Reports

Eruptions of the St. Augustine Volcano: Airborne Measurements and Observations

Abstract. *Airborne measurements of the effluents from the St. Augustine volcano obtained during a 10-day period of activity showed that aerosol was ejected at the rate of about 10^5 kilograms per second during brief eruptions (3 to 8 minutes). Steadier emissions contained much more water vapor and gaseous sulfur but less aerosol mass. A nuée ardente (glowing avalanche) produced by one eruption reached a maximum average speed of about 50 meters per second.*

St. Augustine Island is located in lower Cook Inlet about 280 km southwest of Anchorage, Alaska. Eruptions from the volcano, which forms the island, were reported in 1812, 1883, 1902, 1935, and 1963–1964; the volcano represents a serious threat to life and property in low-lying areas situated near the shoreline on Cook Inlet (*1*).

The most recent series of eruptions, which began on 23 January 1976, produced heavy ash falls in Homer, 100 km east-northeast of St. Augustine. During the period 8 through 18 February we obtained a unique set of airborne measurements of the emissions from this active volcano and also documented a nuée ardente (*2*).

The aircraft used for this research, the University of Washington's B-23, is equipped to measure atmospheric aerosol and gases (*3*) and has been used in studying volcanic emissions (*4*). We report here measurements and observations made of the St. Augustine volcano during two eruptions (at 1400 A.S.T. on 8 February and at 1222 A.S.T. on 13 February 1976) that occurred while we were flying downwind of the volcano.

On the basis of appearances, the emissions from St. Augustine consisted of two main components: white emissions of gases and aerosol (Fig. 1a), which were usually rather constant, and intermittent eruptions of brown clouds of material. Although the white plumes resembled steam, preliminary results indicate that the white appearance was often due primarily to particles rather than droplets.

Several eruptions occurred on 8 February. One, which lasted for a period of about 8 minutes, was accompanied by a nuée ardente which traveled down the flank of the volcano (Fig. 1, b and c) reaching the sea near Burr Point. Much of the main eruption cloud was generated by this nuée ardente. One hour after the initial eruption this cloud reached an altitude of 3.8 km and covered an area 60 by 20 km to a depth of about 2.5 km, at a range of 120 km from St. Augustine. Over 40 photographs of the nuée ardente were taken with an automatic camera on the aircraft which records the time and the aircraft heading. From the angular field of view of the camera, the known positions of the aircraft, and topographical features on the island, we have reconstructed the movement of the nuée ardente and estimated its speed. The nuée ardente began to move down the slope simultaneously with the start of the eruption. During the first 2.5 km, it descended 900 m and its average speed was about 50 m sec^{-1} (assuming its origin to be the summit). During the next 2 km, it descended only about 190 m and slowed from an average speed of about 20 m sec^{-1} to 10 m sec^{-1} as it reached the more level terrain approaching the sea.

Shown in Fig. 2a are the aerosol size distributions for the white plume on 8 February and the ambient air unaffected by the plume. The corresponding aerosol surface area distribution for the white plume is shown in Fig. 2b. Thirty-eight minutes after the measurements shown in Fig. 2, a and b, were obtained there was an eruption. The size spectra of aerosol in the brown cloud of material produced by this eruption, obtained 74 km downwind of the volcano at an altitude of 2440 m, are shown in Fig. 2, c and d. The suppression of aerosol particles with diameters from about 10^{-2} to 1 μm in the eruption cloud apparent in these data may have been due to the collection of these small aerosol particles by larger ash particles.

We computed the density of the brown eruption clouds, due to aerosol 0.3 to 68 μm in diameter, from the measured size distributions assuming a particle density of 3 g cm^{-3}. We used this value and the estimated volume of the eruption cloud to determine the total mass of ejected aerosol. The average density of the 8 February brown eruption cloud at 74 km was about 0.1 g m^{-3}. The estimated total mass of aerosol 0.3 to 68 μm in diameter ejected by this eruption was 3×10^8 kg (6×10^5 kg sec^{-1}, since the eruption lasted about 8 minutes). Most of the mass was due to aerosol less than 40 μm in diameter.

