of the lake coincided with the cessation of the explosive phase on 26 April.

The second phase of the eruption was characterized by the quiet extrusion of viscous basaltic andesite lava (3), resulting in the growth of a dome or coulee over the vent (Fig. 3). This extrusion continued to grow until October 1979, when 50×10^6 m^3 of lava had spread over the crater floor. The total mass of rock produced during the 1979 eruption was 2.4×10^{11} kg, as compared with 3.8×10^{11} kg during the destructive eruption of 1902.

Prior to the eruption, geologic, seismic, and ground-deformation data were gathered on the island by scientists of the University of the West Indies and others, and this information provided important baselines for comparison once the volcanic activity got under way. During the explosive phase of the eruption, however, a largely different group of scientists, most of whom never set foot on the island, focused their attention on the large eruption clouds ejected from the volcano. These scientists made observations from a National Aeronautics and Space Administration (NASA) P-3 research aircraft, from an Air Force KC-135 aircraft, from the National Oceanic and Atmospheric Administration (NOAA) geostationary SMS-1 satellite, and from NASA's SAGE (Stratospheric Aerosol and Gas Experiment) satellite.

The rapid communication that took place among concerned scientists when it was first learned that the volcano was erupting was a crucial factor in the success of the overall scientific response. The Smithsonian Institution's Scientific Event Alert Network formed the hub of this ad hoc communication network in the United States, and telephone contacts were established with interested scientists at NOAA's National Weather Service, NASA's Langley Research Center, and the Los Alamos Scientific Laboratories. Thanks to rapid and effective communication, a NASA P-3 research aircraft, which happened to be in Barbados at the time, was ordered to remain in that part of the eastern Caribbean. By chance, this aircraft was in the air near St. Vincent on 17 April when the largest of the eruption columns unexpectedly penetrated the dense, low-altitude layer of weather clouds and rose toward the stratosphere (Fig. 2). Timely communication with the National Earth Satellite Service resulted in the saving of the data tapes from the SMS-1 satellite (such tapes are normally erased every 24 hours). Rapid deployment of an Air Force KC-135 aircraft from Patrick Air Force Base, Florida, made it possible to obtain high-altitude filter samples of tephra from some of the eruption clouds before they could disperse. The experience gained at St. Vincent clearly demonstrates that, with effective communication among a group of interested scientists and the prompt availability of logistical and instrumental support, a considerable body of scientific information can be gathered from moderately large eruptions in remote regions of the world.

The Smithsonian Institution hosted a Soufriere Conference in September 1979 at its facility in Front Royal, Virginia, where interested geologists, geophysicists, and atmospheric scientists were able to meet and discuss preliminary findings before attempting more detailed analysis of the data. A special symposium on the atmospheric effects of the eruption was held at the western meeting of the American Geophysical Union in December 1979 (4).

Except for the account of ground-deformation studies on St. Vincent (5), the reports that follow describe the results of remote observations and airborne sampling of the eruption plumes. The results of most studies carried out on the ground in St. Vincent during the eruption, such as studies of seismic activity (6), the petrology of the ejecta, and the mechanism of the eruption (7), are still in preparation or in press.

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8. All times in this report are local civil time (LCT); add 4 hours for universal time.
9. For purposes of comparison, R. S. J. Sparks obtained motion picture footage from the ground of the Soufriere eruption cloud of 22 April; his unpublished analysis of this film indicates an upward cloud velocity of 45 to 58 m sec^{-1} to an altitude of 9 km.
10. We thank the government of St. Vincent, the U.S. Coast Guard, the Barnard family, and D. Richardson for logistical support. The Smithsonian Institution's Scholarly Research Program provided funds for the Soufriere Conference, held in September 1979.

