

Introduction – dangerous neighbors: volcanoes near cities

CRISIS IN THE CONGO

It was a total disaster: tens of millions of yards of lava flowed down the volcano's lower slopes and into the city of Goma in the Democratic Republic of the Congo. In January of 2002, fissures opened along the southern flanks of Nyiragongo volcano, draining a lava lake and unleashing the massive lava flow. After damaging 14 villages on the volcano's slopes, lava flowed down Goma's broad main street; commercial buildings served as the molten river's banks as it moved at a walking pace. Within hours, lava flows reached the airport, covered most of the runway, and severely disrupted the ongoing United Nations relief effort for war refugees from Rwanda.

The lava flows were another form of hell for the one million residents of Goma, which lies on the border between the Congo and Rwanda. The political scene in 1994 had been bad enough: the city was overwhelmed by as many as 12,000 refugees a day fleeing the genocide in Rwanda. At the peak of the conflict nearly a million refugees camped along this strip of land between towering volcanoes and Lake Kivu. Many of the refugees had returned to Rwanda or moved on to other places, but Goma continued to feel the effects of the Congo wars in 1997 and 1998 as well as intermittent conflicts after that. Food shortage, overcrowding, and socio-political difficulties were the natural results.

Nyiragongo erupted into this overcrowded, desperate situation, displacing more than 120,000 people; there were 170 deaths, chiefly caused by exploding gasoline storage tanks. A French-Italian volcanological team, working under very difficult conditions, concluded that future eruptions could still occur farther downslope along the same fissures. The volcanologists also realized that if the fissures had continued to grow into nearby Lake Kivu, they might have triggered a

massive release of the carbon dioxide and methane being held under pressure in the lake. This type of gas release would result in thousands of casualties from carbon dioxide asphyxiation. This was an additionally significant volcanic event because Goma was the first large city actually invaded by lava flows since Catania, Italy, was damaged during Mount Etna's eruption in 1644.

Goma has the misfortune of being located along a line of volcanoes that follow the broad East African Rift Valley. Two of the largest of these volcanoes are 10,032-foot-high Nyamuragira and 11,384-foot-high Nyiragongo, which towers over Goma. Nyiragongo, whose summit crater is only 11 miles north of the city, has demonstrated beyond a doubt that it is a dangerous neighbor – one to be watched closely and trusted not at all.

TWELVE-STORY-HIGH WAVES OF VOLCANIC MUD: 23,000 FATALITIES

Volcanic mudflows from the 1985 eruption of Nevado del Ruiz in Colombia caused the greatest loss of life during a volcanic eruption within the last 50 years. The towns of Chinchina and Armero were overrun by massive, rapidly moving mudflows.

Armero, Colombia, is located at the base of the Andes where a narrow valley incised by the Lagunillas River flows out into the Magdalena River valley. In 1845, a large volcanic mudflow had inundated the area, leaving a wide fan of fairly level land upon which the modern town was conveniently but (as it turned out) disastrously located. After more than 100 years the catastrophic origin of the gently sloping alluvial fan that straddled the river had long faded from memory. In November 1985, a relatively small eruption of Nevado del Ruiz volcano, 31 miles from Armero, melted snow and ice on the summit. Water, ash, and volcanic debris flowed down the volcano's slopes and into river valleys. Barely two and one-half hours later, the first of a series of destructive volcanic mudflows hit Armero with 131-foot-high waves at flow rates of 27,000 cubic yards per second. Most of Ruiz' 22,942 victims were crushed by debris, cobbles, and boulders in the mudflow; those victims not crushed were smothered.