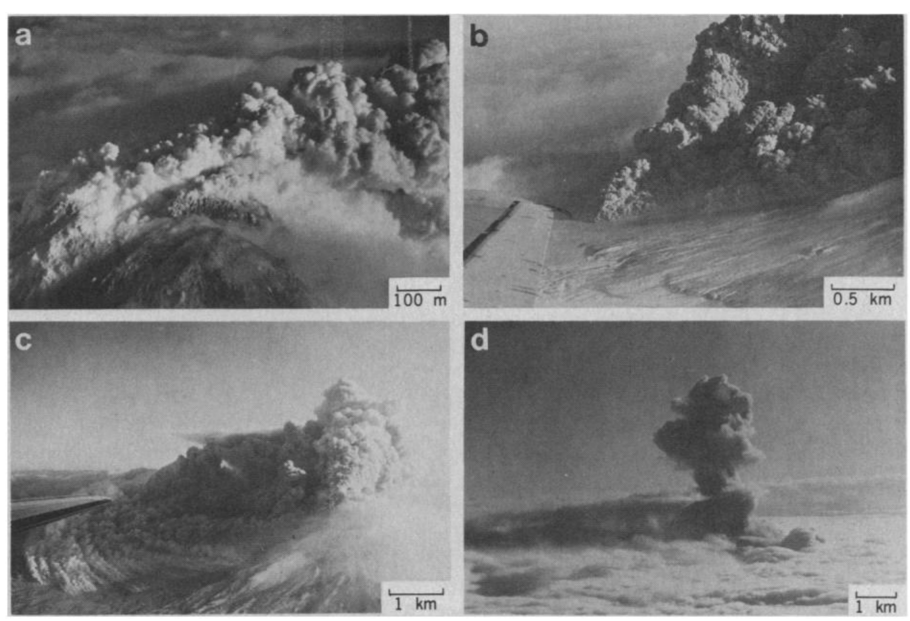

Fig. 1. The St. Augustine volcano: (a) white plume at 1346 A.S.T. on 8 February 1976; (b) nuée ardente at 1402 A.S.T. on 8 February 1976 produced by a major eruption; (c) another view of the nuée ardente at 1420 A.S.T.; (d) brown mushroom cloud from the eruption on 13 February 1976 (photograph taken at 1230 A.S.T.); the top of the cloud was at an altitude of about 5.3 km.

Another eruption, which took place on 13 February while we were in the air (Fig. 1d), produced a brown mushroom cloud which rose rapidly to an altitude of 7 km. Radiosonde observations from nearby King Salmon, Alaska, indicated the tropopause to be at 8.5 km. At 1000, 2000, 3250, and 5300 seconds after the eruption the volumes of the eruption cloud were estimated from the airborne photographic records and aircraft penetrations to be 4×10^{10}, 1×10^{11}, 2×10^{11}, and 4×10^{11} m^3, respectively. The average density of the eruption cloud at 6.5 km was 0.1 g m^{-3}, but below 4 km it was greater than 12 g m^{-3}. The total mass of ejected aerosol 0.3 to 68 μm in diameter was estimated to be 4×10^7 kg (2×10^5 kg sec^{-1}, since the eruption lasted about 3 minutes). Most of the mass was concentrated in aerosol with diameters greater than 20 μm; the estimated mass of ejected aerosol with diameters less than 20 μm was 6×10^6 kg.

The average concentration of gaseous sulfur (5) in the brown mushroom cloud 5300 seconds after the eruption on 13 February was about 7×10^{-5} g m^{-3}. The total mass of gaseous sulfur emitted was about 3×10^4 kg ($\simeq 10^2$ kg sec^{-1}, sinc the eruption lasted about 3 minutes). The frost point inside the brown cloud was -44°C, and the air temperature was -33°C; therefore, the cloud was far from saturated. The calculated upper limit to the emitted mass of water vapor was 5×10^6 kg (3×10^4 kg sec^{-1}).

