillas River. The kinetic energy of the mass flowing through the river canyon and out onto the floodplain was sufficient to transport large angular rocks several meters in diameter for distances of up to 2 km. Once the flood reached the floodplain, it spread laterally up to 2 km on either side of the river and continued east until it reached the Magdalena River. The waters of the Magdalena River were muddied by the introduction of mudflows from the Lagunillas and Gualí rivers. The historical account also indicates the occurrence of significant earthquake events three days prior to the eruption.

It should be noted that the city of Armero was built in 1895 at a site on the floodplain in front of the Lagunillas River canyon, approximately 2.0–2.5 km east of the foothills. This site was covered by the lahars of the 1595 eruption, which transported large angular blocks as far as the modern location of Armero.

Mudflows of February 19, 1845

A description of the 1845 mudflows was initially given by Acosta (1846). This report establishes the occurrence of a significant earthquake on the morning of February 19, 1845, followed by large mudflows that descended along the Lagunillas River. The mudflows rapidly filled parts of the Lagunillas River valley, spilling out of the river channel and killing much of the population in the vicinity of the upper river valley. Once the mudflows disgorged onto the alluvial fan they split into two branches. The main branch followed the Lagunillas River course towards the Magdalena River. The other branch was diverted by relatively high ground in front of the Lagunillas Canyon and turned 90 degrees to the north until it reached the Sabandija River, which flows east towards the Magdalena River.

Numerous blocks of ice descended with the mudflows and were observed a few days later floating down the Magdalena River. It is estimated that 1,000 people were killed by the mudflows in the floodplain between the eastern foothills and the Magdalena River.

The historical account indicates that the area covered by the mudflows resembled a desolated beach interrupted only by a few isolated groups of large, broken trees that resisted the momentum of the flooding mass. Acosta indicates that the thickness of the remaining mud varied considerably; the thicker layers are located upstream, with a volume of approximately 300 million m^3.

A later report by Acosta (1850) describes observations made during a field visit to the area five years after the 1845 mudflows. The text indicates that the sediment from the 1845 mudflow was consolidated, with the appearance of a "trachytic conglomerate" very similar to others that can be observed along a 25-km-wide band that parallels the Magdalena River for at least 150 km. Acosta noted the similar nature of the old and new lahar deposits, indicating that 8–10 layers of superimposed flows can be observed at various locations within the floodplain. The accumulated thickness of these deposits becomes greater in the low-gradient areas of the plain near the Magdalena River, where they can reach a total thickness of up to 100 m.

Acosta (1850) also carried out an inspection of the large boulders transported by the 1845 mudflows. The author indicates that a 500 m^3 dioritic block was carried by the mudflows a distance of 2 km beyond the mouth of the Lagunillas River canyon onto the floodplain. Farther south on the floodplain, especially along creeks and in the lower areas, the author observed "millions" of smaller angular blocks ranging from 10 cm^3 to 5 m^3. The blocks were resting on top of the "trachytic conglomerate" that had transported them. These blocks were so numerous at some locations that they entirely covered the ground. Acosta indicated that the reduction of volume that took place during "drying" of the mud had exposed blocks previously submerged within the mudflow.

The velocity of the mudflows in the floodplain can be estimated by eyewitness accounts indicating that people were able to escape by running ahead of the flows until they reached high ground (Acosta, 1850). Based upon Acosta's descriptions, it can be concluded that the mudflows that descended the Lagunillas River in February 1845 were as voluminous, if not more so, than the November 1985 Lagunillas River flows that destroyed

Armero. Furthermore, the course followed by the 1845 flows was nearly the same as that followed by the mudflows 140 years later.

Other Historic Events

The occurrence of large earthquakes south and southwest of the area of the volcano are reported to have occurred at various times in the past (Boussingault, 1849). Two of the most significant earthquakes took place on June 16, 1826, and on November 16, 1827. Thick mudflows with an intense odor of sulfur (indicating possible volcanic eruption as well) were observed along the Magdalena and Cauca rivers immediately after these earthquakes (Boussingault, 1849). Other reports (Acosta, 1850) indicate that after these earthquakes large numbers of dead fish were observed in the main rivers that drain the eastern flank of the Ruiz volcano. Thus, it is very likely that lahars of a lesser magnitude than those of 1845 have occurred at various times in the recent past.

2

The November 13, 1985 Eruption and Subsequent Lahars

CHRONOLOGY OF VOLCANIC EVENTS

Beginning in November 1984, intermittent seismic and fumarolic activity was observed in the proximity of Arenas Crater at the summit of the volcano. Seismographs were installed during the late spring and summer of 1985, and the resultant data confirmed abnormally high levels of seismic activity that were considered possible precursors of a major volcanic eruption (Herd, 1986). An increase in seismic activity during early September 1985 culminated in a phreatic (steam-producing) eruption on September 11, 1985.

The explosive phreatic eruption started at about 1:30 p.m., continued for at least six hours, and was audible in surrounding communities. Lithic ash and blocks were deposited on the ice cap as far as 1 km from the vent. Light ash fall was reported in Manizales and Chinchina, 25–30 km northwest and west of the summit. An avalanche, initiated when the eruption mobilized snow, ice, and volcanic debris, descended 27 km down the upper Azufrado River valley (McClelland and Simkin, 1986). The avalanche became a debris flow as it reached an estimated velocity of 10–30 km/hr, scoured rock walls 10–20 m above the valley floor, and finally terminated at about the 3,000 m elevation (Simkin and McClelland, 1985).

This eruptive episode had ended by the morning of September 12, 1985. However, fumarole, seismic, and ash emission activity continued sporadically throughout the rest of the month—notably on September 23, 24, and 29—depositing traces of ash more than 10 km from the crater (Simkin and McClelland, 1985). For the next three weeks the level of activity decreased significantly, but between October 19 and October 23, earthquake activity again increased, culminating in a small phreatic eruption (Herd, 1986). Scientific teams (R. Van der Laat, Observatorio Volcanológico de Costa Rica; Instituto

Geográfico, Agustín Codazzi; F. Barberi, National Volcanological Group of Italy) visiting the volcano in October noted a decline in fumarole activity, a lack of juvenile material in the superglacial ash of the previous month, and the presence of magmatic gases in fumarole samples (Simkin and McClelland, 1985).

Bernardo Salazar (Centrales Hidroeléctricas, Manizales) reported that from November 7 to 9 the seismicity was characterized by discrete high-frequency earthquake swarms. Each series, however, occurred less frequently than those that had preceded the September 11 eruption. On November 10, continuous harmonic tremors began and were to continue until the eruption of November 13, 1985 (McClelland and Simkin, 1986). No other precursory evidence suggested the immediate danger of an eruption.

Disaster Chronology

The following events are extracted from the Smithsonian Institution Scientific Event Alert Network data printout for November 13 and 14 (Simkin and McClelland, 1985) and from Herd (1986).

3:05 p.m., November 13. A phreatic eruption began that was described as similar to the September 11, 1985 eruption.

4:00 p.m. Ash and small lapilli were reported to have begun falling in Armero, 45 km east of the volcano summit. The sky was darkened and intense rainfall began, saturating the ash.

9:09 p.m. Bernardo Salazar, who was tending a seismic array 9.2 km from the volcano, heard the start of a noise much louder than the noise of the September 11, 1985 eruption. This was the beginning of the paroxysmal eruption initiated by two strong explosions and followed by a succession of pyroclastic flows and surges emitted from the vent. These flows and surges crossed the ice cap and descended the steep upper flanks of the volcano. Herd (1986) notes that they scoured and melted substantial amounts of the ice cap surface, and that these meltwaters were channelled into the Las Nereidas, Molinos, Gualí, Azufrado, and Lagunillas valleys.

9:37 p.m. A very strong explosion shook the building where Salazar was tending the seismic array. He stated that the explosion "lighted the rainclouds over the Ruiz like a lamp." This explosion marked the onset of the development of a Plinian column of gas and pyroclastics rising several thousand meters above the volcano. Glowing ballistic bombs and blocks up to several meters in diameter fell several kilometers from the vent.

The high-altitude ash in the rising column would eventually be deposited across a region hundreds of kilometers downwind (east) from the volcano. Pumice and lapilli up to 10 cm in diameter began to fall in Murillo, 17 km east of the volcano, at approximately 9:40–9:45 p.m. Larger pumice blocks

30–60 cm in diameter were found later at Murillo. Local authorities reported that these larger blocks also fell at about the same time in areas approximately 8 km east of the summit.

10:00 p.m. Intense fall of rain and lapilli began at Líbano, located approximately 32 km east of the volcano. Rain and ash fall continued as a downpour at Armero.

10:30 p.m. Lahars, which coalesced from Molinos and Las Nereidas valleys into the Chinchina valley, swept through Chinchina destroying hundreds of homes.

11:00–11:30 p.m. According to interviews with survivors, a first wave of "water and some mud" reached Armero around 11:00 p.m. The water temperature was normal or perhaps slightly cold. This first wave did not reach too high but was strong enough to drag people and even cars with the current. A few minutes later (3–6 minutes, depending on the accounts), a roaring noise was heard as successive waves of warm to hot mud swept through Armero. The mud wave at the local hospital was up to 6 m deep. At about the same time, lahars passed Mariquita on the Gualí River.

Survivors that remained on the roof of the local hospital at Armero indicated that wet ash, lapilli, and rain continued to fall all night. The air had an intense sulfur odor and burned the lungs when breathed. Survivors also indicated that the roar of the flow along the Lagunillas channel continued until early morning.

1:00 a.m., November 14. Mudflows reached Honda, at the confluence of the Gualí River and the Magdalena River, approximately 75 km northeast of the summit. Much of Armero had been essentially obliterated by this time.

SUGGESTED LAHAR-TRIGGERING MECHANISM

The summit of the volcano above the 4,600 m elevation is covered by an ice cap estimated at 4.5–5.0 km in diameter, with an average thickness of 15 m (INGEOMINAS, 1985). Partially covered by ice, and just below the elevation of the ice cap (between elevations 4,600 and 3,800 m), lie large deposits of loose, partially saturated pyroclastic materials ejected during previous eruptions. Substantial amounts of unconsolidated deposits have been mapped by Herd (1982) and Thouret et al. (1985) in the upper valleys of the Azufrado, Lagunillas, and other rivers draining from the volcano. These deposits generally rest on bedrock on relatively steep slopes ranging between 10° and 12° and are thus marginally stable.

The fumarolic activity that preceded the eruption began melting portions of the ice cap, increasing the already high level of saturation in these loose, fine-grained sediments. The rapid accumulation of hot pyroclastic material on the ice cap during the eruption accelerated the ice-melting process and added large quantities of water to the headwaters of valleys draining the ice cap. The scouring and melting produced by the pyroclastic flow and surges that traversed the ice cap generated additional water (Herd, 1986). Further, the falling ash and pyroclastic debris added substantial mass to the already unstable preeruption sediments.

A schematic representation of the relationship between undrained shear strength and strain of loose, saturated, fine-grained deposits is shown in Figure 2.1. As depicted, strength initially increases with onset of strain, but once a given level of strain is reached, this gradual increase in strength ceases. With additional strain, soil strength begins to decrease and eventually, at large strain levels, the strength becomes almost negligible. This strength reduction is due to the excess pore water pressure buildup that develops in loose granular soils during the shearing process and which ultimately can become so large that the effective stress between grains approaches zero.

Before the eruption, a large percentage of the available shear strength of the soil was required to maintain stability of the sediments on the steep 10°–12° slopes (Point A in Figure 2.1). The continuous introduction of large quantities of water due to precipitation and ice cap melting induced the

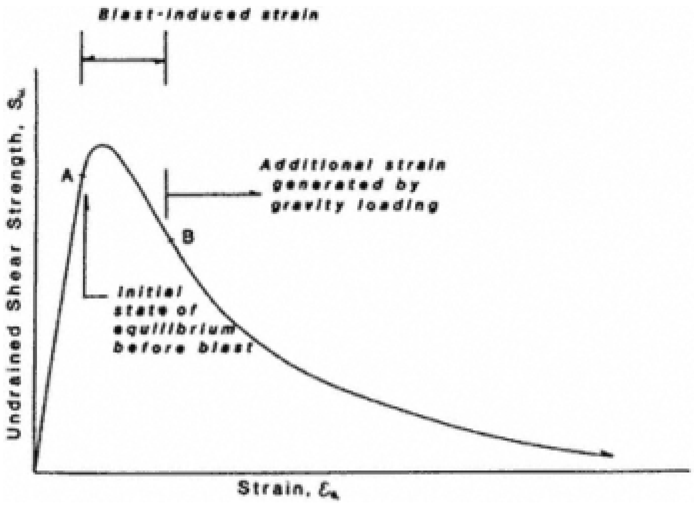


Figure 2.1
A schematic representation of the behavior of loose, saturated granular materials under rapid seismo-volcanic loading.

mobilization of an additional portion of the available shear strength of the soil.

Further, the eruption-induced ground motions caused an additional shear stress large enough to rapidly increase pore water pressure, which decreased the static shear strength of the soil (Point B, Figure 2.1). The magnitude of the vibration-induced strain is directly proportional to the peak particle velocity generated by the vibrations and inversely proportional to the speed at which the shear waves travel within the sediment.

Once the available shear strength of the deposits has been reduced below the value required to maintain equilibrium, failure takes place and large displacements result. These displacements further increase the shear strain in the soils, resulting in continued shear strength reduction. The combination of rapid increase in moisture content, increase in vertical stress due to pyroclastic deposition, and cyclic loading due to volcanic tremors results in a process similar to soil "liquefaction," where the soil behaves as a viscous liquid.

The debris flows of 1845 may support this model. No significant volcanic eruption was recorded prior to the flows and, in the author's opinion, it is unlikely that ice melt was significant enough to trigger the debris flows. In fact, numerous large blocks of unmelted ice brought down within the debris flows were observed floating down the Magdalena River afterwards. The study team believes that the earthquake-generated ground motions recorded by Acosta (1845) could have played a major factor in "liquefying" large amounts of loose, saturated sediments deposited by previous eruptions near the summit, resulting in the debris flows.

The phreatic eruption on September 11, 1985 and its associated tremors were large enough to trigger a small debris flow, which advanced down the upper Azufrado River valley. The flow was relatively modest, possibly because of the moderate magnitude of the tremors, limited introduction of rain and ice-melt waters, and small additional sediment load stress. Due to limited available water and mobilized soil mass volume, the movement of this flow was counteracted by frictional forces along the flatter, 3°–5° inclination of the winding stretch of the Azufrado River canyon below the 3,000 m elevation.

AREAL EXTENT AND GRADIENT

The lahars generated by the November 13, 1985 eruption of the Ruiz volcano followed various paths, which are shown by some of the shaded areas in the preliminary volcanic risk map prepared by INGEOMINAS prior to the eruption (Figure 2.2). The lahars descended from the summit along five river channels, three lahars flowing to the east and northeast, and two down the Las Nereidas and Molinos rivers and into the Chinchina River valley to the west. The study team's field efforts were concentrated on the three eastern and northeastern flows, which can be summarized as follows:

Figure 2.2
Sketch map showing volcanic hazards to the region surrounding Nevado del Ruiz. This map is derived from a map prepared by INGEOMINAS (1985) immediately prior to the November 13 eruption. The map accurately predicted the paths of the November 13 lahars.

The northeast lahar descended the Gualí River valley in a northeasterly direction and flowed approximately 58 km to the foothills at the western edge of the Magdalena plain. The lahar flowed out from the narrow canyon channel 1.5–2.0 km onto the plain, and then turned almost 90° to the north, continuing down the Gualí River valley. Mariquita, located at the base of the foothills on the south side of this northern turn of the river, was spared from serious damage.

Once on the alluvial plain, the lahar followed the Gualí River north 7–10 km, and then east to the Magdalena River. The elevated Tertiary sedimentary rock units on both sides of the Gualí River restricted the lahar flow to the river channel. Near its mouth, where the city of Honda is located, the Gualí River becomes entrenched in Quaternary sediments, forming a narrow valley 25–35 m deep. This incised section of the Gualí, near its junction with the Magdalena River, was subjected to substantial erosion of the valley walls by the lahar (Figure 2.3). This erosion caused significant damage to and subsequent evacuation from a large number of structures along the river as it flowed through the city. Specific damage to these structures will be discussed later in the report.

Figure 2.3
Erosion of bluffs along a sweeping curve of the Gualí River at Honda, just before entering the Magdalena River. Houses on bluffs above the river have been condemned and are mostly abandoned. (Photo by R. Updike, USGS.)

The second major lahar, which destroyed the city of Armero, was initiated in the headwaters of two separate river channels: the Azufrado and the Lagunillas rivers. The upper Azufrado River valley is aligned with the 3-km-wide lahar-filled trench produced by previous volcanic eruptions. From the vicinity of the summit ice cap, the Azufrado River flows northeast for approximately 26 km to an elevation of 1,800 m, and then turns almost 150° south for another 10–12 km, at which point it joins the Lagunillas River.

The Lagunillas River, also starting near the summit, flows east for approximately 22–24 km to an elevation of about 2,200 m. The river then turns northeast for 8–9 km to its confluence with the Azufrado River. Downstream of this junction, the river retains the name Lagunillas River. The lahars initially descended both river valleys, and then continued in the single course below their juncture (temporary damming of the mud flows may have occurred at the valley intersection for short periods of time). The Lagunillas River descends from an approximate elevation of 1,800 m at the confluence of the two rivers to an elevation of 400 m at the canyon mouth in a distance of about 20 km.

An inspection of contour line elevations in the vicinity of the summit indicates that the lahar initially descended along a steep slope of approximately 10 degrees to an elevation of 3,500–3,800 m. Below this elevation, the slope of the narrow, "V"-shaped valleys of the Azufrado and Lagunillas rivers decreases to an average of 4 degrees. A view into the mouth of the Lagunillas River canyon from the alluvial fan is shown in Figure 2.4.

Once the mudflow reached the Magdalena plain, it spread radially into two main lobes (Figure 2.5) separated by slightly higher ground. The central part of Armero, built on higher deposits from previous lahars, was not swept away by the 1985 mudflows (Figure 2.6). The hills of Tertiary sedimentary rocks immediately east of Armero, with elevations up to 500 m above sea level, further prevented the lahars from flowing directly east into the Magdalena River. A detailed map of the mudflows in the immediate vicinity of Armero is shown in Figure 2.7.

Figure 2.4
The mouth of the Lagunillas River canyon. Vegetation and soil were entirely removed from the floor and walls of the canyon to a point approximately 75 ft (25 m) above the river level, resulting in extensive exposure of bedrock. (Photo by R. Updike, USGS.)

Figure 2.5
A view from near the mouth of the Lagunillas River canyon, looking down the fan toward the site of Armero (middle distance). Most of the panorama was covered by the lahars, the edge passing through the trees immediately beyond the water treatment plant in the foreground.

Once out of the canyon mouth, the largest amount of debris tended to follow a southeasterly direction along the course of the Lagunillas River (Figure 2.7). Within the first 1.5–2.0 km downstream from the canyon mouth, the channel was substantially enlarged and deepened by mudflow erosion of the preexisting Quaternary alluvial deposits and minor amounts of the upper Tertiary strata. Downstream from Armero the main flows followed the southeast-oriented Lagunillas River channel for 2–3 km and then shifted into a more easterly direction north of the present Lagunillas River channel, which may have been partially filled by previous lahars (Acosta, 1845). The lahar continued to flow east for approximately 6 km on a relatively flat surface with an average inclination of 0.3–0.4 degrees (8 m/km) until forward momentum ceased on the broad plain.

The width of the mudflows on the Lagunillas floodplain varied from relatively narrow (300-400-m-wide) sections to 2.0-2.5-km-wide fans. The narrow stretches correspond to those locations where the flow passed through gaps in the sedimentary rock hills, which are as much as 100–150 m in relief above the floodplain. The wide fans developed immediately behind these gaps due to the temporary damming of the mud flows when entering the narrow gaps. Aerial photographs taken within a few days after the eruption show high flow marks several meters above the present lahar surface that were left by these reservoirs of mud.

The northern branch of the lahar that spilled out of the Lagunillas River canyon into the floodplain swept away the northern section of Armero and abutted against sedimentary rock hills immediately northeast of the city. The flow turned north and followed the course of an existing creek (Santo Domingo Creek) for nearly 6 km, until it reached the Sabandija River where it terminated (about 1 km south of the town of Quayabal) (Figure 2.7). At its widest point, this lobe of the Lagunillas lahar spread laterally as much as a kilometer in the broad valley of the Santo Domingo Creek. Farther north the flow was restricted to a width of 300–400 m until it reached the Sabandija River.

