2007

1991: Pinatubo Eruption

Monish Ranjan Chatterjee

■ 1991: Pinatubo eruption

Volcano

Date: June 12-16, 1991
Place: Luzon, Philippines
Result: About 350 dead (mostly from collapsed roofs); extensive damage to homes, bridges, irrigation-canal dikes, and cropland; 20 million tons of sulfur dioxide spewed into the stratosphere up to an elevation of 15.5 miles

As early as April 2, 1991, people from a small village named Patal Pinto, on the Philippine island of Luzon, observed steam and gases smelling of rotten eggs (indicating hydrogen sulfide) emanating from near the crest of Mount Pinatubo, along with intermittent minor explosions. Within ten weeks, these early ominous activities culminated in a volcanic eruption that has come to be regarded among the largest that occurred in the twentieth century.

Pinatubo, located about 62 miles (100 kilometers) northwest of Manila, belongs to a chain of composite volcanoes constituting a volcanic arc in the Philippines. It is believed to have been the result of a lava dome that formed about five hundred to six hundred years ago during the last-known eruption. Its lower slopes and foothills were composed primarily of pyroclastic and lahar (volcanic mudflow) deposits from voluminous eruptions that occurred in prehistoric times.

More than 30,000 people inhabited the foothills of the volcano before the 1991 eruption. Cities and villages surrounding the base of the volcano on gently sloping alluvial plains were populated by as many as 500,000 inhabitants. Located about 15.5 miles (25 kilometers) to the east of the volcano was Clark Air Base, and 25 miles (40 kilometers) to the southwest was Subic Bay Naval Station, both belonging to the United States.

Prior to the 1991 eruption, Pinatubo had the appearance of a steep, domelike spheroid that rose about 2,297 feet (700 meters) above a gently sloping apron made of pyroclastic and epiclastic materials. Such a volcano belongs to the class of stratocones, of which such well-known exemplars as Fuji and Mayon are considerably larger than Pinatubo. The extensive pyroclastic apron of Pinatubo, however, indicated that the volcano was extremely active in prehistoric times. Until the collapse of the summit in the 1991 eruption, Pinatubo rose 5,725 feet (1,745 meters) above sea level, surrounded by older volcanic centers, including an ancestral Pinatubo due south, east, and northeast.

The Onset of Eruption. Following the emission of hydrogen sulfide gas and steam together with a few minor, phreatic (steam-charged) explosions along a 1-mile-long chain of vents on the north side of the volcano around April 2, 1991, the Philippine Institute of Volcanology and Seismology (PHIVOLCS) installed seismometers near the mountain, which immediately began recording several hun-

dred earthquakes a day. By April 5, nontelemetered seismographs installed on the northwest side of Pinatubo about 6 to 9 miles (10 to 15 kilometers) from the summit recorded between 40 and 140 seismic events (of magnitude less than 1.0 on the Richter scale) each day.

On April 23, a team of volcanologists from the United States Geological Survey (USGS) arrived at the scene following a request by PHIVOLCS to assist in the monitoring of the seismic activities near the mountain. Together, the Philippine and American experts installed a radio-telemetered seismic network and tiltmeters. These devices could locate the earthquakes and detect any new ground movement, respectively. They also measured fractures that opened during the early steam and vapor emissions from the chain of vents near the summit of the mountain.

Between May 13 and May 28, the geologists, with the help of the U.S. Air Force, measured a tenfold rise in the sulfur dioxide gas content of the steam plumes emanating from the summit. These and other measurements indicated that magma was rising within the volcano, and immediate preventive measures were necessary for the safety of people living in surrounding communities. The geologists established a set of alert levels ranging from 1 (implying low-level unrest) to 5 (indicating that eruption had started). On May 13, the alert level was set at 2, which meant that the seismic unrest probably involved magma.

Before April 2, 1991, the available geologic information on Pinatubo was quite limited. It was known to be a dacite dome complex about 2 miles (3 kilometers) in diameter, with voluminous fans of ash-flow deposits that were geologically young (less than ten thousand years old). The volcano was known to be thermally active, however, and had previously been explored as a potential geothermal energy source by the Philippine National Oil Company.

Anticipating that an eruption might be imminent, the geologists went to work designing a hazard map, in preparation for the worst-case scenario. This was an urgent matter, especially since a large number of small villages lay scattered on the northwest slope of the volcano and part of Clark Air Base and several urban communities (such as the city of Angeles, with a population of 300,000) lay within the potential range of pyroclastic and debris flows extending well beyond the volcano. Based on knowledge of the best-known distribution of each type of volcanic deposit from past eruptions, a joint USGS-PHIVOLCS team rapidly compiled a worst-case hazard map showing areas most susceptible to ash flows, mudflows, and ashfall.

Around May 23, the hazard map was distributed to officials of the Philippine civil defense organization, the local governments in neighboring communities, and the U.S. military. Based on data obtained following the actual eruption on June 15, the predictions by the hazard map vis-à-vis areas where the impact would be most severe were proven to be fairly accurate.

Near the end of May, the number of seismic events per day was fluctuating in a random fashion, and measurements of key seismic parameters such as earthquake hypocenter locations proved quite inconclusive. The likelihood of an actual eruption, though highly plausible, could not be precisely forecast. From late May until early June, indicators such as relatively long earthquake periods interspersed with periods of tremor, as well as the location of hypocenters beneath the steam vents, were clear precursors of imminent eruption. It was also observed that the emission rate of sulfur dioxide, which had dramatically increased during the preceding two weeks, had suddenly decreased. This finding was consistent with the escape vents of the gas being sealed off by magma rising within the volcano.