24 July 1981; revised 11 January 1982

Tephra from the 1979 Soufriere Explosive Eruption

Abstract. *The explosive phase of the 1979 Soufriere eruption produced 37.5 × 10^6 cubic meters (dense-rock equivalent) of tephra, consisting of about 40 percent juvenile basaltic andesite and 60 percent of a nonjuvenile component derived from the fragmentation of the 1971–1972 lava island during phreatomagmatic explosions. The unusually fine grain size, poor sorting, and bimodality of the land deposit are attributed to particle aggregation and the formation of accretionary lapilli in a wet eruption column.*

During the explosive phase of the 1979 Soufriere eruption on St. Vincent, a series of vulcanian explosions ejected tephra columns 8 to 20 km above the volcano. The eruption proceeded through the 1971–1972 lava island in the 1-km-wide crater lake, and disruption of the island by the explosive activity led to flooding of the vent at an early stage of the eruption. Ground observers noted three unusual features during these events that accompanied the evolution of the eruption plumes and tephra fallout near the volcano and that may be taken as an indication of the very high water content of the eruption column. These features include (i) the rain of mud droplets from the eruption plume, (ii) the fall of accretionary lapilli from the eruption plume, and (iii) severe electrical disturbances. Lightning discharges were observed to occur at a rate of more than one per second (1), and there is photographic evidence that electrical discharges in the plume occurred at the rates of 100 to 1000 events per second. In this report I propose that the ejection of the crater lake water, together with the tephra, gave rise to these phenomena, which in turn produced an unusually fine grained, poorly sorted, and bimodal tephra deposit near the volcano.

The explosive events led to the accumulation of a thin pyroclastic deposit on St. Vincent, most of it within a radius of 9 km from the summit crater. The deposit shows an abrupt change in thickness at a distance of 3 to 4 km from the crater (Fig. 1B). Near the crater rim and as far as 2.5 km from the 1979 vent, the deposit is 25 to 45 cm thick and consists mainly of base-surge beds and minor interstrati-

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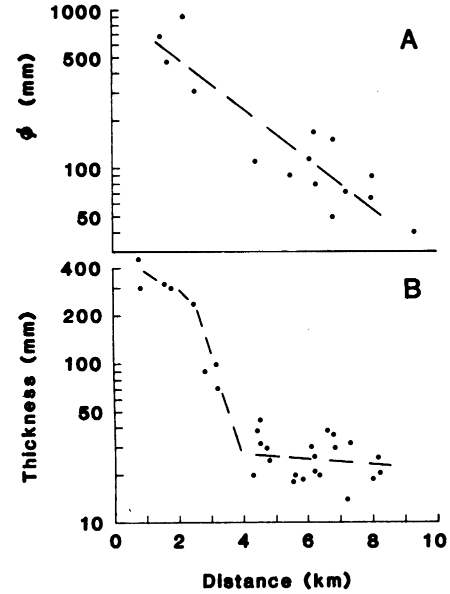

Fig. 1. Variation in the diameter of the largest lithic fragments (A) and the thickness of the tephra deposit (B) as a function of distance from the 1979 Soufriere vent (*2*).

fied air-fall tephra. The extent of base-surge beds corresponds closely with the zone of devastation of vegetation on the upper slopes of the volcano. At a distance of 3 to 4 km from the vent, the deposit thins rapidly to a 30- to 40-mm layer of air-fall tephra. This layer shows little variation in thickness with distance from the vent and is about 20 mm thick at a distance of 8 to 9 km on the east and west coast of St. Vincent (Fig. 1B).

Large dense lithic clasts were ejected from the vent during the strong vertical explosions. The maximum diameter of lithic fragments in the tephra layer decreases exponentially as a function of distance from the vent (Fig. 1A), ranging from 70- to 80-cm fragments at a distance of 1.5 km to 4-cm fragments at 9 km. Most of this lithic material is basaltic andesite torn from the 1971–1972 island.

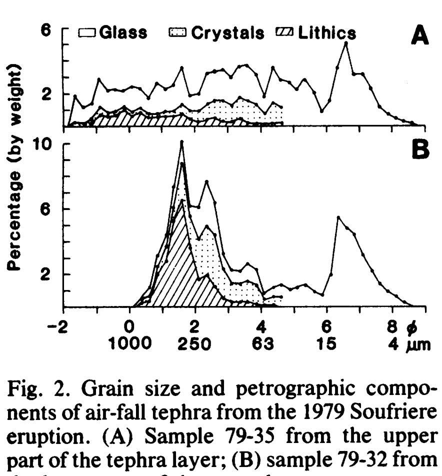

Fig. 2. Grain size and petrographic components of air-fall tephra from the 1979 Soufriere eruption. (A) Sample 79-35 from the upper part of the tephra layer; (B) sample 79-32 from the lower part of the same layer.