Figure 2.6
A business district in Armero on gently sloping terrain a few meters higher than most of the city. Buildings are erect, but the street is filled with mud and debris. Note that at the far end of the street (upstream direction), the mud level increases in height relative to doorways. The main force of the lahars was directed north and south of this area, due to topography. (Photo by R. Updike, USGS.)

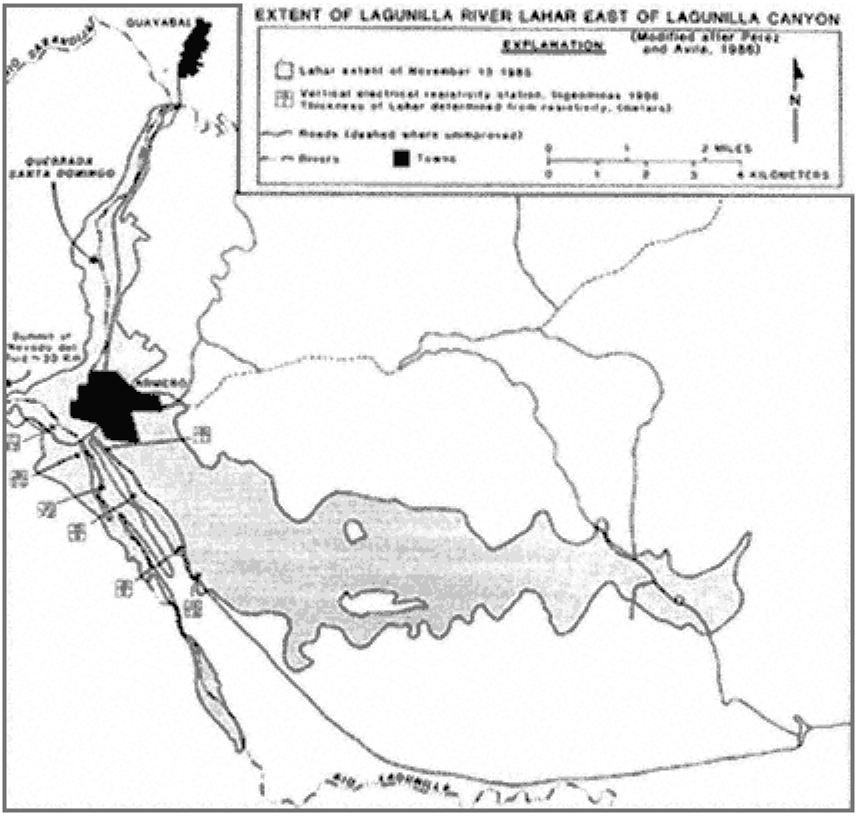


Figure 2.7
A map showing the extent of the Lagunillas River lahar beyond the mouth of the canyon west of Armero. Locations are referenced in the text of this report. Thicknesses of the lahar were determined by INGEOMINAS using electrical resistivity. (Map modified from Plazas and Vasquez, 1986.)

VELOCITY OF LAHARS

Estimates of the velocity of the mudflows triggered by the November 13, 1985 eruption are presented in Table 2.1. These were obtained by establishing the times of arrival of a mudflow's first wave at a few points along the flow path. The study team obtained the arrival times at three locations by interviewing eyewitnesses during the course of the team's field work. The team assumed a 20-minute delay in initiation of the flows after the paroxysmal eruption began at 9:09 p.m. to account for the necessary processes of melting, saturation, and channelizing to occur. This delay is called the "mobilization time" and it is factored into the travel times listed in Table 2.1.

TABLE 2.1 Mudflow Arrival Times and Average Lahar Velocities at Various Sites

Location	Approximate Length of Flow, km	Time of Arrival	Estimated Travel Time*	Average Velocity
Murillo, Lagunillas	17	9:52 p.m.	23 min	44 km/hr
Armero, Lagunillas	60	11:00 p.m.	90 min	40 km/hr
Honda, Gualí Valley	86	1:00 a.m.	210 min	25 km/hr

* Time elapsed from the 9:09 p.m. eruption, minus 20-min mobilization time.

Table 2.1 indicates that the lahar developed a velocity of approximately 45 km/hr in the steeper highlands. The velocity was subsequently reduced due to increased friction and the lower inclination of slopes as the lahar passed out of the foothills at the mountain front onto the Magdalena plain. The estimated velocities agree well with a velocity calculated by Lowe and others (1986). These investigators made measurements of superelevation run-up where the lahar flowed around a sharp bend in the Lagunillas canyon approximately 1 km upstream from the mouth. Such measurements resulted in a calculated value of 43 km/hr. If less delay is assumed in initial mobilization of the flows, then resultant estimates of velocity will be less than those indicated in the table. Thus, it seems unlikely that mean velocities between the source areas and the mountain front exceeded 45–50 km/hr.

As the flows exited the mountains, the lateral constraints on the material rapidly diminished and the velocity undoubtedly decreased rapidly as well, due to the flow gradient, increased ratio of surface area versus volume (which affects frictional coefficients), and the energy-dispersive effect of the broad, undulating terrain. Interpolations of the average flow velocities downstream from the foothills toward the Magdalena River, suggest a mean flow velocity of approximately 10–15 km/hr on the plain. This estimate corresponds well with eyewitness accounts of persons who were saved by sprinting ahead of the flow for short distances to reach safety in the hills. Similar accounts were given by Acosta (1850) in the description of the 1845 lahars.

COMPOSITION OF THE LAHAR DEPOSITS

Deposits at various locations along the flow paths of the Lagunillas and Gualí lahars were inspected, sampled, and preliminarily analyzed. The approximate locations where the inspections were made and samples and measurements taken are given in Table 2.2. Remnants of significant man

TABLE 2.2 Site Location Inspected Along Flow Path

Site No.	Approximate Location	Site Identification	Notes
1	Main Road—3.0 km north of Armero	La Caimana Creek	Cluster of small boulders; structural behavior of railroad bridge; trees standing
1A	5.5 km north of Armero along flow	Serpentarium	Flow elevation; consolidation process of lahar deposits
2	Main Road—2.1 km north of Armero		General view of north branch of Lagunillas River lahar; boulder size and distribution; trees standing
3	Warehouse—1.5 km	Warehouse II	Structural behavior of warehouse; traces of mudflow on the warehouse walls
4	Armero	Upper central part of town; high ground	Remaining structures not swept away by the flow
5	Armero	Southern part of town; low ground	Complete destruction of existing structures
6	Armero—1.5 km in front of Lagunillas River canyon	Warehouse I; western part of town	Structural behavior of warehouse under frontal impact of mud wave
7	Armero—1.0 to 1.5 km east of canyon mouth	Lagunillas River channel	Size and shape of boulders carried by mudflow
8	Armero—eastern part of town Lagunillas	Close sedimentary hills behind Armero	Dam effect produced by high ground elevations
9	River channel 1.0 km above canyon mouth		Mark of flow elevation; "V"-shaped geometry of canyon
10	6 km southeast of Armero, along Lagunillas River	Lagunillas River	General view of flow; boulder size and distribution; marks of mud
10A	12 km southeast of Armero	South branch of Lagunillas mudflow	Fine-grained lahar deposits typically encountered away from foothills
11	Sedimentary hills behind Armero (east)	Foothills	Containment of flood advance by sedimentary hills east of Armero
12	Honda	Near junction of Gualí and Magdalena rivers	Flood damage to building foundations
13	Floodplain—1.5 km east of Gualí River canyon	River plain of Gualí River	Size of boulder transported by mudflow

made structures impacted by the flows were also inspected. The locations of these structures are also given in Table 2.2. The various locations are identified with a site number that will be referred to in the description of the main characteristics of the pertinent deposits or structures.

The initial flows in the upper river valleys involved a loose, granular mixture of silt, sand, gravel, and water (Figure 2.8). As the flows descended, they eroded valley walls and floors, stripping away a wide range of materials ranging in size from the clays derived from altered bedrock and the organic layer to large alluvial boulders weighing several tons.

The particle size distribution, extent, and morphology of the lahar deposits at various locations beyond the mouths of canyons have similarities to typical alluvial fan deposits. Sediment transported down the mountain canyons was deposited gradually on the low-gradient plains as flow velocity—and, therefore, transport energy—diminished. Where lahars followed and overtopped the existing stream channels, levees of boulders and coarse gravels were built up along the channel margins. Although the largest boulders were observed in the primary axes of flow, smaller boulders up to about 0.5 m in

Figure 2.8
Oblique aerial photograph showing the distributary pattern of laharic deposits on the intermediate slopes below Nevado del Ruiz. Note the channelized debris flow in the canyon in lower center. (Photo by D. Herd, USGS.)

diameter were widely distributed within a few kilometers downstream from the mouths of canyons.

Overbank deposits, which spread out across the broad lowland valleys up to 2 km wide, deposited finer sediment beyond the levees, often partially or entirely burying the previously transported boulders. This general pattern of distribution of the coarse lahar deposits was observed in the floodplain areas near the edge of the foothills, within a zone 5–7 km from the mouth of the river canyons. Beyond this zone, the large boulders and cobbles decrease in maximum size and abundance and gradually disappear. These farthest lahar deposits consist mainly of gravel, sand, silt, clay, and debris.

The largest boulders encountered were observed within the first 1.0–1.5 km downstream from the canyons. For example, a large boulder weighing several tons was observed in the Lagunillas River channel at Site 7 (Table 2.2), approximately 1.5 km east of the mouth of the canyon. The principal axes of the angular metamorphic rock boulder measured approximately 5 m × 3.5 m × 3 m. Smaller angular and rounded blocks, ranging from a

Figure 2.9
Two Colombian Red Cross workers stand in front of a monzonitic boulder in the floodplain of the Gualí River near Mariquita. The boulder, a local landmark, was transported approximately 400 m by the lahar. Note lahar sediment on top of the boulder and across the floodplain in the background. (Photo by R. Updike, USGS.)

few centimeters to a few meters in diameter, were deposited around the large block in a matrix-supported fabric. Such a heterogeneous distribution of unsorted particle sizes—from sands to cobbles, with no apparent stratification—is typical of high-energy, turbulent-flow transport.

Figure 2.10
"The margin of safety" is the mudline drawn against this hillside north of Armero. Hundreds of survivors were found on these low hills. In the middle foreground, segments of building walls are exposed beneath the blanket of mud. (Photo by R. Updike, USGS.)

In the vicinity of Mariquita, on the Gualí River floodplain (Figure 2.9) approximately 2.3 km downstream from the mouth of the Gualí River canyon (Site 13, Table 2.2), the study team encountered a large, angular boulder (approximately 8 m long, 6.5 m wide, and 4 m tall) surrounded by other angular boulders, as well as finer clastic sediments. Inhabitants of Mariquita reported that this boulder, which had been present prior to the November 13 lahar, had been moved approximately 300 m downstream by the flow that night. Finer clastic sediments of the lahar were found deposited on top of the boulder, suggesting that the lahar was at least 4 m thick as it passed this location.

Boulder distribution showed a remarkable association with preexisting stream channels. For example, Figure 2.10 shows the typical appearance of the northern branch of the Lagunillas River flow that followed the Santo

Domingo Creek valley. The line of boulders found strewn along the bed of the Santo Domingo Creek (at Sites 2 and 3, Table 2.2) was not characteristic of the stream channel prior to November 13, 1985. Boulders forming the levees on the edge of the stream were approximately 1.5–2.0 m in maximum diameter. There was a gradual decrease in the size of boulders deposited away from the river bed.

Figure 2.11
Large boulders (commonly more than 2 m diameter) littering former agricultural fields along the southern lobe of the Lagunillas lahar, approximately 3 km. southeast of Armero. (Photo by R. Updike, USGS.)

Another boulder-strewn tract was observed along the southern lahar branch that followed the preexisting Lagunillas River channel (Figure 2.11). Again, large boulders (approximately 1.5–2.0 m in diameter) were strewn along both sides of the Lagunillas River channel; lesser-diameter boulders shown in Figure 2.11 were deposited in both directions away from the channel. The boulders were found approximately 6 km downstream from the mouth of the Lagunillas River canyon.

THICKNESS OF LAHAR DEPOSITS

A simple method for determining the thickness of the viscous mudflows at various locations along their flow paths was to make estimations by measuring the height of remnant mud tracks above the ground surface on various physical features that survived the destruction. Mud track elevations on the walls of the Lagunillas River canyon, approximately 1.0 km upstream of the canyon mouth (Site 9, Table 2.2), were estimated to be 30 m above the valley floor (Figure 2.4).

Once the mudflows emerged from the canyon mouths onto open, gently sloping terrain, they spread laterally, reducing in thickness and simultaneously depositing substantial amounts of sediment. The thickness of the Lagunillas mudflow was measured at the remnants of a warehouse located 1.0 km directly east of the mouth of the Lagunillas River canyon (warehouse I, Site 6, Table 2.2). Mud tracks on the walls of the warehouse, which is approximately 7 m high, indicated that at peak discharge the flow reached the top of the building (Figure 2.12).

Farther east, in central Armero, at an approximate distance of 2.5 km from the canyon mouth, the accounts of survivors who spent the night on top of the hospital indicate that the mudflow almost reached the roof of the building. The study team observed that the lahar deposits at this location completely filled the first floor of the hospital building and partially filled

Figure 2.12
A granary complex located within Armero. Note the polygonal jointing of laharic mud in foreground. At peak discharge, the flow reached the top of the building in the background. (Photo by R. Updike, USGS.)

the second floor (Figure 2.13). The height of the first floor was measured to be approximately 2.75–3.0 m and the estimated total thickness at this location is about 4.0 m.

Figure 2.13
The public hospital in Armero. Two stories were constructed above grade and one below grade. Only the topmost story remained above mud level, sustaining minor damages. (Photo by R. Updike, USGS.)

The thickness of the Lagunillas River mudflow was further reduced downstream as it bifurcated into the northern and southern lobes. While in the central business district the peak flow must have been several meters thick (no structures remain to record a mudline), toward the south the thickness decreased to 1–4 m within a distance of about 1 km. In the southeast section of the city, the walls of many homes and shops remained erect even though the mudflow entered virtually all buildings, filling them to a depth ranging from a few centimeters to about 2 m (Figure 2.14). The fact that many walls remained upright suggests that forward momentum in this section of the city had diminished drastically compared to the city center.

Along the northern branch of the Lagunillas lahar, at a location 0.5 km north of Armero (2.5 km from the canyon mouth), the height of the mud traces left on a large standing tree reached approximately 4–4.5 m above the ground surface; debris was entangled in tree limbs at this height. In addi tion, the study team estimated that about 1 m of lahar deposit covers the original ground surface for a total lahar thickness of about 5 m.

About 1 km farther downstream from the tree described above (approximately 3.75 km from the canyon), mudflow elevations were measured in another warehouse (Figure 2.15). This structure, identified as warehouse II in this report (Site 3, Table 2.2), is a 45-m-long structure located near the main Mariquita-Armero highway. A view toward the downstream side of the warehouse (Figure 2.16) shows that the long axis of the warehouse is in an east-west direction perpendicular to the course of the Santo Domingo Creek, which runs between the warehouse and the hills shown in the background. The far corner of the warehouse is thus nearest to the creek, at a distance of approximately 50–75 m. Traces of mud left on the warehouse walls indicate that in sections of the warehouse nearer to the creek the lahar reached an approximate height of 2.5 m above the present ground surface, breaking the masonry wall panels between columns. Approximately 1.5 m

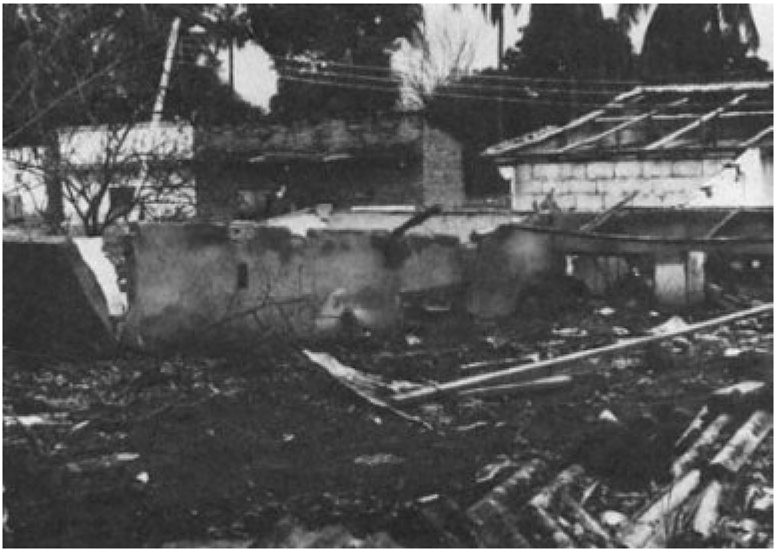


Figure 2.14
A residential area of Armero situated near the margin of the mudflows. Although the buildings remained intact, mudflows nearly reached the top of the doorways. Roofs and wall members partially collapsed due to torsional stresses caused by the impacting mud. Most buildings seen here were constructed of nonreinforced concrete or abode block. (Photo by R. Updike, USGS.)

of consolidated sediment covers the warehouse floor, so that total lahar thickness during peak flow was about 4.0 m.

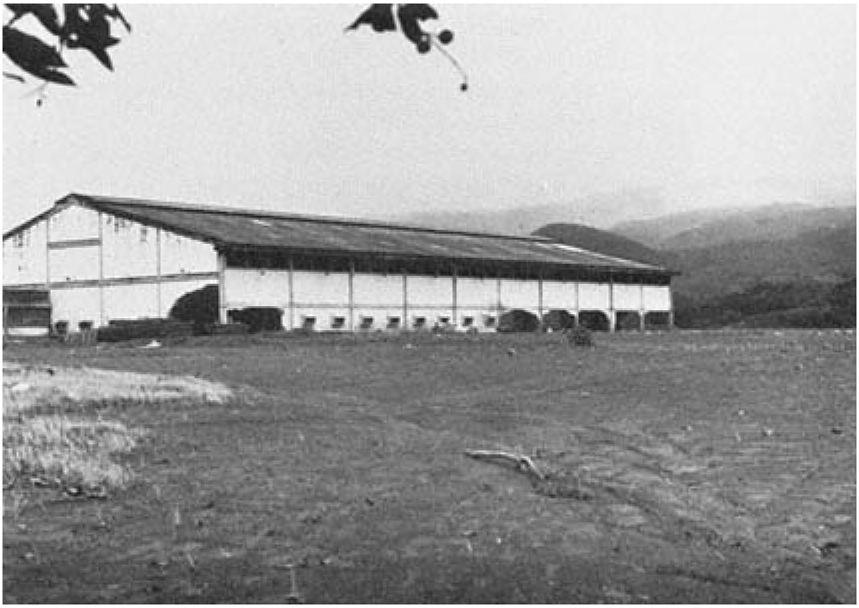


Figure 2.15
An engineered granary structure 4 km north of Armero. Construction consisted of steel rebar-reinforced concrete pillars and beams with nonreinforced concrete block fill-in between pillars. This view is of the downstream side of the building where pillars remain but concrete block has been carried away. (Photo by R. Updike, USGS.)

Farther away from the creek, the elevation of the mudflow significantly decreased, as indicated by the mudline on the remaining wall panels about 2.0 m above the warehouse floor. A close-up view of the interior of the warehouse shows the upstream corner closest to the creek bed. The mudflow traces on the exposed column reached an approximate height of 2.25 m above the consolidated lahar surface. The boulder-strewn tracts along both sides of the creek are visible in the background and the estimated thickness of the lahar cover at this point is about 2.0 m. The fine-grained materials in the foreground and directly behind the warehouse are a mixture of silt and sand, with some gravel and occasional boulders.

Approximately 1.5 km north of warehouse II, the study team examined the lahar deposits near a former ranch. Although the buildings were still standing, moderate structural damage had occurred. Splash-up above the mudline and flow marks observed in the mud (Figure 2.17) indicated that the flow was moving rapidly and turbulently at the time of impact. The mud tracks on the buildings were approximately 1.5 m above the original ground surface.

The edge of the lahar was found in a field a few hundred meters east of the ranch buildings. This outer boundary gradually thinned to a few centimeters of thickness at its transition to the cultivated field. Even here, however, the study team found that massive debris had been in transport (e.g., railroad tracks, tree trunks). This suggests that as the flow passed through this area it was significantly thicker than might be assumed from the sediment deposits left behind. This impression was further supported downstream where a tributary of Santo Domingo Creek passes beneath the Armero-Mariquita highway. Considerable debris was piled against and over the reinforced concrete culvert beneath the roadway and the mud beneath the culvert was approximately 2 m thick. The fact that the lahar overtopped the culvert indicates that it was up to 4 m thick at this point.