FIGURE 1 This view across what remained of the town of Armero, Colombia, shows the devastation caused by volcanic mudflows in November 1985. The massive mudflows were generated by an eruption of Nevado del Ruiz, 30 miles away. The flows followed the Lagunillas River and then burst out onto the floodplain from the canyon visible at the head of the alluvial fan near the top of the photo. The 131-foot-high mudflows overwhelmed the town, and 23,000 residents died in the catastrophe. *(Photo: US Geological Survey's Volcano Disaster Assistance Team)*

Warnings had been issued, but communications broke down, government authorities took no action, and Armero's people had built up a feeling of false security based on the substantial distance between them and the volcano. Had the warnings been heeded, people could have saved themselves by walking just a few hundred yards to the nearest hill.

How far away is far enough? Nevado del Ruiz may not have been immediately next door but still wreaked havoc in this neighborhood.

SOCIAL AND POLITICAL FALLOUT FROM A VOLCANIC EVENT – SOUFRIÈRE DE GUADELOUPE, FRENCH ANTILLES

Basse-Terre is a colorful French provincial town near the southernmost tip of the island of Guadeloupe, a département (overseas state) of France.



FIGURE 2 The eruption cloud from Soufrière de Guadeloupe's steam blasts rises high above the town of Basse-Terre. (*Photo: Grant Heiken*)

This coastal town grew around Fort St. Charles, which was the object of many attacks between the British and French as they competed to control the new world. Modern Basse-Terre is a sleepy place, warm, humid, and very green: not the expected scene of chaos and disaster.

The town was developed on an alluvial fan that rises from sea level to the 4809-foot-high peak of Soufrière, a volcanic dome about 5 miles northeast of the town. Wreathed in clouds and covered with a blanket of tropical plants, this impressive mass of lava is now under a constant internal attack by hot gases and fluids, which are turning the rock to clay. Even if there was no volcanic eruption, this unstable rock mass could pose a threat to the town and villages below if it were to collapse. Occasionally the steam and hot water within the volcano erupt, catapulting large rocks and coating the forest with mud. Mudflows cascade down the dome's slopes. This sort of activity, which occurred in 1690, 1797–1798, 1812, 1836–1838, and 1956, could be simply relieving an over-pressured geothermal system or it could be the precursor to a volcanic eruption. The threat to Basse-Terre and nearby communities was great enough to persuade the French government to establish a volcano observatory in 1948, staff it with observers, and install a small seismic network.

In July 1975, swarms of small earthquakes occurred below the summit of Soufrière, increasing to about 30 per month, but that rate soon returned to the normal background of about 10 per month. The number of earthquakes rose to 607 in March 1976, certainly enough to make local residents uneasy. The higher rate of activity continued until July 1976 when the summit volcanic dome was broken open by large steam blasts. Alarmed residents, some coated with sticky mud from the steam blasts, fled the town and villages nearest to the volcano summit. By August, the continuing mud-laden steam blasts contained volcanic glass fragments, which some volcanologists believed was evidence of magma close to the surface and an omen of an imminent full-scale eruption. Guadeloupe's governor ordered the evacuation of 72,000 people from populated zones below the volcano. Soon, interested volcanologists from around the world outnumbered the small staff of the Soufrière observatory at the temporary observatory set up in the colonial Fort St. Charles with logistical support from the French military and police. (In hindsight, this seems an odd siting because the fort is located on deposits from the last eruption in 1530 and a new eruption would have undoubtedly overwhelmed the temporary structure and all of its occupants.)

And now, everyone waited – somewhat fearfully and somewhat impatiently – for the eruption. An evacuated town is a strange place: empty streets covered with a thin layer of mud from the steam eruptions, wandering domestic animals, and the occasional resident who sneaked past police blockades to tend to farm animals – an eerie setting worthy of a science-fiction film.

Volcanologists use a variety of methods to determine what's happening far beneath the surface, and these methods are constantly enhanced by new technologies. In the best of circumstances, after-the-fact examination of volcanic products from an event, coupled with historical activity, records of real-time observations, and monitoring data provide a substantial body of information from which to predict future behavior by that volcano and others of its type. However, scientists don't always draw the same conclusions from these resources.

The way in which the information is conveyed to the public plays a vital role in saving lives and property.

