VOLCANOLOGY

The Ongoing Eruption in Montserrat

Montserrat Volcano Observatory Team

At the beginning of the 20th century, volcanology began to evolve into a modern, multidisciplinary science. The circumstances that triggered this growth involved two volcanoes in the Caribbean—Soufriére on St. Vincent and Mont Pelée on Martinique—and one—Santa Maria—in Guatemala. Within 6 months in 1902, explosive eruptions from these volcanoes killed about 36,000 people (*1*, *2*). Jaggar, one of the scientists sent to study the effects of the eruptions, recognized that the reactive, "expeditionary" approach to volcanology then in vogue was inadequate and that it was necessary to observe and measure the behavior of volcanoes—including their seismic, thermal, and gas emission aspects—before, during, and after the eruptions (*1*). The devastation he witnessed, particularly in the tropical city of St. Pierre, Martinique, the Pompeii of modern times, convinced him of the need to understand the processes, then inexplicable, that could kill thousands of people with little warning. Thus, within a decade, the first volcano observatories were established, one in Hawaii and the other in Japan. Others followed, but Jaggar's visionary objective of a global network of observatories has still only been partially achieved, because many of the world's most dangerous volcanoes are still poorly understood, little studied, and inadequately monitored (*1–4*). This lack of knowledge represents the most pressing problem in reducing volcanic risk in a global context.

Scientific and public interest in volcanoes and volcanology has increased greatly since 1980, stimulated by the dramatic and well-publicized eruption of Mount St. Helens and the tragic failure of hazard management at Nevado del Ruiz in Colombia, where the death toll at Armero approached that of St. Pierre and left sobering lessons that must not go unheeded (*5*, *6*).

Now, as the century draws to a close, the Caribbean is again the focus of attention for volcanologists worldwide, for the Soufriére Hills volcano on the Lesser Antilles Emerald Isle of Montserrat is erupting, the hazard management problems are severe, and the necessary scientific response promises a renaissance for volcanology in the United Kingdom and Caribbean comparable to that in the United States produced by Mount St. Helens. The lessons being learned there and the new techniques developed are making this eruption one of historic importance to volcano science (*7*).

Since the onset of eruptive activity, Soufriére Hills has become one of the most closely monitored volcanoes in the world. Montserrat Volcano Observatory has been established, with staff drawn primarily from the Seismic Research Unit (SRU) of the University of the West Indies in Trinidad and from the U.K. volcanological community, facilitated by the British Geological Survey. Additional assistance has been provided by the U.S. Geological Survey (USGS), the French CNRS, and academic institutions around the world, as well as the citizens of Montserrat. The main foci of the operation comprise seismic, deformation, and gas monitoring, along with visual observations, with helicopter support providing access to crucial locations. Visual monitoring is supported by remote video surveillance of the crater area and by still photography and video recording of dome growth patterns and block-and-ash flow emplacement. Hazard evaluation and zoning has been aided by availability of a modern hazard map published in 1988 (*8*), with zone maps revised to meet new developments.

A telemetered seismic network provides real-time coverage to a permanently manned operations room. Earthquake swarms since 1992 provided the first clues to the impending eruption; unlike earlier swarms in 1897–1898, 1933–1937, and 1966–1967 (*8*), these swarms led to the current eruption, which began as a small steam-ash outburst on 18 July 1995. The swarms were sufficiently intense in 1994 to prompt SRU to increase the number of seismometers on Montserrat; after the initial eruption, additional instruments were added by SRU, and the USGS Volcano Crisis Assistance Team brought a system of telemetered seismometers and data acquisition and analysis computers and software (including real-time seismic amplitude and spectral amplitude technology) tested in the Pinatubo emergency and since improved (*9*). The network has continued to function with a minimum of eight short-period instruments in continuous operation to the present (with some relocations and replacements).

Fig. 1. A dome in a dome in a dome. The plume, rising on 22 January from the most recent, growing dome, is inset into a hole blasted on 17 September 1996 into the next oldest dome, formed since November 1995. Both are enclosed within the crater rim (on the right) in a prehistoric dome complex, in which the younger domes are pushing outward on the crater rim. [Photo by Mark Davies]

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In October 1996, the network was supplemented by an array of state-of-the-art broadband, wide–dynamic range digital seismometers, intended for long-term monitoring.

The current network records and locates seismic events and classifies the signals into various types, as seismic signals can be generated by magma-pressure–related rock breakage, resonance of magma or gas-filled cracks or conduits, rockfalls, and pyroclastic flows, or by regional tectonic events and cultural or natural noise. By April 1997, more than 60,000 individual events had been detected and recorded.