The thickness of the northern branch of the Lagunillas lahar was measured near its terminus at the National Serpentarium Administration Building, located approximately 5.5 km north of Armero (Site 1A, Table 2.2). A

Figure 2.16
Upstream corner of building in Figure 2.14. G. Fernandez stands by pillar dangling by rebar. Approximately 1.3 m of mudflow debris covers the interior floors of the building. (Photo by R. Updike, USGS.)

clear trace of the flow line elevation was left on the walls of this building (Figure 2.18). The flow line reached an elevation of approximately 0.9 m above the consolidated lahar surface, which was about 0.3 m thick over the original land surface. A summary of the measured depths of the Lagunillas River lahar at the various locations described above is given in Table 2.3.

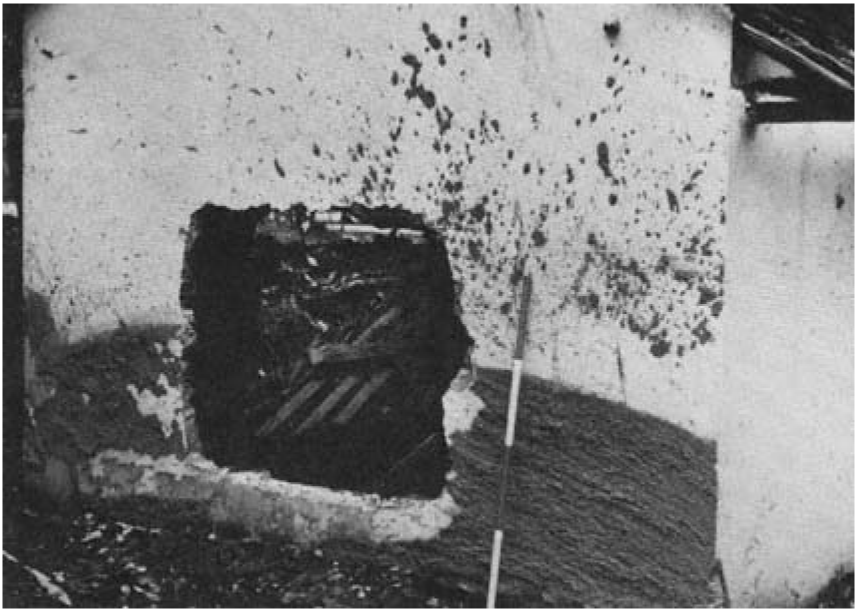


Figure 2.17
An out building at a ranch about 5 km downstream from Armero. Note "blow-out" of windows, typical of buildings that remained standing. Also note the sweeping pattern of the upper flow zone, the spatter on the wall above the flow, and the unmarked wall on the downstream wall at right, all of which suggest remarkable speed, turbulence, and viscosity. (Photo by R. Updike, USGS.)

Additional measurements of the thickness of the lahar deposits in the floodplain near Armero were carried out in 1986 by INGEOMINAS using electrical resistivity methods. Vertical profiling was conducted at seven locations on the lahar using a Schlumberger array. Figure 2.7 shows the sites where the resistivity measurements were taken, identified with the numbers 17, 18, 19, 26, 32, 33, and 34. The measurements were all made on the southern branch of the lahar, at distances from the mouth of the canyon ranging from 1.0 to 5.0 km. The thicknesses of the lahar deposits measured at these seven locations are recorded in Table 2.4 and indicate a range from 0.5 to 8.3 m. An inspection of the locations where the measurements were taken indicates that the smaller values were recorded in the vicinity of

Figure 2.18
The administration building at a serpentarium 5.5 km north (downstream) from Armero. Note the high mud line on the building wall. According to trapped survivors, the mud gradually lowered to the present surface in about three days. (Photo by R. Updike, USGS.)

TABLE 2.3 Estimated Thickness of Lagunillas Lahar

Site No.	Approximate Location	Distance from Canyon Mouth	Depth of Flow	Notes
9	Lagunillas River valley: 1 km upstream canyon's mouth	1.0 km upstream	30 m above river bed	Estimated
6	Armero warehouse I: on west side of town	1.0 km in front of canyon's mouth	7–8 m	Measured
	Armero: tall trees 300 m north of town	2.5 km in front of canyon's mouth	4–5 m at mudline + 1.5 m of sediments = 5.5–6.5 m total depth	Measured
3	Warehouse II: 1.5 km north of Armero	3 km north of canyon's mouth	2.5 m at mudline + 1.5 m of sediment = 4.0 m total depth	Measured
1A	Serpentarium: 5.5 km north of Armero	6.0 km north of canyon's mouth	0.9 m at mudline + 0.3 m of sediment = 1.2 m total depth	Measured

TABLE 2.4 Measured Thickness of Lahar Deposits in the Vicinity of Armero

Measurement No.	Approximate Distance from Canyon (km)	Measured Thickness of Deposits (m)
17	1.18	8.3
26	2.0	0.5
18	2.3	3.0
32	2.75	4.2
33	3.12	8.0
34	4.8	8.0
19	5.4	1.8

hills adjacent to the Lagunillas River and therefore represent the thinner edge of the deposits against the higher ground. Measurements taken in the low-lying topography near the Lagunillas River channel represent the thicker deposits.

Estimates of the height of the mudflow upstream from the junction between the Gualí and Magdalena rivers were also obtained during field inspection. Here, the Gualí River valley narrows considerably into an incised channel as it passes through the city of Honda. The mudflow in the Gualí River valley was contained within the steep banks bounding the river floodplain. Upstream of the narrow incised section the lahar covered the open flood-plain of the river to a height of 1.5–2 m above the river bed. The marks of the mudflow can be seen in the partially collapsed building in the background—the abandoned remains of an electrical power plant for Honda. The surface of the mudflow, however, was substantially elevated at the entrance into the narrower portion of the river channel downstream. The narrower channel section resulted in a constriction of the mudflow, raising its height in the channel 7–8 m above the river bed. Traces of the mudflow and the considerable erosion and mass wasting of the bluffs it caused were visible. These observations strongly suggest that the lahar at Honda was highly fluid. The erosive problems downstream in Honda will be discussed later.

CONSOLIDATION OF LAHAR DEPOSITS

Once the forward momentum of the materials had been arrested, a consolidation process began to take place in the loose, saturated materials. The sediment began to consolidate under its own weight, with most of the drainage taking place through the upper surface. Eyewitness accounts indicate that on the morning after the eruption large amounts of water were observed seeping upward to the mud surface, establishing various drainage paths across the surface of the recently deposited materials. The amount of water coming out of the sediment rapidly decreased within two to four days, according to these accounts. During its inspection three months after the eruption, the study team found that in some low-lying areas the surface of the deposits was still moist and that small amounts of surface dewatering could occasionally be observed.

Accounts by eyewitnesses reaching Armero in the early hours of the morning after the eruption indicate that the surface water coming out of the lahar was hot enough to burn the flesh of survivors and that associated vapors had a strong sulfuric odor. In addition, the lahar was too soft to traverse on foot or by vehicle for one to three days after the eruption. Thereafter, the deposits hardened rapidly. This consolidation process made the digging out of trapped survivors difficult for rescue workers who could not, at first, safely reach the victims and, when they could, found the people severely burned and encased in hardened mud.

Figure 2.19
Vertical exposure of the upper fine-grained zone of the lahar downstream from Armero. This zone is believed to have behaved as a quasiviscous suspended flow. Note the rudimentary columnar jointing extending nearly 1 m into the sediment from a polygonal fracture pattern on the surface. Penetrometer values consistently exceeded the 3.0 tsf limit of the instrument, used on both the surface and exposed face. (Photo by R. Updike, USGS.)

At the time of the field inspection, the primary consolidation was nearly complete, and shrinkage and desiccation of the lahar deposits were well under way. A pronounced pattern of polygonal jointing of the fine-grained lahar deposits was observed at several locations, for example, in the immediate vicinity of warehouse I (Site 6, Table 2.2). An identical polygonal joint pattern was observed at the Serpentarium (Site 1A, Table 2.2). At an excavated pit in the southeast sector of Armero, these desiccation polygons were found to be columnar joints extending nearly 1 m into the upper, fine-grained phase (Figure 2.19). The unconfined compressive strength of the silty fine sands in this upper 1-m-thick zone, as measured on both the flow surface and the exposed face, consistently yielded pocket penetrometer values that exceeded the 3.0 tsf limit of the instrument. Penetrometer resistance measurements taken in the upper, fine-grained deposits at sites in the vicinity of the Serpentarium were consistently in excess of 1.5 tsf.

Shrinkage and desiccation of the lahar deposits were observed in the mudflow materials along exterior walls of the Administration Building in the Serpentarium complex (Figure 2.20). This observation, in conjunction with the mud traces left on the wall of the building, provided an indication of the process of sedimentation, primary consolidation, partial desiccation, and shrinkage that have occurred since November 13, 1985. A caretaker who survived the disaster at the Serpentarium and remained there for several weeks after the event was able to confirm these conclusions through his own observations.

A quantitative evaluation of the reduction in the thickness of the initial mudflow was carried out based on measurement of the uniformly horizontal mudflow tracks left on the wall of the Administration Building. The surface of the mudflow reached a height of approximately 90 cm above the initial ground surface. The velocity of the mudflow at this location (approximately 5.5 km north of Armero) was apparently very low, presumably

Figure 2.20
Foundation corner of building in Figure 2.18. The desiccation has drawn the silty sand away from the foundation as consolidation continues. (Photo by R. Updike, USGS.)

because the highly fluid lahar had become sufficiently thin, was on gently sloping terrain, and was temporarily dammed downstream.

After three months, the maximum mudflow thickness of 90 cm had been reduced to a hard desiccated layer of fine-grained materials from 30–35 cm thick. A close inspection of the mud tracks left on the wall revealed the presence of a heavy, dense layer of sandy mud on the wall at a height of 30 cm above the desiccated sediment surface. In the remaining upper 25–30 cm, the trace of mud consisted of a very light silt, having the appearance and texture of chalky paint. The study team believes that within the first 48 hours the 90 cm initial thickness had decreased 25 cm due to rapid sedimentation of the suspended material. The dewatering at the surface was accommodated by slow drainage to topographically lower areas. The remaining 65-cm-thick layer of loose, saturated sediment underwent a rapid primary consolidation process and partial shrinkage due to desiccation, which further reduced the thickness to approximately 30–35 cm.

If an assumption is made that most of the lahar's thickness reduction took place during the primary consolidation process, an estimated value of the unit strain induced can be obtained using Equation 2.1 as follows:

$$S = \frac{e}{1 + e_o} H \qquad (2.1)$$

Where S = settlement of the layer
e = change in void during primary consolidation process
e_o = initial void ratio of the deposits before primary consolidation started
H = initial thickness of the layer
Replacing values (Equation 2.2), the unit strain can be estimated as follows:

$$\frac{e}{1 + e_o} = \frac{S}{H} = \frac{30\text{ cm}}{65\text{ cm}} = 0.46 \qquad (2.2$$

Based on its observations, the study team concluded that as the lahars emerged from the mountain canyons a crudely two-layered transport medium developed. The lower layer was dominated by tractive flow. This was the zone in which most of the cobble and boulder fraction was concentrated and transported. Above this zone, suspended flow predominated, containing sediments ranging from clays to gravels, with attendant debris entrained. As with other types of debris flows, basal shear stresses on the perimeter (bottom and, if present, confining walls) are dictated by depth, viscosity, density, and velocity of the flow. As has been shown, near the canyon mouths flow depth ranged up to several meters and velocities probably exceeded 40 km/hr. In the downstream direction thickness decreased (e.g., to less than 1 m at the Serpentarium) and velocity diminished to near zero. As a result, the tractive transport of coarse sediment decreased significantly within the first 5–7 km from the canyon mouths. Thus, in the distal areas, such as to the north and east of Armero, tractive boulder flow diminished rapidly. Similarly, if the channel of the Gualí River had remained wide at Honda, tractive erosion of the channel and bluffs would not have been nearly so severe. However, because of relatively large discharge through an area with a constricted cross-section, tractive energy was concentrated on the channel perimeter.

The study team believes that the upper suspended flow regime most accurately characterized the lahar as it first began to descend the mountain. The presence and magnitude of the tractive forces, which were so destructive downstream, are dependent upon velocity, flow thickness, viscosity of the medium, and flow boundary conditions. In the opinion of the study team, the initial void ratio and density of the initial lahars can be reconstructed by back-calculating through the consolidation phenomenon in the distal areas where the primary transporting medium is better isolated.

The tangential shear stresses resulting from the down-gradient flow of a lahar are responsible for the buoyancy effects keeping the various sizes of clasts "aloft" and in motion in the flow. As these stresses are reduced, sedimentation of the clasts and consolidation of the material around the clasts will begin almost immediately. Observations and discussions with eyewitnesses indicate that the lahars began to undergo sedimentation even while still in motion.

Simultaneously, as the suspended particles began to settle through the fluid medium, the primary consolidation process takes place at a very rapid rate. The presence of large amounts of volatile gas within the fluid as well as the elevated temperature of that fluid probably initially delayed the consolidation process. In this regard, two members of the Colombian Red Cross reported that on November 14 a strong sulfur odor and steam cloud lingered over the Lagunillas lahar. Several eyewitness accounts indicated that a substantial portion of the primary consolidation occurred within a few days to a few weeks after deposition.

The fluidity of the Lagunillas lahar was noted in a partially excavated pit around a jeep buried in the lahar deposits. The interior of the vehicle was evenly filled with sediment. The jeep excavation (near Site 3, Table 2.2) was approximately 0.7 m deep at the time of our inspection, and the lahar materials exposed were hard (pocket penetrometer values in excess of 1.5 tsf) and fine-grained. The total depth of the lahar deposit at this location was estimated at 2.5 m.

In the central part of Armero the study team found bulldozer excavations to a depth of 2.0 m. The lahar deposits exposed in the walls of the excavation were hard and, at the time of excavation, consistency was firm enough to maintain a vertical-cut wall. This observation indicates that a substantial thickness of the lahar had densified and strengthened in a relatively short period of time.

Other phenomena besides desiccation and shrinkage could have contributed to the thorough and rapid hardening of the lahar deposits, for example, the development of a cementation between particles as a result of the combination of the acidic fluids and elevated temperatures within the voids, depositing chemical precipitates in intergranular voids during cooling. Such precipitates result from solution interaction with iron-magnesium silicate minerals, which we observed to be abundant in the silt-sand (matrix) of the lahar. Iron oxide precipitates were not immediately apparent, but were common in all areas of the lahars.

3

Performance of Various Structures Along the Lahar Paths

The effects of the lahars on the structural behavior of facilities at various locations along the flow path is presented in this section.

A granary (warehouse I; Site 1A, Table 2.2) located on the west side of Armero 1.5 km from the mouth of, and directly in line with, Lagunillas Canyon experienced a strong impact from the lahar. The mudflow reached the top of the building, which is approximately 6–7 m high. The reinforced-concrete frame of the building did not collapse under the impact of the flow. However, some of the reinforced structural members were severely damaged. In addition, the exterior masonry wall fill-in within the structural frame was "blown out" by the lahar.

A close-up of one of the front columns of the granary building is shown in Figure 3.1. Complete removal of the concrete from the face of the column on the front of the building, exposing the steel bar reinforcement within the column, demonstrates the high abrasive effect of the lahar. Two steel hoppers installed in a front room inside the building were buckled by the force transferred through the wall.

Within much of the southern half of Armero, total destruction of all buildings was observed. Here only the remnants of the foundations of the buildings in the business district remained. The lahar sheared off the upper part of all structures at the foundation level even though some of these structures had steel-reinforced connections between the walls and the foundations. The twisted reinforcing bars, stripped of concrete, attest to the shear forces that impinged on these structures. Very little debris was noted throughout the city center, since most of it had been transported several kilometers to the southeast.

In southeast Armero, in a downstream direction, numerous structures were at least half buried in the lahar, yet most of the walls remained erect.

Figure 3.1
A corner pillar of the building shown in Figure 2.12, showing concrete abraded to expose rebar. This degree of abrasion is particularly noteworthy given the short duration of the event. (Photo by R. Updike, USGS.)

This was particularly true near the flow margins. Most of the structures were constructed of adobe bricks or concrete blocks, with individual structural elements (e.g., walls, ceiling beams) poorly tied to each other.

Another type of construction typical in Armero was adobe reinforced with bamboo laths and then faced with stucco. Although the laths offered some degree of flexibility to the wall elements, the stucco and adobe tended to crumble when large deformation occurred. Without the adobe support, the walls tended to crumble to the level of the roofline. Failure of these buildings often began at the corners, since the wall elements at the corners were poorly tied together, and thus prone to fail under flexure.

The impact of the mudflow on various structures along the path of the northern lobe was less severe. The main steel-reinforced concrete framework of warehouse II, located approximately 2.0 km north of Armero (Site 12, Table 2.2) did not sustain catastrophic damage under the impact of the mud wave. The corner of the building closest to the central axial flow along Santo Domingo Creek had one steel-reinforced concrete column of the warehouse frame, which was dangling by the reinforcing bars. This column was the only structural element that failed in the warehouse. Because this column was located at the corner of the building nearest to high-energy flow, the possibility of one or more large boulders impacting the column was more likely. In fact, a 1-m-diameter boulder was found slightly downstream of the column, inside the warehouse.

Although the structural framework of the warehouse generally remained intact, some of the lower concrete block walls filling in between structural framework elements were carried out by the mudflow. The block walls removed were on that side of the building nearest the creek where the level of mudflow was higher and the removed walls were totally submerged in the mudflow. Figure 3.2 shows a detail of the downstream wall of the building where bulging of the walls and columns resulted from the impact of the mudflow. The foreground of the photograph also shows the sheared surface of the concrete blocks from the removed fill-in wall, as well as the entrained debris that accumulated behind the wall.

Structures located in the same valley farther downstream, where the mudflow became more fluid and somewhat shallower, sustained moderate damage. For example, at the ranch previously mentioned, parts of the five buildings in the complex remained erect. An adobe block building remained fully intact, sustaining only damage to doors, windows, and roof covering. The lack of large boulders in tractive transport reduced the amount of flow impact damage.

An inspection of the structures at the Serpentarium complex, located 3 km downstream from warehouse II, indicated no structural damage to the various facilities. The most serious problem at this locality was dealing

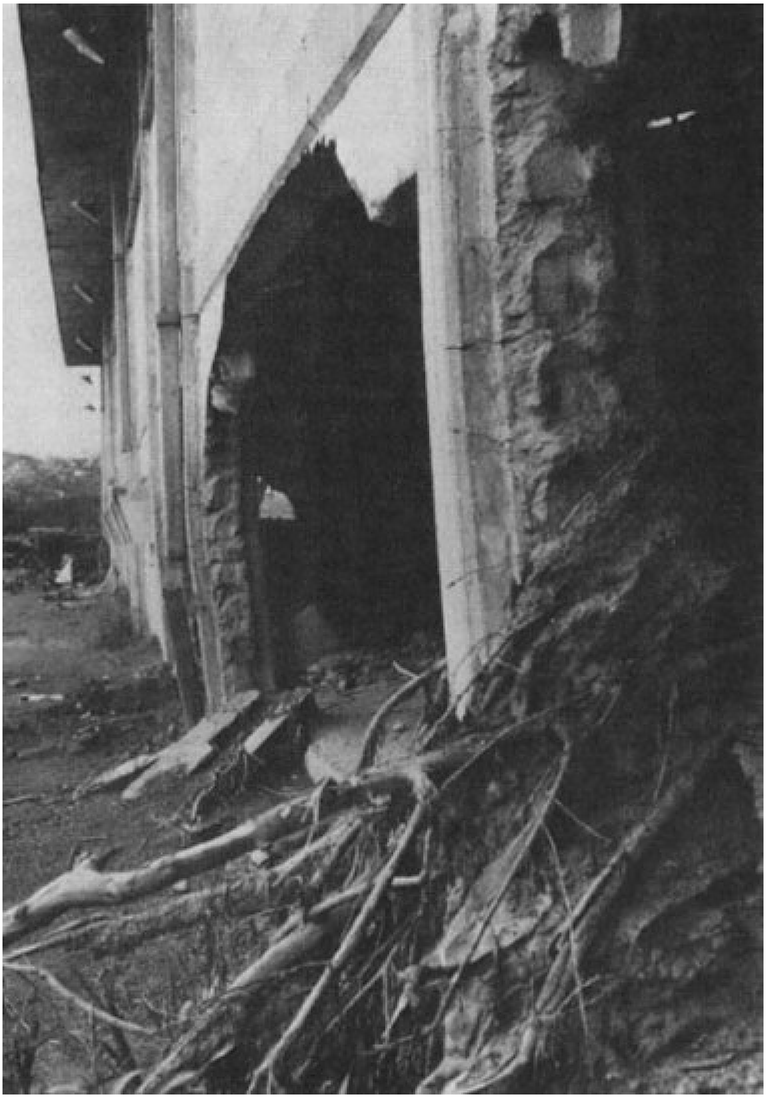


Figure 3.2
Reinforced pillars on downstream wall of the building in Figure 2.15. The concrete block fill-in has been nearly entirely removed. Pillars are cracked and bent in the downstream direction. (Photo by R. Updike, USGS.)

with the 30 cm or more of consolidated mud that had flooded most of the facilities.