In the 1970s, a number of tools were used to forecast an eruption. A seismic net was used to identify the depth of the earthquakes: before eruptions, the foci for earthquakes become shallower as magma rises. Ground deformation was measured by several kinds of tiltmeters and by leveling surveys: these methods found that Soufrière was bulging, and many presumed this was because of rising magma; however, short-lived deformation can also occur when steam builds up within the volcano but declines after mud-laden blasts relieve pressure. So now, scientists analyzed volcanic gases to see if the type of gases characteristic of molten rock were reaching the surface; the gases were mostly in the form of steam from an overheated geothermal system within the volcano. After-the-fact analysis of the debris from the steam eruptions determined that there was no fresh volcanic ash that would have been characteristic of magma near the surface; instead, the glassy ash particles were actually from deposits left by the last eruption, hundreds of years earlier.

The evacuation decision created a vigorous and nasty debate between the two French technical teams. One group supported the evacuation because, on the basis of the geophysical monitoring tools available in 1976, they believed that magma was working its way slowly to the surface. The other group said that there was no problem and people should return home but continue to pay close attention to monitoring reports for the volcano. This conflict did not resolve the problems of the thousands of refugees or restore calm; instead, it confused the public, led to headlines in the major French newspapers and gave the scientists a black eye in the world's view.

By October, the number and intensity of steam eruptions had decreased. In November, the eruption formally was declared "over" and people returned to their homes. Based on real-time observations, monitoring data, and examination of volcanic products, the evacuation was justified.

From an historical perspective, deposits from the 1530 eruption indicate that the area was swept by earlier pyroclastic flows and

blanketed with pumice falls. Since 1997, Soufrière has been in a state of unrest, with gas releases and seismic activity. Its dome, which sits high above Basse-Terre, is being altered from rock to mud by continuing geothermal activity near the summit. Collapse of this unstable mass could occur without an actual eruption, perhaps triggered by a large earthquake, sending “cold” volcanic mudflows down the slopes and through the towns of St. Cloud and Basse-Terre. The French government has established a permanent volcano observatory at Soufrière to monitor ground movement as well as other activities that could be interpreted as precursors to an eruption. These observations can be used to determine if this neighbor is beginning to awake from its nap.

THE NEIGHBOR’S NEIGHBOR IS THE PROBLEM —
2010’S ERUPTION OF EYJAFJALLAJÖKULL, ICELAND

In late 2009, a seismic network operated by the Icelandic Meteorological Office and the Institute of Earth Sciences (University of Iceland) began tracking precursor activity below Eyjafjallajökull, an ice-capped volcano on the south end of the island. Seismic activity increased until March 20, 2010, when a fissure eruption began on a mountain pass between Eyjafjallajökull and the ice-capped Myrdalsjökull. Unique to our times, webcams had been placed to monitor the lava fountains and lava flows from the fissure and transmit data to scientific observers; these dramatic scenes were aired not only to residents but also to international volcano watchers. The eruption drama was irresistible to tourists and local guides who organized trips to see the volcano in action. Broadcast announcers practiced their versions of Icelandic pronunciation.

The eruption soon shifted to fissures beneath the Eyjafjallajökull icecap and a second phase of explosive eruptive activity began on April 14. Buoyant, steam-rich ash columns rose to elevations of about 6 miles. By explosive eruption standards this was not so very high, but the jet stream was crossing Iceland at that time and it drove the plume steadily to the southeast and across northern Europe. Over the next six days the plume shut down air travel to cities in 32 European countries.



FIGURE 3 In 2010, the eruption of the Eyjafjallajökull, Iceland, shutdown many airports across Europe and disrupted flights to and from many other airports throughout the world for more than a week. This photograph was taken on April 17, 2010, during one of the explosive phases that formed the plume of fine-grained volcanic ash that swept across Europe. (Photo: Magnus Tumi Gudmundsson, Institute of Earth Sciences, Iceland)

The danger from airborne ash was not just that it would obscure visibility during flights – its real threat was the inevitable destruction of planes as they sucked the fine material into their engines. Five million passengers were stranded around the world as 95,000 flights were cancelled. Delayed or cancelled deliveries of goods ranging from South African fresh flowers to Asian auto and electronics parts seriously affected worldwide commerce. Sporting and arts events were cancelled. The International Air Transport Association alone estimated their industry's losses at about \$200 million dollars per day.