The air-fall tephra layer consists of two units. A steel-gray, poorly sorted, and lithic-rich ash forms the lower half of the tephra. This unit was produced by the explosions of 13 and 14 April 1979. The upper half of the tephra layer is brown, very poorly sorted, and relatively lithic-poor ash, deposited by the explosions on 17, 22, and 26 April. Accretionary lapilli are common in the air-fall deposit, but they are generally more abundant in the lower part of each unit.

The 1979 air-fall tephra on St. Vincent is characterized by fine grain size and poor sorting (Fig. 2). The median diameter (Md) falls within the narrow range of Md ϕ (*2*) 2.25 to 4.25 (212 to 53 μm), with an average Md ϕ of 2.96 (125 μm). There is no systematic decrease in Md with distance from the vent, and even ash collected on 14 April on Barbados, 180 km downwind, has Md ϕ of 2.75 (150 μm) (Fig. 3). The grain sizes of the two units making up the total ash fall are significantly different (Fig. 2), the Md ϕ of the lower steel-gray ash layer from the explosions of 13 and 14 April being greater (150 to 170 μm) than the Md ϕ of the upper layer, from the explosions of 17, 22, and 26 April (106 to 124 μm).

All the air-fall tephra deposits are very poorly sorted, $\sigma\phi$ being in the range 2.4 to 3.25. Sorting is better in the lower unit ($\sigma\phi$ 2.5 to 2.75) than in the upper unit ($\sigma\phi$ 3.0 to 3.25). The ash fall remained poorly sorted at least as far as 14 km from the crater, as shown by ash that fell on the U.S. Coast Guard cutter *Vigilant*, northeast of the volcano ($\sigma\phi$ 2.33). The evidence from Barbados shows, however, that major downwind sorting took place in the more distant ash plume. The Barbados ash fall from 14 April (Fig. 3) has retained the characteristic median diameter of the Soufriere tephra, but material became much better sorted during downwind transport ($\sigma\phi$ 0.25).

The lower ash layer is strongly bimodal (Fig. 2), having modes at 300 and 12 μm. The upper ash layer also has a principal mode at 12 μm.

The fine grain size, bimodality, and poor sorting of the 1979 air-fall tephra deposit on St. Vincent can be attributed to particle aggregation or the clustering (*3*) of fine ash in the ash plume over the volcano and the production of accretionary lapilli. This aggregation resulted in the premature fallout of fine ash as aggregates or accretionary lapilli, together with coarser particles, with resultant poor sorting. This scavenging of fine ash from the eruption clouds during the formation of accretionary lapilli also resulted in a bimodal grain size distribution. The predominance of accretionary lapilli

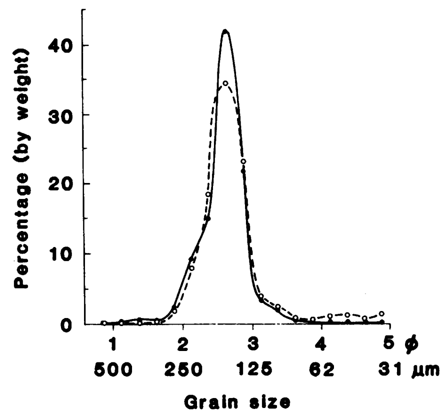

Fig. 3. Grain size as a function of percentage (by weight) for air-fall tephra from Soufriere, collected on Barbados. The solid line represents sample 79-01 from the 14 April 1979 explosions; the dashed line represents the sample from the May 1902 eruption.

in the ash fall is probably related to the high water content of the eruption cloud, due to the ejection of the crater lake water during the explosive events. The great abundance of the finer grain size mode is a striking aspect of the 1979 tephra, even near the crater. On average, the finer mode (< 32 μm) constitutes about 30 percent (by weight) of the air-fall tephra.