Damage in the town of Honda, along the Gualí River, was quite different than at Armero. As previously indicated, the channel and floodplain of the Gualí River are constricted in a narrow, deep valley within 1 km upstream of the city of Honda. As the lahar entered this stretch of the valley it rose in height (nearly reaching the height of the bridge subdeck), was highly fluid, and moved rapidly. The scour of valley walls generated by the high flow resulted in the removal of sufficient foundation materials at the base of the bridges and buildings along this channel to cause partial collapse and serious structural damage to several buildings (Figure 3.3). The substantial removal of foundation materials at the base of some of the bridges across the channel precluded further use of these bridges until remedial measures are implemented or the bridges are replaced.

In summary, the damage to structures in the lahar paths can be attributed to the following factors:

1. forceful impact of the moderately dense, highly fluid mass that ranged up to several meters thick, resulting in normal, shear, and torsional stresses;
2. trajectory impact of large objects (boulders, debris) that were in tractive or suspended transport by the flow;
3. tractive removal of foundations, vertical support members, and roof support framing, as well as nonstructural wall and roof fill-in;
4. rapid abrasion, particularly of masonry construction, by the swiftly flowing clastic material;
5. partial or complete burial by the flows, resulting in preconsolidation lateral stresses, followed by consolidation loading and postconsolidation tension when the material adhered to the structure;
6. accelerated oxidation of metallic elements due to the low pH of the entrained fluids; and
7. erosion of foundation soils, causing ground failure beneath structures.

Figure 3.3
Foundation damage to apartment buildings in Honda along the channel of the Gualí River. (Photo by R. Updike, USGS.)

4

Preeruption Awareness and Preparedness

HISTORICAL ERUPTIONS AND EXPERIENCE

Experience with disasters has long been recognized as an important factor that can influence what people—as individuals and in groups—perceive future risk to be, as well as what they do to mitigate and prepare for future events. Prior to the November 13, 1985 eruption of Nevado del Ruiz, however, recent history did not provide the people of Colombia with experiences to point out the dangers of the Ruiz volcano.

It has been estimated that some ten major eruptions of the Ruiz volcano have taken place during the past 10,000 years, occurring on an average interval of 160 to 400 years (Herd, 1986). The last major volcanic event at Ruiz was in 1595. In 1845, an earthquake, phreatic eruption (Herd, 1986), or avalanche (UNDRO, 1985) caused a giant mudflow that killed 1,000 people as it traveled 86 km down the Lagunillas River to the Magdalena River. This 1845 lahar traversed the current site of Armero (Acosta, 1850). Two significant earthquakes occurred in 1826 and 1827. Finally, in 1916, a more minor event resulted in ashfall in the city of Manizales in Caldas State. The volcano has remained virtually dormant since then.

The relatively minor eruptive events at Ruiz since 1595 and the lack of events of sufficient magnitude (from a social perspective) to illustrate lahar risk since 1845 did little to convince those at risk that volcanoes are a major and significant Colombian natural hazard.

This is illustrated by a 1985 Colombian Civil Defense publication, *What to do in Case of Disaster*. The booklet, which was prepared for public distribution, describes about a dozen hazards along with suggested protective public actions; volcanic hazard is not mentioned.

Pointing up this oversight is in no way an attempt to single out the people of Colombia for criticism. Few are able to recognize a hazard that, for all practical purposes, has not manifested itself for some 140 years. This lack of local experience with volcanic hazards, and, thus, the virtual absence of volcano risk perception among the Ruiz area residents, was likely a major obstacle faced by those scientists and officials who recognized the danger, engaged in preparedness for an emergency, and sought to ready the public to respond.

INITIAL THREAT DETECTION

The ability to predict the precise time and magnitude of a natural disaster depends on two factors: the current state of scientific knowledge about a particular disaster and local observations of precursor activities to the disaster. The earliest perception of threat associated with Ruiz was in December 1984. A landslide formed a dangerous natural dam. At about the same time, mountain climbers began to feel and report earthquakes and gas plumes. These activities persisted, and in February 1985 several geologists from INGEOMINAS (the National Institute of Geology and Mines) conducted a site visit. In March 1985, the Colombian Civil Defense (Defensa Civil de Colombia) and INGEOMINAS requested that the United Nations Disaster Relief Organization (UNDRO) send a scientist to study the volcano.

John Tomblin of UNDRO inspected Ruiz in March 1985. Tomblin concluded that the observed earthquakes and gas plumes could be indicative of an eruption and he recommended that INGEOMINAS install seismographs to monitor the volcano. In addition, he suggested that a risk map be prepared to illustrate the potential hazard associated with an eruption of the volcano. Further, he recommended that the Defensa Civil de Colombia draft an emergency plan to facilitate public warnings and evacuation for high-risk areas.

Thus, INGEOMINAS began a project to monitor and define the volcanic risk in the Ruiz vicinity. In May, UNDRO funded a reevaluation of Ruiz by Minard Hall of the Instituto Geofísico of the Escuela Politécnica Nacional of Ecuador. In May 1985, the U.S. Geological Survey initiated a cooperative effort with UNDRO to provide scientific equipment to monitor Ruiz. First steps began in July 1985 when four portable seismographs were installed on the mountain. At about the same time, the Ruiz Volcanic Risk Committee was formed. Its charge was to begin volcanic monitoring, local emergency planning, and public education about volcanic risk.

In August, the installed seismographs recorded 5–20 earthquakes each day (Herd, 1986). INGEOMINAS pointed out that, on average, such earthquakes have, on a global basis, accompanied large volcanic eruptions about 25 percent of the time throughout recorded history. A minor eruption of steam, ash, and rock occurred on September 11, 1985; this event captured government attention although no one was injured. Surveillance of the volcano contin ued, and by October more seismographs and tiltmeters were installed on Ruiz. On November 12, 1985, the day prior to the major eruption of Ruiz, geologists who climbed to the summit to collect gas samples observed no clear signs of an imminent explosion.

EFFORTS TO INCREASE AWARENESS

A variety of efforts were undertaken to increase awareness of the risk presented by Nevado del Ruiz subsequent to the scientific discovery of an impending eruption and prior to the November 13, 1985 event. These efforts involved many Colombian and other organizations.

Instituto Nacional de Investigaciones Geológico-Mineras (INGEOMINAS)

In August 1985, INGEOMINAS published the first of a variety of reports designed to organize for or further the understanding of volcanic risk in response to the Ruiz threat. The first of these reports, *Riesgos Sísmicos y Volcánicos Del Parque Natural De Los Nevados* (Seismic and Volcanic Risks of Los Nevados Natural Park), was an effort to report on recommended research and monitoring on six Colombian volcanoes and the areas around them. The research agenda proposed recognized the volcanic risk in Colombia, particularly in volcanic regions where people lived close by. The report requested a budget to perform the recommended studies and recognized the inevitable involvement of international scientists in the study of Ruiz.

The proposed project was designed to be undertaken in stages, and it recognized the need for additional funds and international assistance. It also pointed to the need to involve organizations at all levels of Colombian government—including local governments—to define risk and hazard. The preliminary request sought funding to prepare a volcanic risk map for Ruiz; it was recognized that such a map would be needed to help make good hazard preparedness decisions.

A preliminary version of the risk map was completed on October 7, 1985, and it was accompanied by an explanatory report entitled *Mapa Preliminar De Riesgos Volcánicos Potenciales Del Nevado Del Ruiz* (Preliminary Map of Potential Volcanic Risks Associated with Nevado del Ruiz). An additional report accompanied the preparation of the risk map. This report, entitled *Informe Preliminar De Las Actividades Desarrolladas Período Julio 20-Octubre 7 de 1985*, explained that Ruiz was in a stage of activity but that it could not be precisely predicted when an eruption would occur. Continued volcanic activity was reported along with minor ashfall, de-icing of the mountain top, small mudflows, and increased volcanic crater size. The report stated that there was a 100 percent chance of catastrophic lahars when Ruiz erupted.

INGEOMINAS held a meeting in mid-October to introduce the October 7, 1985 risk map to other national agencies. The map was revised in November 1985 in a report issued on the 10th of that month, *Mapa De Riesgos Volcánicos Potenciales Del Volcánicos Nevado Del Ruiz*. This revised map and report were based on additional scientific data, but both maps foretold the total inundation of Armero in the event of an eruption. Finally, on November 10, 1985, INGEOMINAS issued a final preeruption report, *Informe De Las Actividades Desarrolladas (Período Octubre 8-Noviembre 10, 1985)* (see Figure 4.1) in which risk estimates were the most precise. Risk maps reached local communities and were posted in local civil defense offices.

It was difficult for nongeologists (Congress and local officials) to accept the risk imposed by Nevado del Ruiz as revealed in the sequence of reports and maps issued by INGEOMINAS. For example, the Colombian Congress

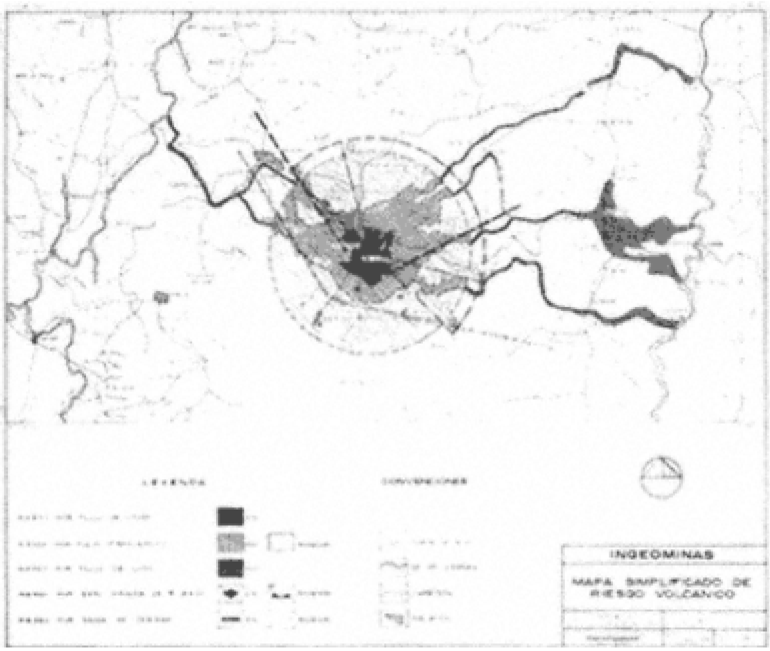


Figure 4.1
Risk map released on November 10, 1985, depicting risks associated with a future eruption of Nevado del Ruiz (original map in color).

criticized both INGEOMINAS and the Colombian Civil Defense for frightening people with their efforts to increase hazard awareness. Local civil defense and Red Cross personnel reported that city officials in Armero never did believe that their town was at risk; they also reported that the mayor of Armero still voiced his disbelief in the risk while talking on a phone at the very moment a lahar hit his building and took his life.

Civil Defense

The Colombian Civil Defense responded to the risk foretold by INGEOMINAS as early as April 1985. In the period between April and October 1985, Colombian Civil Defense spent some 5.3 million pesos on equipment to support emergency preparedness. These resources were expended on emergency communication equipment, uniforms and boots, ambulance tires, gas masks, emergency food and rations, and other items, including body bags. This effort to support preparedness and disaster response was spread throughout the entire area, in all the communities at risk.

In September 1985, after hazard maps work was under way, the director of civil defense created a plan for emergency response to the risk and eruption of Nevado del Ruiz. The plan was based on an assessment of what still remained to be accomplished and was prepared in concert with the National Committee of Regional and Local Organizations, which was established to address the threat of an eruption of Ruiz. The plan consisted of planning elements and implementing procedures for the evacuation of risk areas.

Additionally, in September 1985, the Colombian Civil Defense began flights over the mountain and river valleys near Ruiz to collect risk information. It was also in September that Civil Defense and INGEOMINAS met with Parliament to explain the risk of an impending eruption of Nevado del Ruiz and to discuss the resources needed for preparedness and mitigation, as well as the training needed to accomplish this work.

October 1985 saw even more intense efforts on the part of Civil Defense to prepare for an eruption. Radio communications were augmented in quantity and quality with both fixed and mobile communication devices. This was done in the four states in which risk was present: Tolima (the state encompassing the city of Armero), Caldas, Risaralda, and Quindio. Representatives of these four states conferred with the Colombian Civil Defense at the national level to provide local input into the planning process and the preparedness plans themselves.

Civil Defense volunteers from these same four states went to the towns and villages at risk to alert local officials to the danger and to disseminate information about what to do in the event of a disaster. Volunteers knew of the general risk of an eruption, but they lacked detailed information on the true dangers posed by lahars. This effort also included an attempt to build up public confidence to "minimize the chance of public panic if and when a disaster occurred." Civil Defense volunteers talked directly to local residents in areas at risk, including people in cities, towns, and smaller settlements, and also to squatters living along riverbanks. These conversations were an attempt to inform people about (a) what Civil Defense is, (b) the current general risk of an eruption of Ruiz, (c) preparedness for the disaster, and (d) initial aid after impact. The study team was unable to determine how many people were reached through such activities.

The efforts of Civil Defense in October extended even further. A census of the population at risk was compiled along the Gualí, Recio, Lagunilla, Azufrado, and Chinchina rivers. This census was a detailed field count of permanent and transient inhabitants at risk. Civil Defense held conferences in the cities of Armero, Chinchina, and Honda to provide risk and preparedness information. Although the Colombian Congress had criticized both the Colombian Civil Defense and INGEOMINAS, claiming that their efforts to increase awareness might scare the public, the study team found no evidence of public fear resulting from the effort to inform those at risk.

City and Regional Authorities

The Tolima Regional Emergency Committee was comprised of representatives from a variety of organizations. These included the Governor's Office, the Army's Sixth Brigade, the Regional Health Services, Civil Defense, the Red Cross, INGEOMINAS, and others. The committee contacted officials in local towns and cities at risk to inform them of the need for emergency preparedness and to encourage the development of local evacuation plans. The risk, of course, varied from town to town, and the committee was able to initiate various kinds of preparedness activities in many locales. The regional committee met many times prior to the November 13 eruption, but its last two meetings were particularly noteworthy.

On October 29, 1985, the Tolima Emergency Committee met at the office of the Red Cross. The information presented was elaborate. The risk map prepared by INGEOMINAS was presented and reviewed along with probability estimates for different events, including a worst case scenario. The monitoring activity associated with the volcano was outlined and discussed. Census data of the population at risk were presented. Emergency communications were reviewed by the Red Cross, as was the availability of some 3,000 Red Cross volunteer workers for disaster response. Additionally, the assistance reserves of some 150 countries was discussed as part of the disaster relief available. The meeting obviously made available a range of risk, preparedness, and disaster response information to some dozen at-risk communities.

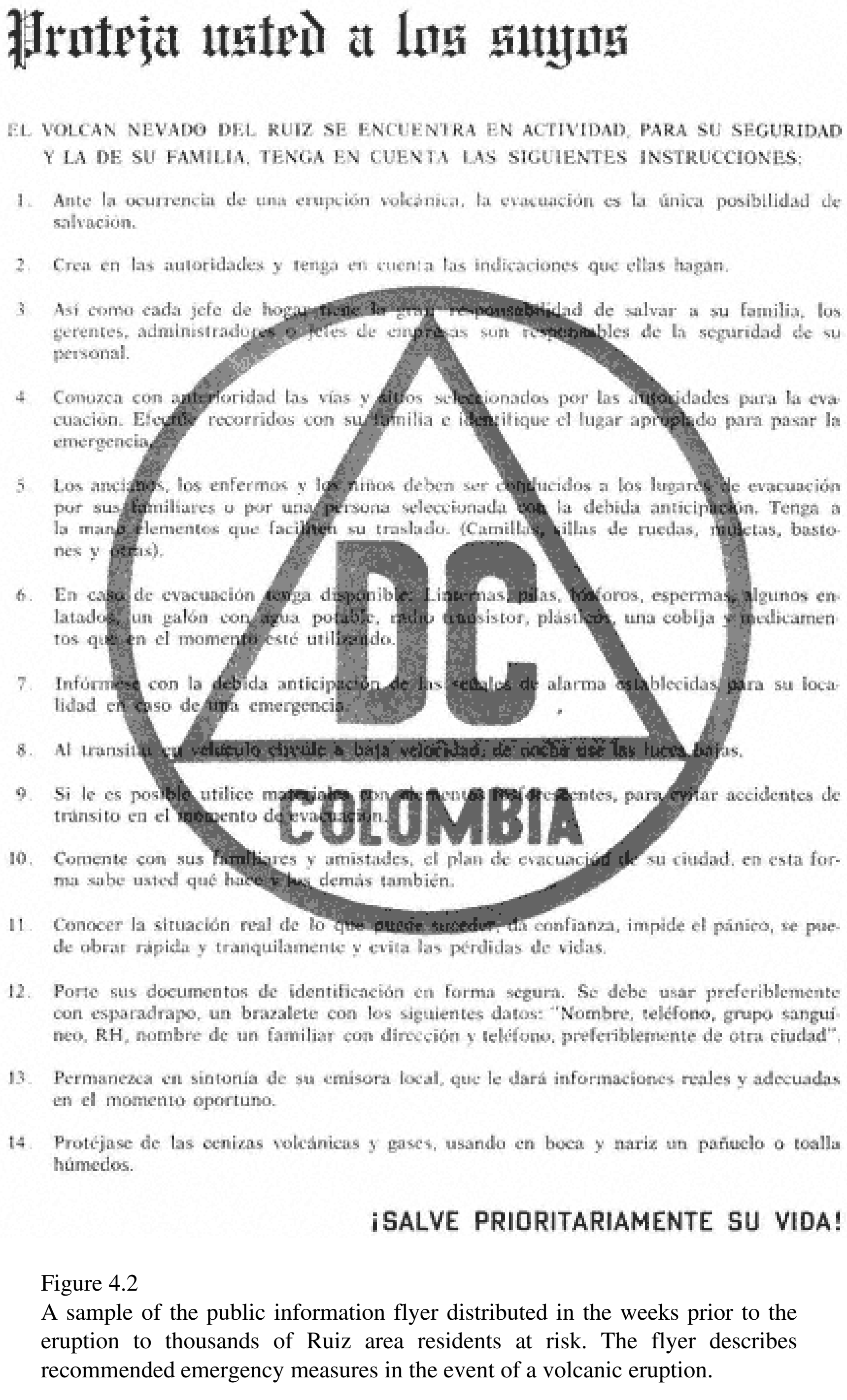
On November 13, the day of the eruption, the Regional Emergency Committee held a regularly scheduled meeting beginning at 5:00 p.m. The president of the Red Cross reported before the meeting officially began that there had been ashfall in the northern part of Tolima. The committee asked a representative of the police to send word to central command to alert all police stations to prepare for mudflows and floods along the shores of the rivers. The Red Cross alerted its field staff by radio and advised that they closely monitor low-lying areas. The director of INGEOMINAS advised those at the meeting what to do about ashfall; this advice was also disseminated over radio to the Red Cross and the police. The meeting was then called to order.

Three topics were discussed once the meeting was officially under way. First, the committee discussed with the police how best to communicate with outlying areas about the existing risk of ashfall and the potential risk of mud and flooding along riverbanks. Second, there was a detailed discussion of the agenda for a major committee meeting two days later on November 15, 1985. The agenda for this meeting was to be quite detailed and aimed at fine-tuning emergency response plans (for example, updating census data on river bank populations). Finally, the Red Cross reported that it had just received word by radio that the abnormal condition in northern Tolima had ended.

Public Information

In the weeks prior to the eruption, risk maps were distributed throughout the areas at risk in each city and town. Thousands of public information pamphlets were distributed (see Figure 4.2) and posted. For example, in September of 1985, public pamphlets were distributed in the State of Caldas that described mudflows and the magnitude of danger involved. In October, the Caldas emergency committee issued a new public brochure. It described the likely presence of environmental cues for the eruption (such as ashfall), as well as what people should do in response to the event. The public brochures for Tolima (the state containing Armero) discussed ashfall, volcanic gases, avalanches, inundation (especially along the larger rivers), explosions, and burning rock. The brochure also discussed what to do in an emergency: (a) in case of ashfall, remove the ash from your roof and cover your nose and mouth with a wet handkerchief; (b) in case of gases, use masks; (c) in case of avalanches or mudflows, evacuate zones near the shores of rivers and stay high in the hills.

It was reported that, in response to public information, a few people simply moved away from the rivers in October 1985, especially after seeing unusually dirty water in the rivers.