The Eruption and Its Aftermath. During the second week of June, the east flank of the mountain became tilted by inflation, and a small lava dome extruded near the most vigorous steam vent. The tectonic earthquakes became progressively shallower and weaker, while the emission of low-level ash became continuous.

PHIVOLCS raised the alert level to 3 on June 5, indicating that eruption was likely within two weeks. On June 7, the extrusion of a small dome on the north flank, accompanied by numerous small earthquakes, triggered a level 4 alert, signifying eruption within twenty-four hours. Residents of Zambales, Tarlac, and Pampanga Provinces, within 12.4 miles (20 kilometers) of the volcano, were evacuated. As the dome continued to grow and ash emissions increased to alarming levels, alert level 5 (signifying eruption had begun) was declared on June 9. On June 10, a total of 14,500 nonessential personnel and dependents were moved by road from Clark Air Base to Subic Bay Naval Station. Most of the aircraft had already been removed from Clark Air Base at this time.

On June 12, the first of several major explosions occurred at 8:51 A.M., spewing airborne ash to the west of the mountain and sending pyroclastic flows down its northwest slope. The ash column reached a height of 62,335 feet (19,000 meters) above sea level, according to measurements by the weather radar at Clark Air Base. Explosions continued through the night of June 12 and the morning of June 13. Part of the dome was destroyed, and a small crater was formed adjacent to it. There was intense seismic activity, with buildup periods lasting as long as several hours prior to the explosions during June 12 through 14. The long buildup periods permitted short-term notification to Philippine civil authorities and U.S. military authorities regarding impending eruptions. The city of Angeles was placed on evacuation alert.

The climactic eruptive phase began around 1:09 P.M. on June 14, following an eight-hour episode of vigorous seismic activity. Explosive eruptions continued through the night and into the morning of June 15. Around 5:55 A.M., a massive lateral blast spread north, west, southwest, and northwest from the volcano, sending a broad column of ash 39,370 feet (12,000 meters) above sea level. This climactic blast was followed by six more eruptive pulses, after which the eruption became essentially continuous, lasting between the afternoon of June 15 through the early hours of June 16.

Coincidentally, Typhoon Yunya approached Pinatubo around the same time. The extreme combination of hazards, including the explosive eruption, a complete loss of telemetry between the summit and the observatories, and uncertainty regarding the effect of Yunya on the flow of volcanic debris, made it necessary to rapidly evacuate all remaining USGS, Air Force, and PHIVOLCS personnel from Clark Air Base. This task was accomplished by around 2:30 P.M. on June 15.

The volcano continued to erupt a column of ash rising 32,808 feet (10,000 meters) above sea level for several weeks, even though the overall seismic activity started to decline by late June 15. When the weather cleared on June 16, it was observed that the top of the volcano had been replaced by a 1-mile-wide caldera, and vast areas surrounding the volcano were covered by around 6,540 or 7,847 cubic yards (5 or 6 cubic kilometers) of pyroclastic deposits.

The presence of Yunya exacerbated the volcanic mudflows and the dispersal of water-saturated ash across a large number of cities and villages. Cyclonic winds spread tephra over at least 7,722 square miles (20,000 square kilometers) surrounding the volcano. The weight of the wet, heavy ash led to the collapse of many buildings, which turned out to be the leading cause of the loss of 350 or so lives from the eruption. Mudflows triggered by the typhoon and heavy rainfall destroyed homes, bridges, and irrigation-canal dikes and buried vast areas of cropland.

The Pinatubo eruption was one of the largest in the twentieth century (being about ten times larger than the eruption of Mount St. Helens in the United States in 1980) and potentially threatened 1 million lives. Overall, it must be concluded that the evacuation and safety procedures followed jointly by the USGS, PHIVOLCS, and the various military and civil defense organizations via effective communication and timely, responsible action, helped avert disaster of a far higher magnitude. In fact, it is estimated that timely and effective intervention saved many thousands of lives (the actual casualty figure would be much lower had it not been for the presence of the typhoon), and at least $1 billion in property which might otherwise have been lost. In terms of accurate eruption prediction and highly effective response, the 1991 Pinatubo eruption provides an important model for future volcanic eruptions and other geological cataclysms.

Monish R. Chatterjee

For Further Information:

Fiocco, Giorgio, Daniele Fuá, and Guido Visconti, eds. *The Mount Pinatubo Eruption: Effects on the Atmosphere and Climate.* New York: Springer, 1996.

Newhall, Christopher G., James W. Hendley II, and Peter H. Stauffer. *The Cataclysmic 1991 Eruption of Mount Pinatubo, Philippines.* Vancouver, Wash.: U.S. Geological Survey, 1997.

Newhall, Christopher G., and Raymundo S. Punongbayan, eds. *Fire and Mud: Eruptions and Lahars of Mount Pinatubo, Philippines.* Seattle: University of Washington Press, 1996.

Pinatubo Volcano Observatory Team. "Lessons from a Major Eruption: Mount Pinatubo, Philippines." *EOS/Transactions of the American Geophysical Union* 72 (1991): 554-555.

Scarth, Alwyn. *Vulcan's Fury: Man Against the Volcano.* New ed. New Haven, Conn.: Yale University Press, 2001.

Shimizu, Hiromu. *The Orphans of Pinatubo.* Manila, Philippines: Solidaridad, 2001.

Wolfe, Edward. "The 1991 Eruptions of Mount Pinatubo, Philippines." *Earthquakes and Volcanoes* 23, no. 1 (1992): 5-37.