Petrographic analysis of the tephra shows that it is composed of juvenile

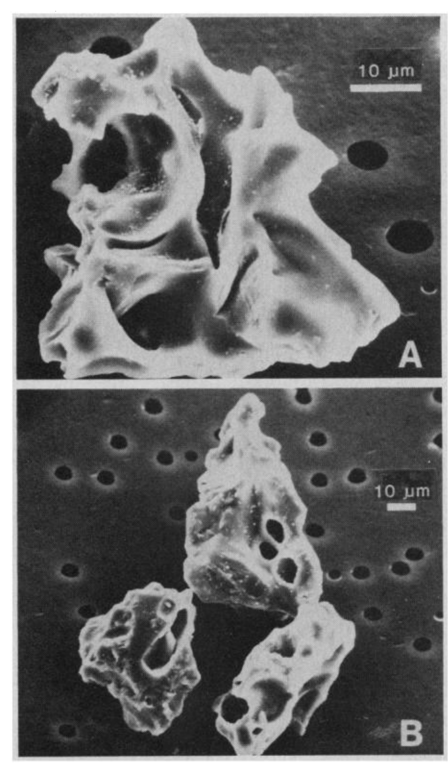

Fig. 4. Scanning electron images of juvenile vesicular basaltic andesite tephra from the 1979 Soufriere air fall. (A) Vesicular glassy tephra; (B) poorly vesicular tephra with microlites.

volcanic glass (Fig. 4), broken phenocrysts (plagioclase, clinopyroxene, orthopyroxene, magnetite, and olivine), and lithic fragments of holocrystalline basaltic andesite. The ratio of juvenile to lithic components changed markedly as the explosive eruption progressed. The initial explosions (13 and 14 April) produced lithic-rich tephra [60 percent (by weight)], as shown by the lower layer (Fig. 2). The tephra from subsequent explosions (17 to 26 April) was composed predominantly of juvenile material and contained only about 20 percent (by weight) lithic material. The color difference between the two layers is a reflection of the increase in the content of juvenile glass in the upper layer.

The 1979 eruption had several features typical of phreatomagmatic explosive eruptions. First, very strong circumstantial evidence links the explosive activity to the presence of the crater lake. It is more than coincidence that the explosive activity ceased when all the water from the crater lake had been blasted out. Shepherd and Sigurdsson (*4*) have presented a model for the phreatomagmatic eruption mechanism, which relies on a three-way interaction of magma, lake water, and hot rock of the 1971–1972 island to drive the explosive eruption. Although the model cannot, of course, exclude the participation of juvenile magmatic volatile materials in driving the explosions, such volatile materials are not required to account for the observed phenomena.

Second, the ash deposits themselves provide evidence of phreatomagmatic activity. The base-surge beds near the crater are a characteristic feature of phreatomagmatic eruptions (*5*). Similarly, the small change in Md of the air-fall tephra with distance from source, the fine grain size, poor sorting, and abundant accretionary lapilli are features commonly associated with ph-eatomagmatic eruptions (*6*).

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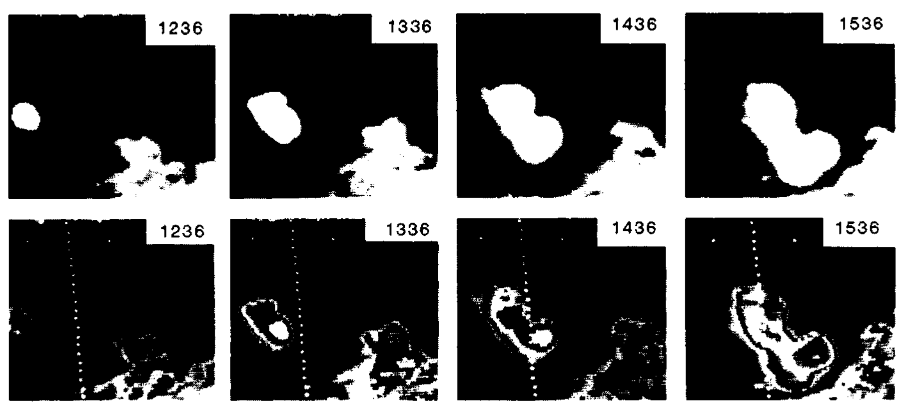
Geostationary Satellite Observations of the April 1979 Soufriere Eruptions