Proteja usted a los suyos

EL VOLCAN NEVADO DEL RUIZ SE ENCUENTRA EN ACTIVIDAD, PARA SU SEGURIDAD Y LA DE SU FAMILIA, TENGA EN CUENTA LAS SIGUIENTES INSTRUCCIONES:

1. Ante la ocurrencia de una erupción volcánica, la evacuación es la única posibilidad de salvación.
2. Crea en las autoridades y tenga en cuenta las indicaciones que ellas hagan.
3. Así como cada jefe de hogar tiene la gran responsabilidad de salvar a su familia, los gerentes, administradores o jefes de empresas son responsables de la seguridad de su personal.
4. Conozca con anterioridad las vías y sitios seleccionados por las autoridades para la evacuación. Efectúe recorridos con su familia e identifique el lugar apropiado para pasar la emergencia.
5. Los ancianos, los enfermos y los niños deben ser conducidos a los lugares de evacuación por sus familiares o por una persona seleccionada con la debida anticipación. Tenga a la mano elementos que faciliten su traslado. (Camillas, sillas de ruedas, muletas, bastones y otras).
6. En caso de evacuación tenga disponible: Linternas, pilas, fósforos, espermas, algunos enlatados, un galón con agua potable, radio transistor, plásticos, una cobija y medicamentos que en el momento esté utilizando.
7. Infórmese con la debida anticipación de las señales de alarma establecidas para su localidad en caso de una emergencia.
8. Al transitar en vehículo circule a baja velocidad; de noche use las luces bajas.
9. Si le es posible utilice materiales con elementos fosforescentes, para evitar accidentes de tránsito en el momento de evacuación.
10. Comente con sus familiares y amistades, el plan de evacuación de su ciudad, en esta forma sabe usted qué hace y los demás también.
11. Conocer la situación real de lo que puede suceder, da confianza, impide el pánico, se puede obrar rápida y tranquilamente y evita las pérdidas de vidas.
12. Porte sus documentos de identificación en forma segura. Se debe usar preferiblemente con esparadrapo, un brazalete con los siguientes datos: "Nombre, teléfono, grupo sanguineo, RH, nombre de un familiar con dirección y teléfono, preferiblemente de otra ciudad".
13. Permanezca en sintonía de su emisora local, que le dará informaciones reales y adecuadas en el momento oportuno.
14. Protéjase de las cenizas volcánicas y gases, usando en boca y nariz un pañuelo o toalla húmedos.

¡SALVE PRIORITARIAMENTE SU VIDA!

Figure 4.2
A sample of the public information flyer distributed in the weeks prior to the eruption to thousands of Ruiz area residents at risk. The flyer describes recommended emergency measures in the event of a volcanic eruption.

CONCLUSIONS

The efforts to share awareness of the magnitude of the risk imposed on Colombia by Nevado del Ruiz were extensive; hazard maps played a key role in the effort to educate local decision-makers. Risk was well recognized by INGEOMINAS, Civil Defense, the Red Cross, the Regional Emergency Committee, and others. This risk recognition was slower in coming for some groups than others. However, it was also reported to the study team that both the Colombian Congress and officials in Armero did not recognize the risk to be as great as did the other aforementioned groups. There was fear reported among members of Congress and on the part of local officials that citizens at risk would panic if they were told about the actual risk.

5

The Warning Period

How did so many people get caught by surprise by Ruiz's catastrophic lahars, in spite of accurate risk assessments and intensive efforts at public education? How is it that so many people lost their lives in Armero, alone? The purpose of this chapter is to describe the sequence of events that took place following the initial volcanic activity on November 13, 1985, in order to examine what types of decisions were made in response to cues and messages about the impending disaster.

The preceding chapter describes what was done to create a public awareness of possible volcanic eruptions and mudflows. The creation of awareness does not itself, however, assure that people will take appropriate actions when emergencies occur. One goal of the study team was to investigate what actions individuals actually take when they receive information about an imminent threat. Social scientists have found (Perry, et al., 1981) that individual responses depend on the following factors:

- what type of message they get—formal or informal, environmental or from humans, specific or vague;
- what type of confirmation of the message they get;
- whether or not they view the threat as real;
- whether or not they think the threatening event is likely to affect them personally;
- whether or not they visualize the potential impact of the threatening event as serious enough to warrant a particular personal protective action;
- whether or not they can devise a "plan" for how to protect themselves and can execute that plan of action for themselves and their families.

Warning messages can come in several forms:

- environmental cues;
- unofficial estimations of the danger and recommendations for prudent response;
- official statements of the danger and recommendations for prudent response.

Typically, to activate the official warning system, information is relayed from scientific observers to emergency response officials. The latter then decide who is in danger, who they need to mobilize to make an appropriate response, and what types of protective actions should be recommended to those at risk. All stages in the process are likely to involve considerable uncertainty about what the scientific information means and what the appropriate response would be (Mileti et al., 1985).

It is of interest to consider information on both what messages were sent from regional level emergency system decision-makers and what responses were made to them by local level emergency system decision-makers. To facilitate this, the warning period for the Nevado del Ruiz November 13 eruption and lahars is described here in terms of

- the sequence of events related to the decision by responsible officials that an evacuation warning should be given, and
- the sequence of events in Armero that preceded the arrival of the mudflow.

A brief sketch is provided here of the warning communication system and major decision-making points on November 13, 1985. This is based on information obtained during the team visit to Colombia, as well as some written accounts (Herd, 1986; Lima, 1986). Not all accounts of the sequence of events on November 13 agree with respect to the details. Also, an important part of the story was lost with those Armerans who perished. The evacuation decision process of the emergency officials included several other communities in Tolima and Caldas, and deaths occurred in other towns as well.[1] The brief description here focuses on the events related to the disaster in Armero.

The major groups involved in the warning system on November 13 for the Department of Tolima included the following:

- scientists in the city of Manizales, where the volcano data were compiled and analyzed, and those at observation posts on Ruiz;
- emergency committee members in Manizales, linking the scientists, national level emergency response decision-makers, and regional emergency committees;

- regional (located in Ibague, capital of Tolima) and local (e.g., in Armero) emergency response officials;
- regional and local private emergency response agencies (e.g., Red Cross);
- traditional information sources (e.g., radio, priests);
- the public.

3:00–5:00 P.M., NOVEMBER 13

Around 3:00 p.m., Ruiz emitted a black column of ash, the result of a phreatic explosion (mainly steam). Although Ruiz often is shrouded in clouds and not visible, some people north of the volcano observed this ash column. About two hours later, ash began falling in Armero, which is east-northeast of the volcano.

Within about an hour of the eruption, the regional director of Civil Defense (CD) in Ibague received information about its occurrence over the CD radio.[2] He made contact with the regional director of INGEOMINAS in Ibague, who considered the event to represent a serious threat to the vulnerable populations and recommended that preparations for evacuation be made. The regional CD director also contacted the national CD director in Bogotá, who instructed him to alert CD stations in northern Tolima.

5:00–7:00 P.M., NOVEMBER 13

A regularly scheduled session of the regional emergency committee was convened at 5:00 p.m. Members were briefed by the scientific representative for INGEOMINAS. Using the volcanic hazards map that had been prepared by INGEOMINAS, the towns in Tolima—including Armero—that warranted evacuation preparations were specified. It was suggested that police stations in Armero and neighboring towns be alerted immediately.

There are various reports that traditional information sources (e.g., radio announcements, or the Catholic priest who provided reassurances at a 6:00 p.m. mass) urged people to stay calm and to stay indoors. Some say that after a while the ash stopped falling in Armero, suggesting that the eruption was over. About 7:00 p.m., a severe storm arose in the vicinity.

7:00–9:00 P.M., NOVEMBER 13

When the emergency committee meeting ended about 7:00 p.m., some of the members, including the INGEOMINAS representative, proceeded to the Red Cross office to request that the towns of Armero, Mariquita, and Honda be prepared for evacuation.[3] It had been reported that the Ibague Red Cross, while communicating by radio to its Armero office at about 7:30 p.m., ordered an evacuation. This apparently was to be executed by local officials.

In Armero there was heavy rainfall and frequent thunder, which may have masked sounds and movements associated with the volcano. The storm also caused intermittent electrical outages throughout the evening. If all the alerts reported to have been given in Armero were actually given—we were unable to confirm them all—at least the Red Cross, the Civil Defense, and the police would have known that the volcano was now viewed as a serious threat by the members of the regional emergency committee. However, there were no reports that systematic efforts to warn large numbers of Armero residents had actually taken place.

Although most families evidently used the lack of information and general uncertainty as justification for continuing routine activities, some families did leave Armero during this time. At the same time, the storm and the darkness made conditions under which to convince the public to leave the town difficult at best.

9:00–11:00 P.M., NOVEMBER 13

A few minutes after 9:00 p.m. a paroxysmal eruption and some explosions commenced on Ruiz. The ice melt accompanying the eruption led to a large accumulation of glacial meltwater around the crater that was then channeled into the rivers draining the flanks of the volcano. This water picked up soil and debris in the river valleys, thereby creating the lahars that damaged the communities along the rivers.

Specific evidence about the lengthy tremor that accompanied the eruption was not available until seismograph records were collected the following day. Immediate information about rumblings and explosions apparently came mainly from scientific observers on the mountain. An airline pilot reported the thick column of smoke and ash. River observers on the mountain made visual sightings of the mudflows rising in the rivers and radioed this information to others.

At about 9:45 p.m., CD officials in Murillo radioed the regional CD director in Ibague that Ruiz had erupted. He attempted to radio Armero to order an evacuation, but could not make contact. There is another account of a river observer above Armero also being unable to make radio contact with the CD office in Armero to report the mudflow.

Around 10:30 p.m., approximately the time a lahar destroyed part of Chinchina on the west side of the mountain, the regional CD director overheard various other radio transmissions directed at Armero. These included messages from the towns of Ambalema and Murillo that an "avalanche" (the word often used in Spanish) was approaching and Armero should be evacuated, and a conversation between a CD official in Líbano and one in Armero in which the latter was advised to leave for safety.

11:00 P.M.–1:00 A.M., NOVEMBER 13–14

Sometime after 11:00 p.m., Armero was inundated by a swift flow of watery mud, rocks, and other debris. Thus, there may have been as much as 1–3/4 hours in which local officials could have sounded a general alert and directed residents to seek higher ground. Many residents could have reached higher ground on foot in less than half an hour, and thousands of lives might have been saved.

Some interviewers reported that the mayor of Armero was talking with someone over his ham radio and saying that he did not think there was much danger when he was swept away. Also, a Red Cross staff person in Ibague reported that he was discussing the situation by radio with the Red Cross in Armero only to have the conversation abruptly cut off when the mudflow overran the office.

Some citizens of Armero reported in interviews with our research team that they received unofficial warnings by telephone from relatives and friends. These calls most probably came from Líbano, which is about 12 miles upstream from Armero and close enough to the river that the mudflow was clearly heard, if not seen, in the dark. Families who received this information and acted quickly had time to escape.

Officials from the impacted areas and towns informed us that, for the most part, the nature of the impending event simply was not understood. They reported that some thought that the major consequence would only be ashfall, or a flood, not unlike a recent one that had done some damage in Armero and seemed to pose no real threat. When the event was described as mud, the mayor of Armero was described to have envisioned a slow-moving substance affording plenty of time to take action later. A national television station had broadcast news of the 9:00 p.m. eruption, but most remember the message as having indicated that there was no cause for alarm. It is likely that many people in the community were totally unaware of any of the events that had taken place after the mid-afternoon ashfall.

With the electricity out and the weather stormy, efforts to escape a little-understood natural phenomenon with a very rapid onset were unsuccessful for most. Many survivors report that they were asleep by 11:00 p.m. and took flight only after hearing others running and shouting in the streets after the first of the surges of mud had reached the community. There was much confusion in the streets, with no electricity, explosions from gas storage facilities, and many people trying to leave in their cars. Most families did not possess cars and went on foot. Those near enough to some of the higher elevations in town and having the presence of mind to head in that direction were able to escape on foot. But for an estimated 22,000 Armerans, there was no escape from death in the swirling mud. Thousands of others in the area were injured. Most of those who made it to high ground ahead of the mud, along with those who escaped from it, spent the remainder of the night in the rain on the hills along the mudflow's path.

News of the disaster was quickly spread by radio operators. Red Cross paramedics from Ibague informed other emergency response personnel and left for Armero after losing radio contact during a conversation with the Armero Red Cross office. They had no other information about what was happening at this time. They were among the first responders on the scene, arriving at Armero around 1:00 a.m. Nonetheless, rescue and medical efforts were somewhat limited until daylight.

SUMMARY AND CONCLUSIONS

A warning system was in the process of being developed at the time of the November 13 eruption. A meeting was scheduled for November 15 to address, in part, how local officials were to transfer the warning message to the public in Armero and instruct the populace in exactly what to do.

Prior to the sighting of mudflows, the decision to call for community evacuation was based on a fairly high level of uncertainty about its need. A recommendation that people leave their homes amidst the darkness and rain for a fairly unspecified reason would not have been effective.

Advice given to townspeople earlier in the day relating to the ashfall ran counter to what would have been an appropriate message about preparing to leave the area. Even with eyewitness information about the mudflow, there apparently was not sufficient understanding of what the eruption meant to the town, with the consequence that responsible officials discounted the extreme nature and imminence of the threat and took insufficient action.

Although some public information materials had been distributed, it is not certain that a large proportion of the population had received information about the hazards associated with the volcano. Further, the available materials had not provided adequate specificity about the mudflow hazard in particular, and what to do if a warning was given. Although some families are said to have left the area throughout the day and evening, for most families the first effective message came from either seeing the advancing mud or hearing or seeing others fleeing from it.

Since the night of November 13, the Colombian preparedness agencies have made some efforts to correct the obvious deficiencies in the warning system and evacuation process. These actions are discussed further in Chapter 8.

NOTES

1. The purpose of the sketch is to give the reader some idea of what activity took place, set in motion by the physical activity of the volcano. The study team did not have the objective nor the resources to verify every detail of the warning decision process. Enough accounts exist that this sequence is believed to be, in general, what occurred.

2. It is assumed that this information came from the scientific post in Manizales, although the source report does not say specifically. Another possibility for its origin would be some local source.

3. The roles of the various agencies such as the Red Cross and Civil Defense differ somewhat in Colombia and in the United States. For example, in Colombia, the Red Cross, in addition to its relief activities, seems to be a principal part of the warning system, and also engages in search and rescue and medical aid activities immediately after disasters.

6

Disaster Impacts

This chapter describes the immediate impact of the mudflows on the communities in northern Tolima and the characteristics of the disaster that created special problems. A brief description is provided of rescue and relief activities and of the types of losses caused by the mudflows. Long-term consequences to the region also are discussed.

IMMEDIATE POSTIMPACT ACTIVITIES

The Colombian Red Cross and Civil Defense personnel were the principal first responders to Armero, participating in and organizing rescue and medical care. The Colombian military also played an important role in the logistics of the rescue activities by providing helicopter airlift for victims in need of medical care, fueling and maintaining airlift operations, transporting and distributing supplies, and establishing field medical care and shelter facilities.

After the first 24 hours, resources of all types began to arrive through the joint efforts of the international disaster relief community, and the individual efforts of over 30 foreign countries. A major logistics problem in the first few hours concerned the requisitioning, fueling, and use of helicopters to rescue survivors trapped in or near the mudflow, and to carry those needing urgent emergency medical care to designated sites.

The primary activities during the immediate postimpact period of a disaster include search and rescue of those trapped or injured; assessment of the damage; emergency medical care for the injured; provision of short-term food and shelter for those displaced; recovery, identification, and burial of bodies; and reestablishment of lifelines.

Accounts of the Armero disaster emergency period indicate that it was fairly typical of most disasters: assessments of the disaster began quickly; means for carrying out necessary functions were organized; and, over time, the coordination of the numerous players in the operations improved.

Early on in the emergency period, the Colombian president made a request for international assistance and much aid was received. However, in general, the disaster did not seem to be viewed as of unmanageable magnitude. National resources were transferred into the disaster area as needs were identified. With respect to organizing available resources, the nature of the disaster agent (mudflows) and the setting presented some specific challenges not present in all disasters. Some examples include the following:

- The disaster occurred in the night, hampering initial rescue and assessment activities.
- The mudflows affected many square kilometers, so survivors were scattered over a wide area and mobility in the valley was hampered by the impassable mud deposits. Aircraft, primarily helicopters, thus became the main method of search and rescue.
- With Armero mostly destroyed (and possibly still in danger) and victims scattered widely, it was difficult to establish centralized emergency medical and care locations in the early hours.
- Even with the high ratio of deaths to injuries, local medical care facilities (the largest hospital having been destroyed) were overwhelmed and many patients had to be taken to distant cities.
- The limited number and small size of helicopters available in the first 48 hours limited the number of injured who could be transported to receive timely medical care.
- The velocity as well as the abrasive and caustic properties of the mud created burns and other injuries that required special attention.
- Clean water, in short supply due to damage to water systems, was needed not only for drinking purposes but in larger quantities for washing mud-covered survivors.
- There was an initial concern about possible threats to the emergency operations from guerilla groups active in the Colombian countryside. (Such activities turned out to be minimal, and at least one major group declared a moratorium on hostile activities in the area because of the disaster.)

Additional problems became evident. These included:

1. *Assessing the number of survivors to plan for*. Because of the nature and extent of the mudflows, survivors were spread over a great area and the number of dead was not readily apparent. While a few thousand people were rescued by helicopters and taken to official emergency facilities, countless others walked away from the disaster site and made their own temporary care arrangements with relatives, friends, and even strangers in other communities in the region. Many reemerged when recovery assistance became available.

2. *Reuniting families*. In many instances, family members had become separated while fleeing the mudflow in the dark, or by being airlifted to different locations when they were rescued. With Armero destroyed, there was no centralized place to locate each other. Since they did not know where their relatives were, or even if they were alive, family members often advertised in the media or wandered from town to town looking for their kin in refugee camps and morgues for weeks after the catastrophe.
3. *Handling and identifying the dead*. Because of the complete destruction of some parts of town and the high death toll, bodies recovered in the early stages of the emergency period often went unclaimed. Most of the thousands of missing victims were forever entombed in the mud. However, many bodies continued to surface, creating a new set of problems.

RESTORATION ACTIVITIES

As the immediate life-threatening circumstances are resolved following a disaster, attention and resources are generally turned to restoring normal communications, transportation routes, and services. These activities are important to the reestablishment of routine economic and social life, even if the available facilities are makeshift and temporary. Government reports indicated that within two weeks of the disaster the government of Colombia and other organizations had managed to reopen many of the roads in the area; construct some temporary bridges; establish means for supplying potable water to communities whose water systems had been disrupted; begin the repair of some of the damaged water and sewer systems and fuel pipelines; begin clearing river channels and removing other debris; and establish victim reception and locator centers, aid dispatching centers, and temporary refugee settlements.

For many kinds of disasters, the provision of temporary facilities and the reestablishment of routine activities are the major focus after the emergency period. However, for this disaster, there was also considerable urgency to improve and maintain a system for monitoring the volcano hazard, for providing a warning system, and for implementing community evacuations in the event of future eruptions or mudflows.

There was a high level of concern in the scientific community that there could be future events similar to or more devastating than that of November 13, 1985. Thus, resources had to be distributed between the two primary tasks of

- reestablishing economic and social life in the region affected by the disaster and
- protecting, on a day-to-day basis, the lives of tens of thousands of persons remaining at risk from the still active volcano.

Although permanent relocation of those at greatest risk was considered, this solution is not popular among those affected by it, and is complicated and expensive to execute. In lieu of permanent relocation, it is necessary to provide an effective warning system. Since the November 13 event, several other evacuations or near-evacuations have occurred in the communities around Nevado del Ruiz, although no further disasters have yet resulted. Concerns about the improvement of the warning system are discussed in Chapter 8.

LONG-TERM IMPACTS

By December 1985, the Colombian government had prepared an initial assessment of its losses, estimated at 34.94 billion pesos (US $218 million).[1] The government also estimated that over 200,000 people were directly or indirectly affected by the November 13 eruption.[2]

Besides the estimated 24,000 deaths and 10,000 homeless, total losses (for all sites affected by the mudflows) included

- approximately 50 school facilities, as well as many experienced teachers and administrators
- two hospitals, including all their equipment and a portion of their trained staff
- over 4,000 housing units
- employment income in the affected regions, as a result of the disruption of major economic activities and the destruction of many industrial and commercial enterprises
- portions of roads and railroad tracks, bridges, water and sewer systems, transmission lines, and fuel pipelines
- 6,000 acres of grain and other crops, as well as many livestock, portions of the agricultural infrastructure, and much prime farmland

While Armero was described by many as the primary regional agricultural service center, the town of Honda at the confluence of the Gualí and Magdalena rivers also served important economic functions for the area. Concern of local officials about indirect impacts from the mudflows in northern Tolima was evident during the study team's visit to Honda, three months after the eruptions. The lahars had destroyed some structures and damaged the underpinnings of several bridges and the foundations of several buildings on the riverbank.