Much of the ash ejected by Eyjafjallajökull was very fine-grained and easily transported by wind for great distances across central and northern Europe. Because volcanic ash is frequently made up of glassy particles, in the extreme temperatures of

high-performance jet engines it can melt, coat parts, and ultimately stop the engine. Fortunately, new sampling techniques, satellite observations, and better plume-trajectory modeling capabilities supplied the real-time information needed to guide the decisions being made by civil aviation authorities.

The airlines pushed hard on the UK Meteorological office, civil aviation authorities, and the many scientists involved to determine when it would be safe to fly through the plume. Eventually, discussions between volcanologists, meteorologists, aircraft manufacturers, airlines, and civil aviation authorities led to an interim policy of allowing short flights through plumes that had light concentrations of volcanic ash. Some airlines even tested this idea with their own sampling flights. Feeling their missions were exempt, some military groups did authorize other flights that resulted in extensive engine damage. Civil aviation authorities rightly held their ground and there were no accidents or deaths before air travel to Europe was restored. This experience makes it clear that increasingly in our international culture even one substantial eruption can have severe economic, social, and physical consequences in other areas of the world as easily as in the immediate neighborhood.

WHY DO SO MANY PEOPLE CLUSTER IN METROPOLITAN AREAS NEAR VOLCANOES WHERE THERE IS CONSIDERABLE RISK?

The reasons are many and vary from the practical to the aesthetic. All large communities need a nearby productive agricultural economy to sustain them, and volcanic soils are excellent for growing everything from coffee to rice. The inherent beauty of some volcanic regions can be a major draw for residents. Geothermal areas have often attracted industrial developers of electrical power and urban heating systems as well as spas and other recreation outlets. Volcanic deposits, especially tuffs (consolidated volcanic ash), are commercially valuable for everything from building stone to kitty litter. Some cities are built on volcanoes because they provide good

harbors: in volcanoes flooded by the sea, crater rims offer a safe harbor. For many cities in overpopulated countries, there is simply nowhere else to be at home.

Worldwide, 67 large cities (with populations greater than 100,000) are located on or near historically active volcanoes, including three megacities (Tokyo, Manila, and Mexico City). The total population at risk in these urban areas exceeds 116 million people (by 2006/2007 census estimates). Because of the proximity of metropolitan areas to volcanoes such as Mount Fuji (Tokyo), Popocatépetl (Mexico City and Puebla), and Taal in the Philippines (Manila), field volcanologists are now moving “into the city.” In fact, a number of cities have now added volcanic hazard studies to their planning of urban infrastructure, civil defense, and public health, as well as to their social and political frameworks for disaster response.

Events over the past decades have served to emphasize the fact that prevention and mitigation of large-scale disasters in cities on or near volcanoes will require more than science-based hazard mapping and volcano monitoring; wider communities must be involved and encouraged to participate in extensive education and public-awareness campaigns such as the “National Disaster Day” in Japan. Increasingly, risk evaluation can and must fund and rely heavily on modeling and visualization of physical processes and their effects – employing tools that are easily grasped by emergency planners, the insurance industry, policy makers, and the public.

CHANGING EVALUATION PROCESSES FOR VOLCANIC HAZARDS

In the early 1990s, volcanologists agreed that their professional meetings must be broadened to include decision-makers such as urban planners, politicians, and public health professionals. This was a unique move for those accustomed to only highly technical scientific presentations at international meetings. The concept was to add a *Cities on Volcanoes* conference component to regularly scheduled international scientific gatherings. The initial meeting *Volcanoes in*