From traverses of the white plume that persisted after the eruption of the brown mushroom cloud on 13 February at 1455 and 1506 A.S.T. we constructed a vertical cross section, perpendicular to the plume axis. We computed the flow rate of emissions by graphically integrating the measured concentrations over the area of the plume and then multiplying this area concentration by the average wind speed. The flow rates of gaseous sulfur and aerosol were found to be about 4 and 30 kg sec^{-1}, respectively. In contrast to the much larger brown mushroom cloud, the white plume was nearly saturated and had a flow rate of water vapor of 70 kg sec^{-1}.

Although the emission rate of gaseous sulfur was larger during the eruption that produced the brown mushroom cloud than in the white emissions that followed, the difference was far less than that between the rates of aerosol emissions. The relatively low emission rate of gaseous sulfur during the eruption of the brown mushroom cloud may have been due in part to the deposition of sulfur onto the aerosol; however, particles collected during this eruption and examined by energy-dispersive analysis of x-rays do not reveal the presence of sulfur. These results illustrate the rapid variations in volcanic emissions during periods of eruption.

As in the eruption on 8 February, the concentration of small aerosol (as measured by a rapid expansion condensation nucleus counter) in the brown eruption cloud on 13 February was low and nearly indistinguishable from the ambient air. By contrast, at 1506 A.S.T. on 13 February, the total concentration of aerosol in the white volcanic plume was 2×10^4 cm^{-3} compared to 6×10^2 cm^{-3} in the ambient air.

We examined the nonvolatile aerosol collected in the white plume and in the brown eruption clouds under a scanning electron microscope and determined their elemental compositions by energy-dispersive analysis of x-rays. The compositions were typical of those of volcanic ash (Si, Al, Mg, Ca, and Fe were the most common elements detected, with occasional traces of K, S, and Ti). All aerosol particles in the size range 0.1 to 1 μm in diameter that we examined had compositions similar to those of the larger aerosol, although several were highly enriched in iron. Therefore, it seems likely that a reasonable fraction of