The mayor estimated there had been more than a 50 percent decline in economic activity in the three months since the eruption. The contamination of the river had greatly affected the local fishing industry and the tourist trade had fallen off precipitously since the eruption. Along with the curtailment of income from these major local industries had come a concomitant downturn in other local commercial activity.

A further problem was created by the damaged structures. Several build ings along one of the town's main commercial streets, perched on the high river bank, were threatened by damaged foundations or the erosion of the river bank beneath them. The issue of whether to permit restoration of damaged and river-threatened structures was a major one in the community. In addition, a plan had been drawn up for developing a new commercial center in a safer area. However, the town officials seemed to feel that this could not be accomplished without outside financial assistance. It was not clear whether Honda would be assured of such assistance for any of these problems as part of the disaster recovery plan.

Social and psychological consequences also seemed likely to be felt for some time to come. One major type of social impact was that of the likely change in importance and character for one or more of the smaller communities in northern Tolima, now that there was a need for some other community to provide important regional functions (e.g., financial services, farm equipment sales and maintenance, a junior college) that Armero once provided. Also, the influx of refugees from Armero into some of the nearby towns was perceived as disruptive and undesirable.

Representatives of welfare and psychological services also pointed out the likelihood of long-term psychological and health impacts resulting from the tragedy. For instance, virtually everyone in the valley knew someone who had died in Armero, and many had lost relatives. In addition, many survivors had sustained handicapping injuries; others had lost their employment or property. Refugee families from Armero could expect to spend months in temporary shelter, with little prospect of returning to their former community.

Past experience would suggest that few will suffer from sustained and grave psychiatric problems. However, the more horrifying a disaster, the more severe and prolonged are the emotional consequences for the survivors. Sadness and depression over the loss of so many relatives and friends seemed likely to persist for a long time, with these emotions typically being heightened around the time of traditional celebrations. Further, the Armero townsite lies at an intersection of five roads. The mud-covered riverplain and the shells of houses will serve as reminders for a long time to come for those traveling about the region. Thus, it was recognized that an increase in special training for local health workers and the development of special mental health programs would be desirable in the affected communities.

NOTES

1. According to the IMF International Financial Statistics, Colombia's 1984 Gross National Expenditure (equivalent to the GNP) was 3,723.6 billion (1984 Colombian pesos).

2. Colombia's 1984 population was 28.06 million.

7

The Recovery Program

This chapter will describe the postdisaster recovery effort up through the point at which the field observations were made in February 1986, three months after the lahars destroyed the town of Armero. Although damage occurred elsewhere as well, the study team's observations were focused on the destroyed community of Armero and on nearby communities that suffered losses or were the site of official refugee camps—Honda, Mariquita, Lérida, Guayabal, and Camboa. (There also were camps in Ibague, the capital city of Tolima.)

The following description of recovery activities is based on discussions with various Red Cross, Civil Defense, reconstruction agency, and U.S. Embassy personnel. The study team also spoke briefly with refugees in the community of Armero and obtained some journalistic and relief agency accounts of the recovery operations and progress. This chapter will describe the general organization of the recovery efforts, the development of a "new Armero," and other special recovery issues.

ORGANIZATION OF THE RECOVERY ACTIVITIES

In the first weeks, the relief activities were directed, for the most part, by the Red Cross and then by the Colombian Civil Defense. About two weeks after the November 13 disaster, a presidential task force was created to design and direct the recovery program. The recovery effort was conceived as a joint effort between the public and private sectors. A well-known and well-regarded private sector entrepreneur was selected to head this task force. With some of his associates the head of the task force formulated an organization known as Resurgir, translated in English as "to rise again." Resurgir was to provide an organizational solution to the need for better management of the receipt and distribution of national and international recovery assistance (financial, materials and supplies, equipment, labor, etc.).

Resurgir functioned as a coordinating body for all the private sector and governmental agencies who were to participate in the recovery, construction, and mitigation activities related to the volcano. The organization was operated out of the director's corporate headquarters in Bogotá. It was staffed with persons from a number of different organizations who were paid by their own parent organizations.

Resurgir was to become the coordinating organization for all activities related to the Ruiz disaster. It was also responsible for organizing continued emergency preparedness in communities at risk from future eruptions. With respect to the losses caused by the November 13 eruption, Resurgir's responsibilities included providing housing, food, employment, reconstruction, and urban development and verifying the identities of survivors.

Meetings of the participating agencies, including representatives from the international assistance groups, Colombian agencies, and the private sector, were to be held in Bogotá and in the disaster region. Separate committees were formed to deal with each of the major recovery and preparedness activities. These committees were structured to include representatives from a mix of relevant agencies and two or three survivors to represent the victims' viewpoints.

By mid-February 1986, the provision of assistance to those designated as survivors was in the early stages of implementation. The League of Red Cross Societies, an international organization, was still managing the refugee camps and food distribution, while Resurgir was responsible for survivors not in camps. Resurgir was involved in the process of identifying persons eligible for disaster assistance and was in charge of the distribution of provisional housing. It had also begun to distribute the cash stipends to eligible victims. Resurgir set up information centers in Bogotá and other communities in the disaster region where victims could inquire about types of available disaster assistance and their eligibility for such assistance. Apparently, permanent housing was to be provided only to those who returned to the area near Armero.

PROVISION OF TEMPORARY HOUSING

Following are some observations about the provision of temporary housing for the Nevado del Ruiz victims staying in the area.

Resettlement

There were few physical remnants of the city on which to focus rehabilitation activities. The continuing risk of mudflows negated consideration of rebuilding on the former site. All former inhabitants were thus forced to take up residence elsewhere. Refugee camps (referred to in Colombia as "albergues") were established in the region around Armero for survivors of the disaster. However, refugee camps are not typically viewed by survivors as the preferred housing alternative. Many of the survivors had found temporary housing with relatives or friends in other communities, or had rented or bought housing as their resources permitted.

The Refugee Camps

As of February 1986, a common estimate of the number of Armero survivors was 5,000. It was estimated that between 1,000 and 2,000 people lived in refugee camps throughout the region, including in the state capital of Ibague. The camp administrators noted that there was some fluctuation in the overall numbers as well as in the specific residents as families entered and left the refugee camp system. Also, more distant camps were being phased out and families transferred into the camps nearest Armero.

The camps in the Armero area included those in Lérida, Guayabal, Camboa, and Venadillo. One group of about 120 refugees was housed in a school; an estimated 630 others lived in the tent camps in these towns. Unfortunately, there was a need to dismantle the camp in the school, as it was past the date that instruction was to have started. A newspaper account of the camps near Ibague indicated at least 600 persons residing there, although they were to be moved to the Lérida area in the near future (El Tiempo, 1986). There also were refugees living in Red Cross-administered temporary quarters in Honda, although these were mostly Honda residents dislocated by damage.

Refugee Camp Organization

The camps around Lérida were supported by the International League of Red Cross Societies. The League had agreed to administer the refugee camps for three months—that is, until the second week in February—at which time the government of Colombia was to assume their support. However, a meeting of relief and recovery agencies working on the Ruiz disaster was held and the League apparently agreed to continue its administration until the recovery agency, Resurgir, was fully organized and capable of taking over.

The camps were largely staffed by volunteers. These included Red Cross volunteers and others who had volunteered specifically for the service (e.g., school teachers). These volunteers came from all over the country. Although those interviewed indicated it had been a gratifying experience to work at the camps, they had not anticipated that their services would be needed for such a long period of time and they reported a need to return to their regular activities. It can be assumed that many other volunteers already had returned to their homes.

Each of the camps visited was organized in a somewhat different manner. In the tent camps there were an average of 3–4 persons per tent, with large families housed in more than one tent. Refugees housed in the school building lived in a dormitory-like setting, with several families sharing each classroom as their sleeping quarters. The camps had started out with communal arrangements for cooking and doing laundry. However, conflict had been generated by such arrangements in some of the camps. Families had preferred to build simple cooking facilities by their tents in order to cook when and how they wanted.

Food was donated by other organizations or purchased locally by the Red Cross. In the camps where families had independent cooking facilities, the food was distributed directly to each family based on the number of persons. Toilet and bathing facilities were communal. In general, these facilities in the tent camps appeared very new, indicating that the provision of these services had been delayed well past the opening of the camps.

The camps in the Lérida area had programs designed to provide work or occupational training for the refugees. Resources from the relief operations were used to provide machinery and materials for such tasks as sewing, baking, carpentry, and fabrication of shoes, fishnets, and bricks. These programs were described as attempting to either provide work for refugees similar to what they had done prior to the disaster, or to provide them occupational training that would be useful to them when they reestablished a permanent residence. The camp workshops also produced products to be used in the camps. For example, refugees participated in the construction of the temporary housing.

Social Conditions in the Camps

According to accounts of the recovery workers, camps differed with respect to social and psychological conditions. The camps visited by the team appeared orderly and the camp program was described as involving the residents in camp maintenance and improvement. However, there were also reports of camps in which social conditions were less satisfactory. One camp reported high crime rates in and around the camp. This was believed to be related to a criminal element that had moved in or developed there. Indicators of this included an increase in burglaries and robberies in the surrounding community by people living in the camps and intimidation of camp inhabitants and volunteers by a small element seeking to control camp life. Another report speculated that some camps were being infiltrated by antigovernment elements who were engaging in activities designed to incite camp inhabitants against the government.

Volunteers remarked that morale was slipping in the camps in the Lérida area. Initially, camp residents had been quiet and accepting of the situation. Even though living conditions were somewhat uncomfortable and inconvenient, the most typical sentiment was "it is a roof." However, refugees were beginning to exhibit frustrations with not having a real roof nor much control over their life style.

By February, the newspapers were reporting that the level of complaints was escalating, noting that some camp residents were voicing increasingly stronger complaints about the quality and quantity of the food being provided them, the uncertainty of when and what kind of food would be distributed each week, and the perceived slowness with which the recovery agency was moving toward permanent solutions to the problems of the Armero survivors (El Tiempo, 1986). The newspapers also carried accounts of demonstrations held both in Bogotá and in the disaster region by disaster refugees to voice dissatisfaction with the speed of the recovery program.

Similar expressions of dissatisfaction and impatience have been observed in other postdisaster recovery situations. In this instance, the extent to which such feelings were held by a majority of the refugees is unknown. It is also reasonable to consider the possibility that such demonstrations were at least partially politically inspired, designed to embarrass the political party in power. In Colombia, the presidential election was only weeks away.

Health Care

The camps surveyed each had a simple clinic that health workers visited regularly. A health worker in one of these camps noted that there were many health problems among the residents. Some were related to the slow healing of burns, lacerations, and other injuries received the night of the mudflow. The majority of the conditions treated, however, were extensions of the generally poor health conditions and health care that characterized the predisaster living conditions of the camp residents.

No specific data were collected on mental health problems in the camps. However, it can be assumed that many of the refugees have or will experience at least moderate psychological consequences, including such symptoms as depression, anxiety, and sleep disturbances. The horrifying nature of the disaster, due to the high death toll, the likelihood that survivors witnessed others dying, and the uncertainty on the part of many as to the actual whereabouts of their kin, represents the type of disaster scenario found to contribute to lingering psychological consequences for survivors (Quarantelli, 1979).

Temporary Housing

Six hundred units of "provisional" housing were projected for the Lérida area. By February 1986, some units had been built in Guayabal and at the edge of Lérida for the households dislocated by the mudflows. It was intended that the first to be moved to these houses would be camp dwellers with the largest families. Apparently the land for this housing had been purchased as part of the recovery program, and a national agency—the Instituto de Crédito Territorial—was financing the construction.

There were 120 housing units nearing completion at Lérida. The project was known as Ciudadela de Jardín. At least 100 more units had been started in Guayabal, a few of which already housed refugees by mid-February. These houses were of simple construction to facilitate quick assembly, with two bedrooms and a combined kitchen and living room. Common bathing and laundry facilities were provided in separate buildings centrally located among the units. The houses were designed so that private bath facilities could be added later.

RECONSTRUCTION/RELOCATION

Many factors must be taken into account when reconstruction decisions are made. In the Armero case, reconstruction entails relocation of survivors and local functions away from the old Armero townsite. As in postdisaster situations elsewhere, the selection and acquisition of a site on which to relocate survivors involve many political, economic, legal, and social factors (Haas et al., 1977).

By February 1986, Resurgir was publicizing plans for the construction of permanent housing for the Armero survivors. These plans designated the development of a "New Armero Regional Center." It was evident that there had been considerable deliberation and some controversy about the specific location. Apparently, there still remained many uncertainties and likely changes in plans or available resources before a "new Armero" could, if ever, be built as a planned development.

Reconstruction planning often involves the progressive use of distinct housing stages such as emergency shelter, temporary housing, and finally permanent housing. Tent camps are considered as emergency housing. In Colombia, as elsewhere in the Third World, tents and other quickly constructed one-room shelters would likely fulfill the needs of the homeless for many months after the disaster.

Designations like "provisional" or "temporary" were also being used with respect to the prefab and cinder block housing being constructed near Lérida. However, it appeared that the tents would still be in use after the newly constructed provisional homes were occupied, since there were far fewer houses being constructed than there were families dwelling in the tent camps in the area or living in other temporary facilities (e.g., sharing housing with relatives). Experience in the Third World with postdisaster provisional housing of the type built at Lérida suggests that this housing is likely to be upgraded and become permanent, whether or not other "permanent" housing is built.

Another typical controversy arising after many urban disasters involves the conflict between the urgent need to rebuild quickly and the need to carefully redevelop the city so that it can avoid similar disasters in the future. In the Armero instance, little thought was given to redeveloping the original townsite. The risk of that site was obvious. However, there is evidence that the site destroyed in 1985 had been built in the same location as a community that was destroyed by a similar event in 1845. Even after the recent event, some structures remain in the higher parts of the town site and of a neighboring community and on farmland downstream. It will undoubtedly require close attention on the part of the government to prevent some type of redevelopment in the hazard zone in decades to come.

As of February 1986, Lérida (approximately 13 km from the Armero site) had been selected in the area master plan as the site for redevelopment of housing and other social and economic functions formerly located at Armero. A colorful master plan diagram had been prepared to show the layout of the development. This plan indicated areas of new housing (for Armero survivors) laid out at the edge of an area of existing housing. It also showed areas designated for community services, with the commercial district stretched along the highway, and undeveloped areas left for parks and open space.

The relevance of such a sophisticated master plan to the short-term problems arising from the disaster remains to be seen. For example, Armero had represented a major regional agricultural service center, and as the area returns to normal the replacement of this function will become ever more critical. There also is some question as to who will inhabit the proposed new town. This is one of the special issues described below.

SPECIAL ISSUES

Many of the issues and concerns the study team heard voiced about the recovery and reconstruction plans were fairly typical. For instance, there were complaints that recovery activities were moving too slowly, that provisions for refugees were not adequate, that too much emphasis was being placed on housing and not enough on the social and psychological needs of the survivors, and that those in charge of the recovery process did not understand or care about the needs of the victims. Potential aid recipients and other critics charged that the concentration of Resurgir's staff and activities in Bogotá—far from the affected area—contributed to a lack of understanding of the local problems created by the disaster.

Two questions of particular interest for the design of recovery programs in the affected area are (1) What categories of victims should be designated as eligible for recovery assistance? (2) How can the economic and social roles that had been filled by the hundreds of community leaders, professionals, and business people killed in the mudflow be successfully reestablished?

Designating Eligible Parties

As the recovery plan was formulated, it was necessary to specify who was eligible to receive the assistance to be provided, such as monthly stipends, educational benefits, and housing in the "new Armero." As of February 1986, two of the stipulations for the Tolima province recovery plan were that those receiving assistance had to return to the region around Armero, and that only those who had "escaped from the mud" (essentially persons who were residents of Armero as of November 13, 1985) were eligible for assistance.

The study team noted that the "mudflow survivor" requirement was not only difficult to implement, but also was proving to be controversial at the time of the team's observations. First, many who owned land or had other financial interests in Armero had not been residents of the community, but had sustained losses nonetheless. Second, controversy focused on the fact that many in the region felt that the effects of the mudflows had extended beyond Armero and the losses of individual families. The economy of the region had been affected in a number of ways, at least in the short term. Both municipal leaders and those representing commercial interests in other towns in the disaster area were hopeful that the national recovery program would ultimately provide assistance to help them overcome the losses they had sustained with the disruption of commercial activities in the area.

The verification of residency in Armero also was fraught with difficulties, especially since many local records were lost in the disaster. A program to identify and provide proof of Armero residency was under way, using tax and other types of records. Once an individual was established as a survivor from Armero, he or she received an identification card. This card had to be presented to receive the monthly stipend (approximately US $24) given to survivors and, eventually, to qualify for other recovery assistance, such as housing. As of early February 1986, over 15,000 people had presented themselves as survivors—a much larger figure than the official estimates suggested there should be.

Replacement of Economic and Social Roles

The demographics of the disaster damage in Armero (Lima, 1986) indicate that the lahars obliterated not only the physical center of the town, but the social core of the community as well. It is believed that few survived from among the wealthier, better educated, or better trained groups that constituted the political and economic leadership in Armero—those managing its public institutions and major businesses. Those who lived at the edge of the community or closer to the hills, and thus closer to safety, were more likely to be of the lower income groups (a pattern opposite that of many U.S. communities). With much of the traditional leadership gone, the issue of who is available to initiate, organize, and manage the economic redevelopment that is to be fostered by creating a "new Armero" gains great practical and social significance.

It is likely that the population found in the refugee camps in Tolima suffered from low education levels, lack of economically viable skills, and poverty even prior to the disaster. This could be because, as mentioned above, a high proportion of survivors had lived in outlying areas populated by low-income groups. It has also been found that those with enough resources to reestablish themselves will not normally be found in the refugee camps. Previous disaster research indicates that economic and social marginality prior to a disaster affects the ability of individuals and families to reestablish themselves after a disaster. Those with personal resources or strong support networks of kin move away from dependence on assistance programs and reestablish themselves using these other resources (Trainer et al., 1977; Bolton, 1979).

It is not clear if those survivors already making a somewhat successful economic recovery elsewhere will return to the Armero area to takeart in the "new Armero" at Lérida. In disaster-stricken communities in which the social structure remains intact, whatever the physical damage, it is fairly likely that the reconstructed community will resemble the former community both in terms of principal activities and economic leadership. The best way to promote the reestablishment of the previous functions fulfilled for the region by the town of Armero may remain a major issue for recovery planning for some time to come. The manner in which the current gap comes to be filled is a worthy focus for social scientists interested in community redevelopment.

CONCLUSIONS

The recovery efforts had not been long under way at the time these observations were made. Two types of events have considerable likelihood of affecting the shape and outcome of the initial redevelopment plans in the Ruiz area. One would be a change in government policy, precipitated, perhaps, by the election of a different administration. The other would be another volcanic event that had further major effects on the residents or economy of the region.

8

Posteruption Hazard Watch and Disaster Planning

RISK AND RISK INFORMATION

The November 13, 1985 eruption of Nevado del Ruiz was one in a series of prolonged volcanic and seismic events suggesting that magma is moving near the surface of the volcano. During the study team's visit in early 1986, geologists from INGEOMINAS, the U.S. Geological Survey, and the Observatorio Volcanológico de Colombia (Colombian Volcano Observatory) in Manizales all concurred that the risk of a future eruption of Nevado del Ruiz—as judged at that time—was high and that the volcano should be regarded as very dangerous. Thus, an effort to monitor Ruiz was begun after the eruption in 1985, employing telemetered seismic and ground deformation networks centered at the Manizales Observatory. The observatory was declared a permanent international volcano observatory by the Colombian government in early 1986 (Herd, 1986).

Geologists were aware that Ruiz had erupted ten times in the past 10,000 years or so, and that these eruptions have typically triggered lahars or mudflows. However, direct seismographic measurements of the Ruiz volcano date back only to July 1985, when four portable seismographs were installed (Murray, 1986).

The lahars of November 13, 1985 that struck the towns of Armero and Chinchina were obviously devastating. Nonetheless, after the eruption and subsequent ice melt that spawned the lahars, about 90 percent of the mountain's original ice cap remained intact. Although it remained difficult for geologists to precisely predict the next eruption of Ruiz, a variety of factors in 1986 suggested that another eruption was likely. These factors included the presence of seismic activity, mountain deformation, cracked glacial segments, and melted glacial ponds. In addition, the sizeable ice cap that remained on the mountain and the existence of cleared channels through which future lahars could move quickly indicated that the risk imposed by additional lahars could be high. Geological and seismological data on the activities of the volcano gathered in late 1985 and early 1986 at the Manizales Observatory also indicated that the volcano had a very high probability of another eruption in the then not-too-distant future, although the magnitude and timing of such an eruption were clearly unknown.