Abstract. *Infrared images from the geostationary satellite SMS-1 were used to study the growth of the eight major eruptions of Soufriere, St. Vincent, during April 1979. These eruptions differed considerably in growth and intensity, the most intense being that of 17 April which formed an ash cloud of 96,000 square kilometers in 4 hours. The weakest eruption formed a cloud of only 16,000 square kilometers.*

Eight of the eruptions of Soufriere Volcano during April 1979 were observed by the SMS-1 satellite, one of a series of geostationary meteorological satellites. This satellite is in a 35,800-km orbit above the equator at longitude 70°W. Because photographs were available at least every half-hour, continuous film loops could be prepared and the eruptions could be viewed by means of a movie projector. On film, the eruptions appeared to grow explosively; in many respects, they resembled the major thunderstorms that form over the American Midwest.

Infrared images from the SMS-1 window channel radiometer (10.5 to 12.5 μm) were particularly useful. Paradoxically, satellite infrared observations of explosive volcanic eruptions indicate these eruptions to be cold. However, only superficial features of the ash cloud can be seen by the satellite. At the edge of the ash cloud, considerable mixing takes place as the cloud rises, and the infrared-sensed temperature approaches the temperature of the environment very quickly.

Generally, the colder the eruption appears, the higher in altitude it should extend. If a nearby radiosonde observation is available, these temperatures can



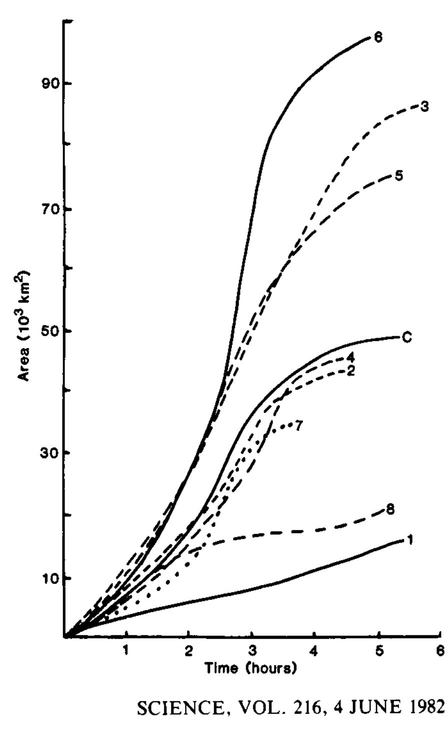


Fig. 1 (above). (Top row) Hourly infrared photographs for the 1150 LCT 14 April 1979 eruption of Soufriere. The times are indicated at the upper right. (Bottom row) Corresponding enhanced infrared imagery. Here the whitest area within the spreading canopy, first appearing at 1336 LCT, corresponds to temperatures colder than −69.7°C, whereas the surrounding black ring represents temperatures between −62.5° and −69.7°C. The nearest radiosonde observation indicates that the central white area represents a growth to altitudes above 14 km. Fig. 2 (right). Growth rates (area as a function of time) for the eight major eruptions of Soufriere that were observed by the geostationary satellite SMS-1. The curves represent eruptions that began at the following times: curve 1, 13 April, 0615 LCT; curve 2, 13 April, 1115 LCT; curve 3, 13 April, 1708 LCT; curve 4, 13 April, 2108 LCT; curve 5, 14 April, 1150 LCT; curve 6, 17 April, 1657 LCT; curve 7, 22 April, 0637 LCT; and curve 8, 25 April, 2353 LCT. Curve C is a composite of these eight eruptions.