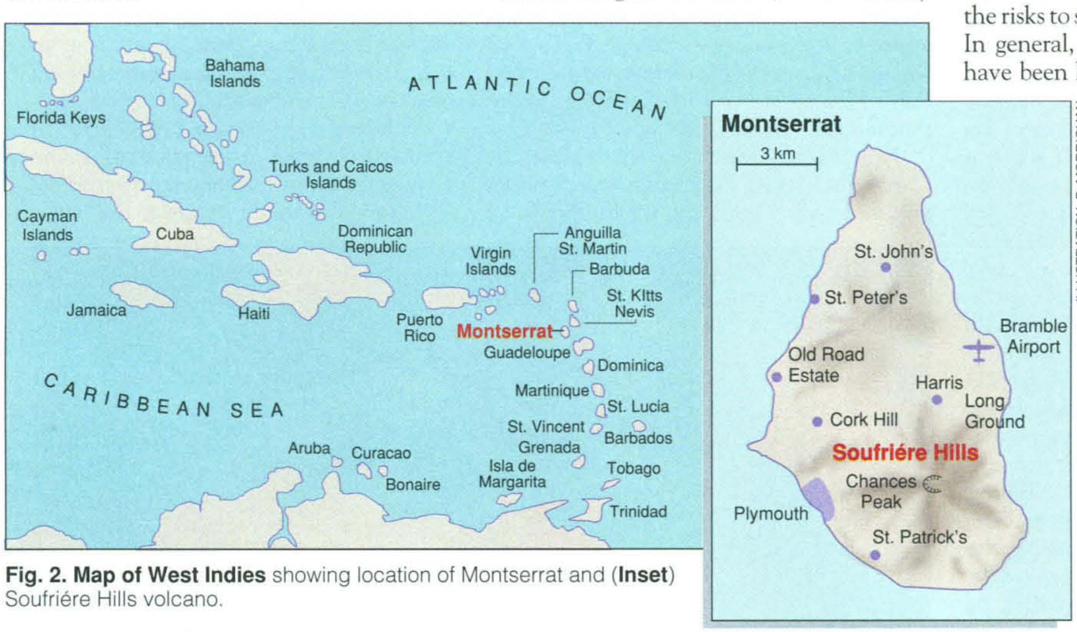

Fig. 2. Map of West Indies showing location of Montserrat and (**Inset**) Soufriére Hills volcano.

Frequent field measurement of deformation is done with electronic distance meter (EDM) and differential GPS (Global Positioning System) networks, supplemented by electronic tiltmeters and crack extensometers. Two telemetered geodetic GPS receivers are also used. EDM monitoring to a reflector within the crater detected accelerated coseismic ground displacements before the emergence of fresh lava on 15 November 1995. The viscous, crystal-rich lava (hornblende andesite, 58 to 60% SiO_2) piled up about the vent, forming a lava dome, which has continued to exhibit a complex pattern of growth, interspersed by intervals of collapse that produce pyroclastic flows. In order to monitor the changes in dome shape and volume, a method has been invented at Montserrat that combines a hovering helicopter platform (with kinematic GPS control on hover point coordinates) and laser range-finding binoculars (providing distances and angles to dome surface points). Surveys of 15 to 30 distributed points enable construction of a digital elevation model, with dome volumes accurate to within 10%. Repeated weekly helicopter surveys, combined with precision ground surveys and photo analysis, have enabled reconstruction of lava flux over time; the resulting data is unprecedented and crucial to the understanding of magmatic processes.

Gas monitoring is undertaken by ground-based correlation spectrometer, diffusion-tube measurements of SO_2, and biweekly analysis of gases from active fumaroles. Chemical analysis of rain, spring water, and ash is also undertaken, in relation to effects on human health. Other methodologies used include petrology and geochemical studies of eruption and hydrothermal system products, experimental phase equilibria, study of pre-eruptive volatiles in glass inclusions, lava viscosity measurements, rock strength measurements, gravity surveys, and elastic deformation and pyroclastic flow emplacement models (Fig. 1).

A notable aspect of the eruption since late March 1996 has been the production of hot, incandescent high-speed flows of blocks and ash resulting from collapse of the lava dome. These pyroclastic flows have traveled from the crater, open to the east, out to the sea, on their way destroying forests and igniting vegetation near the flow path. These flows and related, more dilute, hot ash-cloud surges constitute the principal hazards to the populated areas in southern Montserrat. Up to present, these flows have traveled eastward, but a vertical eruption column could generate pyroclastic flows by column collapse, and these could be directed toward western and northern settlements through low points in the crater wall. This scenario is not wholly imaginative, as on 17 to 18 September 1996, when profound dome collapse led to conduit depressurization and then to an intensive, explosive, nearly vertical eruption column that lasted for nearly an hour. Conduit overpressures are estimated as 20 MPa. The eruption created an ash plume at least 11.3 km high, leading to several encounters with civilian aircraft. A shower of hot ballistic blocks as large as 1 m in diameter rained on the community of Long Ground, 2 km east of the crater, shattering roofs and igniting houses. Thankfully, the community had been evacuated several months earlier.

The capital city, Plymouth (population 5000), only 4 km west of the crater and previously much disturbed by drifting gas and ash clouds, is therefore currently evacuated, along with a number of smaller communities (Fig. 2). The eruption is causing serious hardship and economic distress to the small island, and the flow of critical supplies is being hindered by the risks to ships and local workers at the port. In general, the officials and the population have been highly educated on volcanic hazards and are demonstrating great fortitude under the situation imposed on them.

Since October 1996, a new dome has filled in the explosion vent, and pyroclastic flows have resumed. However, dome growth has been episodic, out of phase with swarms of unusual earthquakes that probably reflect magma fracture during injection; the southern crater wall began to shed large rock slides in response to earthquakes in these swarms, and concerns were raised about its stability, fearing a massive depressurization of the dome and conduit behind the wall. Thus, the scientists on Montserrat have remained intrigued, stimulated, and occasionally alarmed by the continuing activity, but the social and economic pressure building on officials and island folk has been unrelenting. As the volcano nears its third year of eruptive activity, the strain is beginning to show.

References and Notes

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