The possibility of further eruption of the volcano created the potential for a second major disaster with an even higher death toll than the 1985 incident. Using population and other data from township and risk maps, the study team estimated in 1986 that 50,000–80,000 lives could conceivably be at risk should the volcano erupt again. For example, segments of the population in the towns of Honda, Mariquita, Ambalema, Chinchina, Herveo, Villa Hermosa, Salgar, and La Dorada were all at risk. Some of these towns were close enough to potential lahar tracks to be struck within about one-half hour after an eruption; others would not be reached by the lahars for three and one-half hours or so; still others lie in between these two estimates.

The danger posed by a post-1985 eruption of Nevado del Ruiz resulted in a major effort in the state of Tolima to define future risk, to generate useful public information about this risk, and to undertake emergency preparedness and mitigation measures. The potential zone of ashfall, for example, had been estimated to be 10 km in radius. Since no real warning would be possible for those in this impact zone, the government endeavored to relocate the 5,000 or so people who resided there. In addition, INGEOMINAS has sought to research and document the last major eruption of the volcano (Espinosa, 1986), and a simplified map of volcano/lahar risk (Figure 4.1), prepared before the November 13, 1985 eruption, was widely disseminated in towns at risk. This was an attempt to illustrate danger zones and to serve as a basis for enhancing public awareness and for encouraging preparedness and emergency planning for the many areas at risk that are not slated for relocation.

EMERGENCY PLANNING FOR WARNING AND EVACUATION

In the wake of the Armero disaster, Colombia established a plan for the warning and evacuation of threatened areas in the event of another eruption of Nevado del Ruiz. The basis for this planning effort was a 1985 United Nations guidance manual entitled *Volcanic Emergency Management* (UNDRO, 1985). This text outlined topical planning areas, including time-phased response, identification of hazard zones, population and property census, identification of safe transit points and refuge zones, evacuation route identification, means of transport, refugee accommodation, rescue and medical aid, security in evacuated areas, alert procedures in government, formation and communication of public warnings (including sample wording of messages), and the review and revision of plans.

According to the early 1986 Colombian emergency warning and evacuation plan, the Observatorio Volcanológico de Colombia in Manizales was charged with monitoring the volcano for an eruption or signs of an impending eruption. When an eruption was detected or when the risk of an eruption was seen as high, the Observatorio planned to notify the Colombian president. The president, it was planned, would operate through the National Emergency Committee (COE)—Comité Operativo de Emergencia—which was established by the federal government after the November 13, 1985 eruption.

Housed in Bogotá and headed by a representative of the president, COE was an integration of many agencies and departments, including INGEOMINAS, the Army, the Red Cross, the Colombian Civil Defense, the governor of Tolima, and local police and fire departments. The COE was subject to some oversight from Resurgir—the general oversight agency that was responsible for ensuring that all necessary volcano-related activities were assigned to the responsibility of an appropriate organization. The COE was a central link in emergency evacuation planning since it was the sole body with the charge and power to make evacuation decisions should the volcano erupt again. If such a decision were made by the COE, it would then be directly communicated to Civil Defense.

The Colombian Civil Defense (CD) is located in the Federal Ministry of Defense. It was created in 1950 and restructured in 1971. In 1986, the Civil Defense consisted of a headquarters in Bogotá, offices in most cities throughout Colombia, and over 45,000 volunteers across the country. The organization had a general goal of "service to the community" in times of disaster. Specifically, it was charged with the training of people for disaster response, the overall prevention of disasters, the reduction of disaster impacts, the provision of assistance throughout all phases of disasters, and the coordination of other organizations involved in disaster response. Civil Defense in Bogotá was the organization that would receive any evacuation decision from the COE and initiate action. Thus, CD would begin the chain of communication of the evacuation decision through appropriate organizations to the public at risk in the set of towns in the State of Tolima previously listed.

The planned chain of interorganizational communication was as follows: Civil Defense would inform the governor; the governor would then inform radio and television stations, as well as the mayors of all towns in which some risk existed; the mayors would then inform their police departments; the police would inform siren keepers in their town (the plan specifies one siren keeper in each neighborhood of each town); and, finally, the media and siren keepers would inform the public of the need to evacuate.

The mix of available sirens was varied: some were electric, some were battery operated, and yet others were hand cranked. It was planned that the public would gather water and supplies and then evacuate. Although television stations go off the air at midnight, they had agreed to stay on the air if they were needed as part of the warning system.

The communication hardware available to facilitate the interorganizational communications specified in the plan was varied. Mayors had teletype machines in their offices over which they could receive communications from the president about the need to evacuate. This was supplemented by telephone links and, for local use, portable two-way radios that officials carried with them at all times.

An additional contributor to the warning and evacuation system was the network of volunteer river observers that had been established after the 1985 eruption by such organizations as CD and the Observatorio Volcanológico. These observers agreed to monitor the rivers between the volcano and the towns at risk to detect lahars and communicate information about them.

PUBLIC EDUCATION

A public education campaign was also under way in early 1986 in the Ruiz area to educate the citizens in the towns at risk. First, schools educated students about volcanic hazards in general and, specifically, what to do if Nevado del Ruiz erupted. Second, the Civil Defense (Figure 8.1) and the Red Cross both printed and circulated thousands of flyers to the public about the volcanic hazard, informing them that they should evacuate when they heard their neighborhood siren. Third, hazard maps in the form of posters (Figure 8.2) were prepared for towns at risk to illustrate appropriate protective action in response to hearing sirens, that is, evacuation to high ground. There was opposition in a few communities to posting these maps, since some local merchants were concerned that such maps might depress the local economy. Finally, evacuation route markers were painted on buildings in towns at risk to illustrate proper egress from danger areas if sirens were heard.

PUBLIC RESPONSE TO HAZARD WARNINGS

As of February 1986, when the study team visited, the warning and evacuation system set in place in the Ruiz area had been activated twice since the November 13, 1985 eruption. In both instances the public response was disappointing. The first instance was a practice drill in which no risk was present, but the siren system was activated to test public response. The sirens were sounded at midnight and the public had no way to know that the event was an exercise. Nonetheless, few residents evacuated.

The second instance was an actual evacuation decision made by the Comité

DEFENSA CIVIL COLOMBIANA

DIRECCION GENERAL

RECOMENDACIONES ESPECIALES EN RELACION CONLOS FENOMENOS ORIGINADOS POR LA ACTIVIDAD DEL VOLCAN-NEVADO DEL RUIZ

Los fenómenos que probablemente pueden presentarse con motivo de la activación del Volcán-Nevado del Ruiz, son, en términos generales: deshielos, nubes de cenizas, de gases, flujos de lodos, y temblores, no muy fuertes, especialmente en sectores bien próximos al Ruiz.

INSTRUCCIONES ELEMENTALES DE PROTECCION Y SEGURIDAD

1º Vigilancia de los ríos y quebradas que nacen en el área del nevado, especialmente en los primeros kilómetros de la parte alta, por eventuales avalanches que pueden afectarlos.

2º Permanecer alertas y avisar a las autoridades y a todos los vecinos y habitantes del área, particularmente a los que viven en sectores próximos a las vertientes de agua, sobre represamientos, aumento excesivo de los caudales o avalanches. En estos casos deben buscarse sitios ALTOS y ALEJADOS de las corrientes de agua; informar también oportunamente a la Defensa Civil.

3º Debe mantenerse un permanente control sobre los riachuelos, quebradas, ríos y en general toda vertiente que nace en el Nevado, para determinar cambios especiales en el calor, sabor y olor del agua; abstenerse de tomarla y dar aviso oportuno a las autoridades y a la Defensa Civil.

4º Puede presentarse lluvia de ceniza sobre las áreas rurales, caseríos y zonas urbanas de la región. Se evitan sus efectos tapánclose la nariz y la boca con un pañuelo húmedo con el propósito de evitar molestias pulmonares, debido a las finas partículas de cenizas que flotan en el aire.

5º Cuando se deposite alguna cantidad de ceniza volcánica sobre el techo de su residencia, retirarla inmediatamente, ya que el peso de esta ceniza húmeda en caso de lluvia, podráa desfondar su techo, además de ir obstruyendo poco a poco las canales y tuberías de desagüe del techo.

6º Mantener agua limpia recogida en recipientes, no muy grandes, y estarla cambiando cada dos días para garantizar su frescura y pureza.

7º En caso de que algún integrante de su familia, padezca problemas de salud como consecuencia de la inhalaciún de ceniza volcánica, dirigirse al centro de salud más cercano donde lo orientarán y prestarán la ayuda adecuada.

8º Mantenerse alerta, actuar con calma, no propagar rumores falsos, ni dejarse llevar por el pónico constituyen elementales normas de prevenciún que son comunes para hacer frente en forma adecuada a cualquier emergencia.

9º Colabore con las autoridades, apoye a la DEFENSA CIVIL COLOMBIANA que sólo le interesa el bienestar de la comunidad, y préstele a sus funcionarios y a los voluntarios toda la colaboración posible.

"LISTOS EN PAZ O EMERGENCIA"

FIGURE 8.1 A reproduction of the flyer on volcanic hazards distributed by the Colombian Civil Defense to Ruiz area residents.

ATENCION HABITANTES DE HONDA

El Volcán Nevado del Ruiz continúa en actividad.

Es indispensable permanecer atentos Para evitar tragedias.
Para obrar con prontitud y ordenadamente es necesario estar bien enterados sobre el lugar a donde deben trasladarse y las medidas que se deben aplicar ante una EMERGENCIA INMEDIATA.

Consulte las normas con sus amigos, vecinos, autoridades y mantengan en sintonía la Radio.

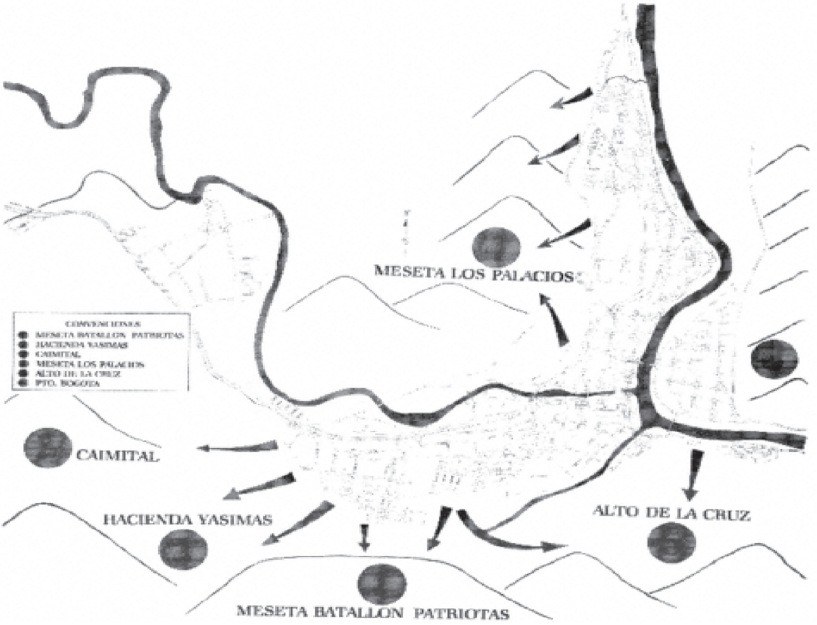


Figure 8.2 A reproduction of a poster depicting an evacuation map for the city of Honda.

Operativo de Emergencia in Bogotá in response to an eruption of Nevado del Ruiz on January 4, 1986. This eruption was not of sufficient magnitude to threaten life, which was fortunate because, again, few members of the public evacuated. The January 4, 1986 experience was an interesting test of the system, since both parts of the evacuation-warning system were exercised—the interorganizational communication component (which resulted in the COE evacuation decision and subsequent siren warning) and the public response component (evacuation).

COMMENTS

In the first few months after the 1985 eruption, the people of Colombia did much to draft, refine, and implement an evacuation/warning system in preparation for a future eruption of Nevado del Ruiz. However, the study team detected two potential flaws in the evacuation/warning system as it was conceived in January 1986. First, the warning system could not work quickly enough to relay a timely warning message to all those who must evacuate. Second, the type of warning then planned to be issued would not be effective enough to convince those who should evacuate to actually do so. Fortunately, work in the field of emergency planning (cf. Mileti and Sorenson, 1987; Perry, Lindall, and Greene, 1981; Mileti, Sorenson, and Bogard, 1985) was available that was useful to address these problems.

The January 1986 warning system in Colombia was designed to pass warnings from scientists to the public through many governmental and bureaucratic levels. As discussed above, the system was activated on January 4, 1986, when a minor eruption occurred that was marked by ash emitted from the summit. Fortunately, no deaths occurred, since this eruption was not accompanied by the emission of pyroclastic flows such as those that triggered the disaster of November 13, 1985.

In the January event it took three hours for the warning message to reach the public. However, some endangered communities could have been affected within 30–45 minutes of an eruption, and most towns at risk would be affected within 2-1/2 hours. Thus, in the minds of the study team, the delay in warning presented obvious problems in the event of a future major eruption.

Plans as of January 1986 called for initiating public evacuation by evacuation warnings, including sirens. Extensive evidence from past evacuation research demonstrates that sirens, even when preceded by elaborate public education before the time of evacuation, are not enough to convince people to leave their homes. Not surprisingly, the evacuation warning prompted by the January 4, 1986 event resulted in little actual evacuation. In light of this research, the study team, through the National Research Council's Committee on Natural Disasters, issued a brief report in 1986 (Mileti et al., 1986) to the relevant Colombian agencies containing recommendations on how to plan for more effective and timely warnings in the Ruiz area, as well as other pertinent recommendations. The text of this report is reproduced in Appendix B. What to say, what not to say, and how to say it are well understood by the research community dealing in emergency planning and are of dramatic importance in increasing the probability of effective evacuations

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Appendix A

Geologic Setting and Prehistorical Volcanic Activities

REGIONAL GEOLOGY

Two geologic provinces, with distinct lithologic and structural characteristics, can be differentiated in the Nevado del Ruiz region. The boundaries of these provinces are marked by a series of north-south-trending faults, as shown in Figure 1.5. One of these provinces is composed of a metamorphic-igneous complex located between the Arnazazu-Manizales fault on the west, and the Mulatos fault (running parallel to the eastern foothills escarpment) on the east. This province forms a 45-km-wide band from the city of Manizales in the west to the foothills of the eastern front of the Central Cordillera and includes Nevado del Ruiz volcano. The second geologic province consists of a thick series of Cenozoic sedimentary rocks of the Magdalena River valley that extends east from the Mulatos fault to the Magdalena River and includes the 20-km-wide floodplain of the Magdalena River.

Nevado Del Ruiz Province

The oldest rocks in this area, which form the base of the Central Cordillera, consist of a series of tectonic blocks of Precambrian granodiorites, schists, gneisses, amphibolites, and migmatites (Barrero and Vesga, 1976). A younger complex of Paleozoic metamorphic rocks, including schists, phyllites, quartzites, and marbles, overlies the older basal rocks. These Precambrian and Paleozoic rocks are intruded by a series of Jurassic, Cretaceous, and Tertiary batholiths and dikes composed of granodiorites, quartz diorites, and quartz monzonites.

Volcanism apparently began during the Miocene with the release of extensive lavas of andesite and dacite that capped the older metamorphic and intrusive rocks. Subsequent periods of effusive activities resulted in an extensive sequence of differentiated lava flows and pyroclastic units consisting mainly of andesites and dacites that were erupted from distinct central vents. These flows seem to have occurred mainly along two series of fractures: one set of fractures strikes in a N20°E direction parallel to the right-lateral Palestina fault that passes near the summit of the volcano; the other series of fractures is oriented in a N12°E to N130°E direction approximately orthogonal to the first fracture set. Ruiz volcano is composed of flows and pyroclastics that extend 30 km to the east and more than 35 km west of the vent area.

Extensive glaciers formed in the Nevado del Ruiz area during late Pleistocene and Holocene times. At the height of Pleistocene glaciation, an ice cap blanketed the summit region and terminated near the 3,600-m elevation on the west flank and near the 3,200 m elevation on the east (Herd, 1982). Valley glaciers drained from the ice cap downstream along river valleys to an approximate elevation of 2,700 m to the east and 3,200 m to the west as indicated by glacial erosion features (striae, grooving), moraines, and "V"-shaped valleys. Some of the preexisting tephra cover was stripped away by the advance of these glaciers.

A postglacial eruptive phase of the volcano began during Holocene time. Episodes of explosive volcanism generated a number of lahars and pyroclastic flows in several directions from the volcano. To the north they are intercalated with the late Quaternary tephra mantle, while to the east the lahar deposits fill most of the upper Azufrado River valley, remaining as terraces above the present river level. The observed degree of soil development between lahars indicates that the mudflows are of substantially different ages. A more detailed description of the lahars in the Nevado del Ruiz area, including two historically recorded events, is given in the body of this report (see Chapter 1).

Magdalena River Valley Province

The Magdalena River Valley, west of the river, includes a relatively flat plain 20–25 km wide between the Mulatos fault along the eastern foothills of Nevado del Ruiz and the north-bound river. The surficial deposits of this region are Quaternary floodplain deposits of stratified sand, silt, and gravel. Mesas, composed of Upper Tertiary sedimentary rocks, stand prominently above this plain and are composed of alluvial conglomerates, sandstones, and siltstones. The various lahars generated during late Pleistocene and Holocene times are intercalated with the Holocene alluvial deposits and both can be seen overlying the Tertiary rocks.

TECTONIC SETTING

The Ruiz-Tolima volcanic centers have erupted astride the Central Cordillera, the middle of three parallel branches at the northern end of the Cordillera mountain belt, which to the south becomes the Andes Mountain chain. This zone of intense deformation and volcanism on the northwest side of South America is a direct result of the subduction of the Nazca tectonic plate beneath the South American plate (Figure A.1) at a rate of about 5 cm/yr. The tectonic setting of this region is even further exacerbated because of a triple-point juncture of the Caribbean, Cocos, and Nazca plates directly to the northwest.

The main fault systems in the Nevado del Ruiz area can be summarized as follows:

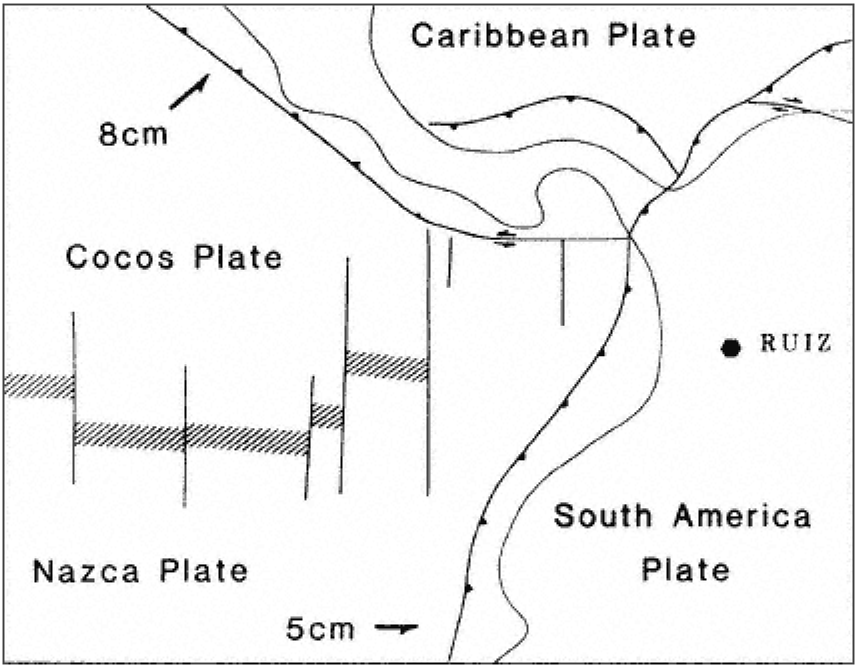

Figure A.1
Diagrammatic map showing the tectonic setting of Nevado del Ruiz. Bold lines are fault zones; barbed lines are subduction zones of underthrusting (barbs are on plate above thrust). Diagonal hachured zones are spreading ridge lines. The values of 8 cm and 5 cm refer to estimated rates of annual plate move ment and general direction (Corvalan, 1981).

1) The Romeral fault system, which includes the Romeral-Cauca and the Aranzazu-Manizales faults, consists of a series of faults and parallel fractures striking between the north-south and N15°E. The fault system has a width that ranges between 8 and 15 km and is several hundred kilometers long. The faults within this system are active and exhibit large horizontal and vertical displacements (Mosquera, 1978). This fault system is located 20–25 km west of the volcano summit and passes through the city of Manizales.
2) The Palestina fault system is more than 350 km long, strikes in a N20°E direction, and passes near the immediate vicinity of the volcano summit. Significant volumes of volcanic material have been extruded along the fractures controlled by this fault. The development of a large depression in the vicinity of the crater due to lateral explosions was also controlled by this fracture system. Predominant movement on the fault is strike-slip, bringing Precambrian metamorphic rocks in contact with the Cretaceous igneous rocks (Feininguer, 1970).
3) The Mulatos fault, which generally strikes N5°E, parallels the eastern foothills of the Nevado del Ruiz, approximately 30–35 km east of the summit. This fault has been interpreted by some investigators (Plazas and Vasquez, 1986) as a normal fault that dips towards the east and has a vertical displacement of up to 250 m. This displacement has brought into contact the Precambrian metamorphic rocks at the base of the volcano with the Tertiary sedimentary rocks of the Magdalena River Valley.
4) The Honda fault, which strikes about N20°E, is located approximately 50–55 km east of the volcano summit in the vicinity of the Magdalena River. The fault dips towards the east and has been interpreted as a thrust fault.

PREHISTORIC ACTIVITY OF THE VOLCANO

The Nevado del Ruiz complex has undergone a phase of explosive volcanism during Holocene times. A number of lahars and pyroclastic flows exposed in the Ruiz area (Figure A.2) provide a record of the various explosive eruptions of the volcano. Almost all of these deposits are postglacial in origin. Radiocarbon dating indicates that the earliest flow occurred between 13,000 and 8,600 B.P. (before the present) (Herd, 1982). Several additional eruptions have occurred between 6300 B.P. and the present. The most recent Ruiz tephra examined in 1985 is believed to be related to the historically recorded eruption of March 12, 1595.

Over time, the violent, episodic eruptions partially destroyed the north and northeast slopes of the Nevado del Ruiz summit. A large depression at the upper Azufrado and Guali river valleys was caused by a lateral explosion corresponding to the intense eruptive activity that took place around 3100 B.P. The depression is approximately 3 km wide, 1,000 m deep, and 5

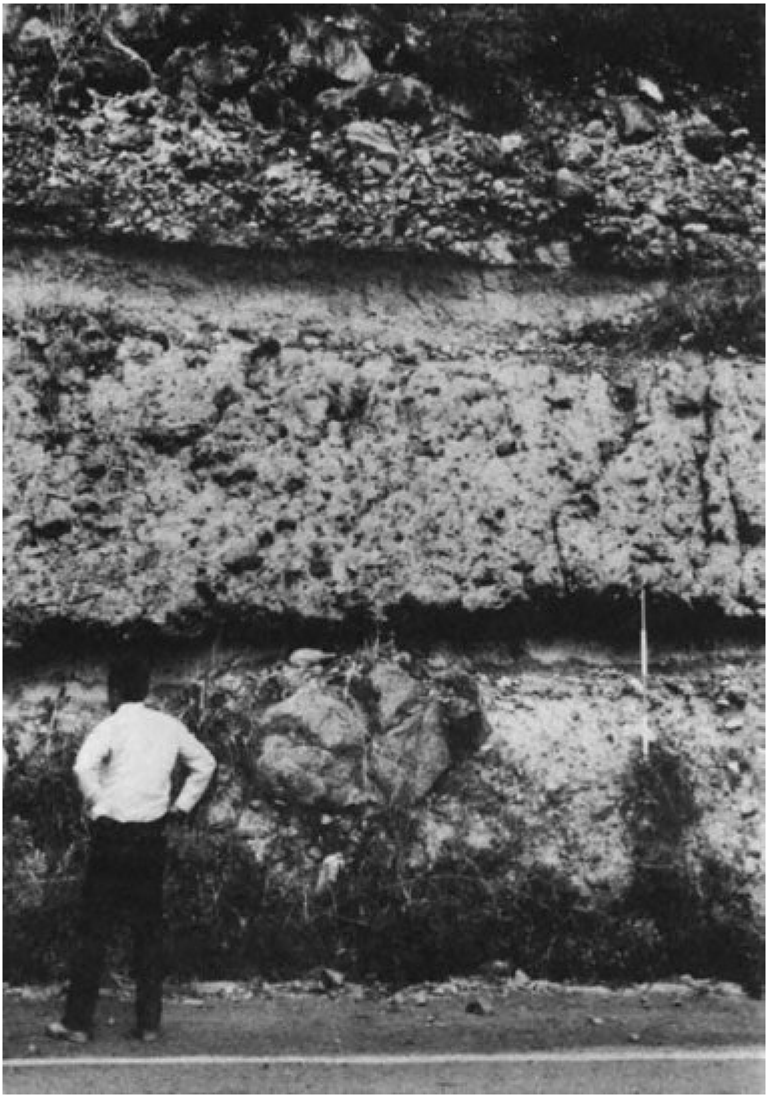

Figure A.2
A roadcut near Lérida showing two Quaternary lahars, each composed of an upper, fine-grained zone and a lower, poorly sorted, coarse clast zone. The upper portion of the picture shows the slope colluvium. However, farther up the roadcut, three additional lahar units similar to those shown are exposed. (Photo by R. Updike, USGS.)

km long. The side walls of the depression are oriented along the N20°E direction of the Palestina fault. Deposits associated with the 3100 B.P. eruption have been mapped at the bottom of this depression by Thouret and others (1985) and include large amounts of debris resulting from the partial collapse of the northeastern flank of the volcano, as well as surge, blast, and lahar deposits. The total thickness of these deposits is approximately 50 m. A more recent sequence with exactly the same succession of deposits overlies the sequence described above. This upper sequence is thinner (about 10 m thick) and is believed by several investigators (Thouret et al., 1985; Herd, 1982) to correspond to the explosion of March 12, 1595.

Deposits of lahars and pyroclastic flows generated during these various eruptions have been mapped by Herd (1982) at various localities in the Ruiz area. Lenses of these deposits have been observed on the north side of the volcano, between the Gualí River and Aguacaliente Creek, at elevations of 3,600–3,800 m. Two extensive lahars in the large depression of the upper Azufrado River valley on the northeast flank of the mountain were also mapped by Herd (1982), who reported that the lahar deposits extend from snow line down to an elevation of 3,200 m. Older lahar deposits in the foothills near the floodplain of the Magdalena River valley were also observed by the study team.

Appendix B

Recommendations for Improving the Existing warning System for an Impending Eruption of the Nevado Del Ruiz Volcano, Colombia, South America: an Advance Report

Committee on Natural Disasters
Commission on Engineering and Technical Systems
National Research Council

Recommendations for Improving the Existing Warning System for an Impending Eruption of the Nevado del Ruiz Volcano, Colombia, South America: An Advance Report

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Prepared for:
Committee on Natural Disasters
Commission on Engineering and Technical Systems
National Research Council
NATIONAL ACADEMY PRESS
Washington, D.C. 1986

ACKNOWLEDGMENTS

The study team wishes to express its appreciation to its Colombian colleagues and to the Colombian officials who assisted it. Their full cooperation was undoubtedly the reason for the trip's success.

RECOMMENDATIONS FOR IMPROVING THE EXISTING WARNING SYSTEM FOR AN IMPENDING ERUPTION OF THE NEVADO DEL RUIZ VOLCANO, COLOMBIA, SOUTH AMERICA: AN ADVANCE REPORT

Overview

Shortly after the 13 November 1985 eruption of the Nevado del Ruiz volcano in Colombia, South America, the Committee on Natural Disasters of the Commission on Engineering and Technical Systems, National Research Council, organized and dispatched a four-person study team to gather data about the eruption, its consequences, and the warning and recovery capabilities available to deal with future eruptions. The team is currently in the process of preparing a full report of its findings. However, the team has also decided to prepare this advance report on the warning system in Colombia to make their findings available without delay to those officials who can take immediate action to correct the deficiencies of the current warning system.

Geological and seismological data on the activities of the volcano gathered at the Manizales Observatory indicate that the volcano has an extremely high probability of another major eruption soon. The only question is how soon and how "major." The impending eruption of the volcano has the potential to be a major disaster that could kill even more people than the 22,000 to 24,000 people killed in the 13 November 1985 eruption. Using population data and information from township maps and risk maps, an estimated 50,000 to 80,000 additional people are at risk of losing their lives when the volcano again erupts.

An effective warning-evacuation system could substantially reduce the risk of a disaster occurring comparable to that of November 1985.

However, the existing system is not considered effective because of two significant flaws: (1) the system may not be fast enough to pass a warning message to those who need to evacuate, and (2) the type of warning issued may not be effective enough to convince those who should evacuate to do so. Overcoming these flaws requires that immediate and concentrated attention be given to transmitting information quickly and effectively from scientists monitoring the volcano to appropriate government officials in order to promptly warn the people who are at risk from an impending eruption.

The Volcano and the Disaster Event

The Nevado del Ruiz volcano, with a maximum elevation of 5,400 m, is one of the high peaks of the central cordillera of Colombia. It is located about 150 km west-northwest of Bogotá and about 30 km southeast of the city of Manizales, which has a population of 350,000. The volcano has been quiet for nearly the past 400 years. The last major eruption, about which few details are available, occurred in 1595. In 1845 the volcano was the source of an avalanche that descended the eastern slope of the mountain and caused mudflows to reach the Magdalena River more than 60 km away, killing over 1,000 people.

At about 9:00 p.m. on 13 November 1985, two sudden blasts followed by a 25-minute eruption of red-hot pumice blocks from the crater of the Nevado del Ruiz volcano melted part of the ice cap that crowns the volcano. The resulting mudflow--a mixture of water, ice, pumice, and soil--sped down the mountainside, at speeds reaching approximately 50 km/hr, via the Azufrado River channel and the Lagunilla River. The mudflow had such force that it caused the collapse of a natural dam on the Lagunilla River and swept away the town of Armero, located about 45 km east of the volcano. Between 22,000 and 24,000 people at Armero perished.

The mudflow also caused the Gaulí River to overflow, which carried away houses and a bridge on the main road to Bogotá, located about 150 km east-southeast of the volcano. Another mudslide descended along the west bank of the volcano, reaching the town of Chinchina. It destroyed about 400 houses and caused an estimated 1,000 deaths.

The Study team's Trip

The National Research Council, through its Committee on Natural Disasters, Commission on Engineering and Technical Systems, dispatched a four-person team in February 1986 to Colombia to study the eruption and its aftermath. The team stayed in Columbia from 9 through 14 February 1986. The team's charge was:

- To provide a reasonably accurate and conveniently available account of the event for historical purposes.
- To study the characteristics of the debris flow (i.e., its velocity, direction, areal coverage, and composition and particle distribution with distance from the origin).
- To identify and recommend areas where additional research could contribute to the improvement of preparedness, warning, evacuation, rescue, recovery, and rehabilitation capabilities.

The team's field trip was extremely productive, especially in the compilation of data on emergency preparedness, response planning, and geological and geotechnical engineering. The following topics will be included in the team's final comprehensive report:

1. The disaster and the events leading up to it
2. Preeruption public education and emergency preparedness
3. The warning system for, and public response to, the 13 November 1985 eruption
4. The immediate disaster response and search and rescue
5. Relief and rehabilitation, including the provision of temporary housing and aid

6. Reconstruction of permanent housing for survivors
7. Short-and long-term consequences of the event However, at least six months will be required for preparation, review, and distribution of this report.

Why an Advance Report?

The 13 November 1985 event was a disaster of immense proportions even though the size of eruption was quite small. Geologists estimate that the volcano has an extremely high probability of a major eruption in the near future. Using population data and information from township maps and risk maps, along with geological and seismological data available to the team members during their stay, an estimated 50,000 to 80,000 additional people will be at risk of losing their lives.

The preparations for the impending eruption of the volcano are matters of utmost urgency. The record of the events of 13 November 1985 confirms that the disaster at Armero resulted not from a failure of scientists to warn of the impending eruption but from breakdowns in attempts to communicate that information to those who could have evacuated. Repeated orders for the evacuation of Armero were constrained from being fully received in the town, were not fully implemented, and never reached many members of the public.

Despite the sincere and elaborate efforts of many dedicated Colombians, the warning-evacuation system designed to save the lives of the 50,000 to 80,000 people currently at risk from the volcano's next eruption is flawed. Left uncorrected, these flaws could result in human deaths of staggering proportions when the volcano erupts. Such a disaster would be extremely unfortunate given that these flaws in the warning system could be corrected through the application of existing knowledge about the warning-evacuation process. For this reason, the study team chose to prepare an advance report in order to make its findings available without delay to those officials who can take action to correct the current deficiencies.

The Existing Warning System

The warning-evacuation system designed for the next eruption is flawed in two ways. First, the warning system may not be fast enough to get a warning message to those who need to evacuate. Second, the type of warning issued may not be effective enough to convince those who should evacuate to do so.

The existing warning system in Colombia is designed to pass warnings from scientists to the public through many governmental and bureaucratic levels. The system was activated on 4 January 1986 when a minor eruption occurred marked by ash emitted from the summit. Fortunately, no deaths occurred since this eruption was not accompanied by the emission of pyroclastic flows, which triggered the disaster of 13 November 1985.

In the January event it took three hours for the warning message to reach the public. However, some endangered communities could be affected within 45 minutes of an eruption, and most towns at risk would be affected within 2-1/2 hours. This delay could result in obvious problems of protecting endangered communities in the event of a future major eruption.

Existing plans call for initiating public evacuation by evacuation warnings, including sirens. Extensive evidence from past evacuation research demonstrates that sirens, even when preceded by elaborate preevacuation public education, are not enough to get people to leave their homes. What to say, how to say it, and what not to say is well understood by the research community for emergency planning and is of dramatic importance in increasing the probability of effective evacuations. The evacuation warning issued because of the 4 January 1986 event resulted in little actual evacuation.

If scientists can predict an impending volcanic eruption of Nevado del Ruiz within a specific time frame--e.g., several days ahead of time--there could be enough time (even without emergency plans) to inform the people at risk and evacuate them to safety. Since this is still not possible and the best scientists can do is to indicate the extremely high probability of the impending event, the implementation of emergency warnings and evacuations will be critical in saving lives.

Volcanic eruptions represent the type of risk that, with modern monitoring and careful preparedness planning, can be significantly mitigated. Moreover, the cost of such predisaster preparedness is low compared with the benefit of saving lives.

Recommended Improvements

Colombia's warning system could benefit from several measures:

- Additional instruments should be installed for monitoring potential mudflows. There is an urgent need to install additional instruments at critical locations to monitor the advance of mudflows in the event of a future volcanic eruption. The telemetered seismic and ground deformation monitoring networks now deployed around the volcano give scientists at the Manizales Observatory immediate notification that an eruption is under way. However, except in a few river valleys, the networks cannot confirm that an eruption has actually generated mudflow activity. In addition, the networks may not be able to detect mudflows that have been triggered by noneruptive mechanisms, such as a landslide or other event. A mudflow detection network, deployed in all of the principal rivers that originate in the snowfields of the volcano, is needed to ensure that no potentially damaging mudflow occurs without public evacuation warnings.
- The time it takes to inform the public at risk should be reduced to much less than three hours. Mudflow experts have calculated that mudflows could travel from the volcano to Ambalema or Mariquita, which are about 50 km east and northeast of the volcano, respectively, in about an hour. The time to get a first alert to the public at risk must therefore be reduced to well

> below one hour. This could be achieved in many different ways. All possibilities involve both technological and preparedness planning components.

In the technological area, a redundant and direct communication system should be established between the scientific monitoring stations on the volcano's western slope and the offices of the President and Civil Defense headquarters in Bogotá. At present, the warning system consists of a direct telephone line between these offices with a battery-operated telephone line as the backup. Consideration should be given to increasing the redundancy of this link by installing a microwave telephone system at the scientific monitoring station. The microwave telephone system is an existing system that provides a direct communication capability between the President and provincial governors in the case of a state emergency.

The option of establishing a reliable means of communication between these offices using satellite communication technology should also be examined. Colombia's membership in Intelsat (the International Telecommunications Satellite Organization) offers it a good opportunity for creating such a system.

If the satellite option is selected, the earth stations and terrestrial rebroadcast stations will have to be either automated or staffed by reliable, well-trained personnel. The former may be preferable, with the stations on keep-alive standby until activated by an emergency signal from the Presidential transmission. A trained cadre of reliable technicians would be required to periodically check and maintain the earth stations.

The President and the head of Civil Defense should have a direct link through any of the communication systems described above to battery-operated radios, sirens, and loudspeakers throughout all of the communities at risk. Officials backing up the President and the head of Civil Defense, who have authority to act in their stead, should also be equipped with the same communication system. The public in the villages could be provided with inexpensive battery-operated radio receivers: the cheapest type would be single-frequency tuned to the emergency broadcasting frequency. Other options also exist that would ensure that members of the endangered public would hear warning messages.

- Preparations should be made to give on-the-spot public information based on what is known about verbal evacuation warnings.

In the planning and preparedness area, planners should catalog the range of potential scenarios that scientists could send to the President and the head of Civil Defense. In concert with provincial governors, mayors from local communities at risk, and other influential local officials, planners should decide when public evacuation would be recommended on the basis of different scientific communications. These "response" scenarios could then be exercised during the planning stage without including the public so that it is clear what scientific events could precipitate the execution of immediate evacuation warnings. The participation of local government is important in any planning effort so that local officials can be bypassed to save time in communicating warnings to the public when the system is activated.

If a response scenario calls for sirens to be activated to alert the at-risk population, then activation of the sirens should be immediately followed by multiple and repeated verbal warnings from a known public official (perhaps the President) directly to the people who should evacuate. These should be followed by further soundings of sirens and verbal warnings through loudspeakers at local levels. Local government and Civil Defense officials, and perhaps even Red Cross personnel, should plan to ensure public compliance with the evacuation warnings. Plans should be developed that would facilitate these officials' ensuring that the public is correctly interpreting and acting upon the verbal warning messages received.

The content of the verbal warnings given to people at risk should be decided ahead of time. This content should be shaped by what has been learned about emergency evacuation warnings through more than 25 years of research and practice in nations like the United States and Japan.

Preparation of verbal warnings should adhere to the following principles, each of which has been shown to increase the odds of people actually evacuating:

1. Source--it should be a credible source who states that the warning is endorsed by the government and scientists.
2. Consistency--the message should not contradict itself (e.g., "the volcano erupted but don't worry").
3. Accuracy--the message should present the best scientific evidence about the possible risk and not forget to tell people why they should evacuate.
4. Clarity--the message should be drafted in words familiar to those who will need to evacuate and not in words that only officials and scientists are comfortable with.
5. Certainty--the message should display verbal confidence in the voice and tone of the speaker.
6. Guidance--people must be told exactly what to do, where to go, and how long they have to follow these instructions regardless of the extent of pre-emergency public education efforts.
7. Level of information--the message must inform people about the details of what is going on (e.g., concerning the eruption, mudflow, height of mud, what will happen to their town, which towns are being evacuated).
8. Frequency--the message must be repeated frequently.
9. Location--the message must clearly state who is at risk and who must evacuate in such a way that those at risk will perceive clearly that the message is directed to them.

A half dozen or so example messages (conforming to the above guidelines) should be developed. More than one are needed because alternative eruption scenarios (a preevent false alarm, another minor eruption, etc.) would require different messages regarding evacuation.

- Existing electrical supplies should not be relied upon.

Electrical power is essential to operate the existing telephone lines, the earth stations in a satellite communication system, and the receivers. A reliable power source could be achieved in part by providing on-site diesel generators with their own on-site fuel supplies sufficient to run these communication systems for whatever warning period is considered appropriate plus a four-to six-times reserve. Power for the public's receivers would almost certainly have to come from batteries installed in the receivers themselves or from solar power. A proper testing schedule should also be established and exercised to periodically check the reliability of these power supply systems to ensure their operability in the event of a disaster.

Conclusions

A number of issues must be addressed in order to implement these recommendations. These issues may be grouped into three major categories: (1) technical hardware for mudflow monitoring, communications from scientists to officials to the public, and backup electrical supply; (2) emergency preparedness and exercises to provide for timely public alert, the delivery of sound verbal warning messages to the public, and local official monitoring of public actions in response to warning messages; and (3) the financial and personnel resources needed to achieve these two objectives.

Technical capabilities for installation of proper instruments for mudflow monitoring can best be obtained from the present international team that is monitoring the activities of the volcano, including geologists from both Colombia and the U.S. Geological Survey. The study team also recommends that Colombia officials consult immediately with a group of experts to resolve issues related to the communication systems best suited for the local situation and the emergency planning needed to upgrade the existing warning system for the impending volcanic eruption. The emergency planning staff of the Long Island Lighting Company has indicated their willingness to assist the group of experts in offering technical and planning assistance to Colombia if called upon to do so.