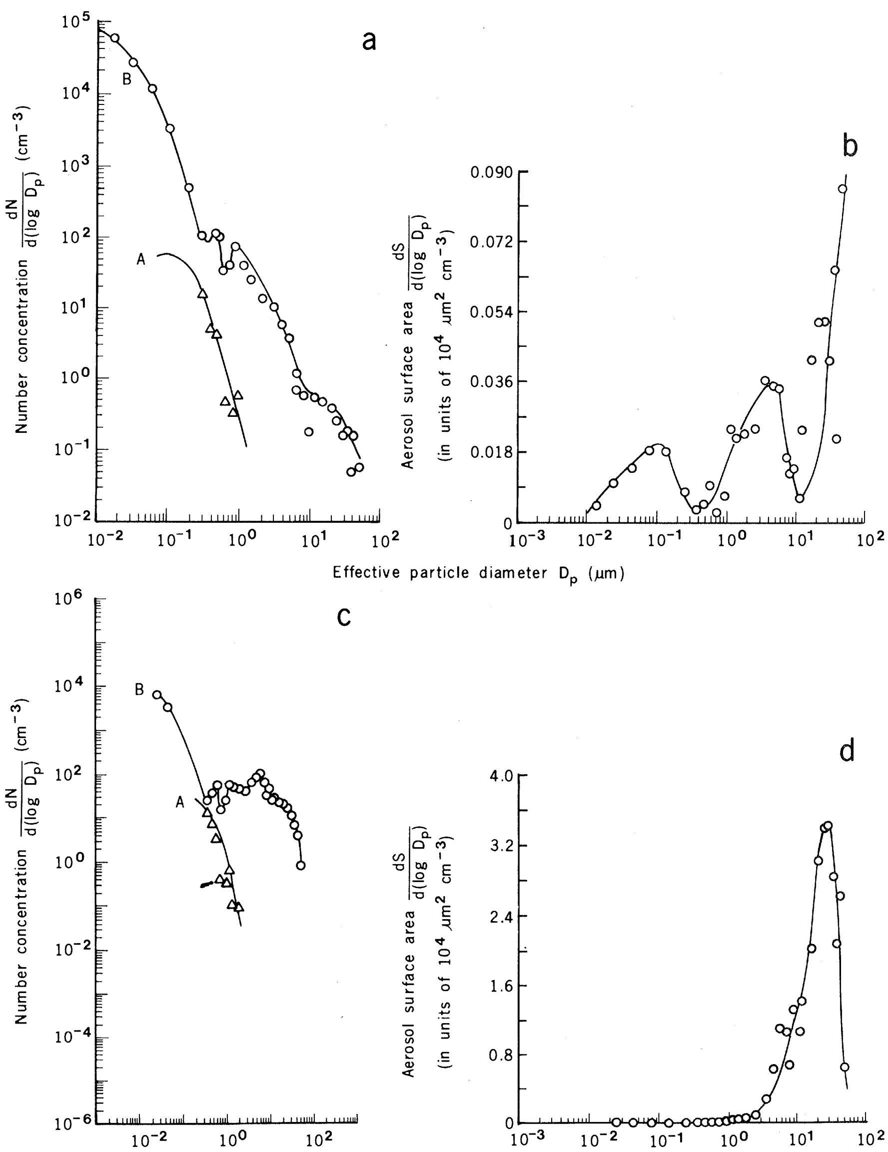

Fig. 2. (a) Aerosol size distribution measured on 8 February 1976 at an altitude of 1670 m [mean sea level (MSL)] at a range of 30 km. Curve A is for the ambient air sample, and curve B is for the white volcanic plume. (b) Corresponding aerosol surface area distribution for the white plume on 8 February 1976 at an altitude of 1670 m MSL and a range of 30 km. (c) Aerosol size distribution measured on 8 February 1976 at an altitude of 2440 m MSL and a range of 74 km. Curve A is for the ambient air sample, and curve B is for the brown eruption cloud. (d) Corresponding aerosol surface area distribution for the brown eruption cloud measured on 8 February 1976 at an altitude of 2440 m MSL and a range of 74 km.

the submicron aerosol was produced in the same manner as the larger aerosol.

Explosive volcanoes, such as St. Augustine, probably account for most of the aerosol emitted into the atmosphere from volcanoes (*6*). Total worldwide volcanic emissions have been estimated to be 25 to 150 × 10^6 metric tons per year for aerosol less than 40 μm in diameter (*7*). On the basis of the data presented here, we deduce that these total annual emission rates are equivalent to about 80 to 500 eruptions of the type that occurred at St. Augustine on 8 February. Since 57 eruptions of various intensities occurred from St. Augustine alone between 23 January and 14 February 1976 (*8*), it appears that the worldwide emissions of particles from volcanoes may have been underestimated.

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References and Notes

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2. The nuée ardente, or glowing avalanche as it is also called, is an avalanche of hot rock and crystalline fragments; at night it often glows a dull red. The speed and intense heat make a nuée ardente a major hazard. The nuée ardente on 8 May 1902 from the eruption of Mt. Pelée, Martinique, killed nearly all of the 30,000 inhabitants of the nearby town of St. Pierre.
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8. J. Lahr and J. Reeder, personal communication.
9. This report is dedicated to the memory of our late pilot, R. D. Spurling, whose untimely death occurred shortly after this research was completed. This research was supported by grants ATM-74-14726-A02 (Atmospheric Research Section, Meteorology Branch) and EAR76-15392 (Earth Sciences Section) of the National Science Foundation. Special thanks are due to Drs. William E. Benson and Frank H. Eden of the National Science Foundation; without their prompt action the results reported here would not have been obtained. Contribution No. 383 from the Atmospheric Sciences Department, University of Washington.

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Avian Muscular Dystrophy: Functional and Biochemical Improvement with Diphenylhydantoin

Abstract. *Chicks affected with hereditary muscular dystrophy were injected twice daily with 20 milligrams of diphenylhydantoin per kilogram of body weight on days 1 to 40 after hatching. The righting ability of dystrophic chicks treated with diphenylhydantoin was improved compared to that of untreated dystrophic chicks, and acetylcholinesterase activity was reduced to normal levels in the posterior latissimus dorsi muscles.*

Unlike a normal chicken, one affected with hereditary muscular dystrophy cannot right itself after being placed on its back (*1*). Although many biochemical and morphological abnormalities have been demonstrated in fast-twitch muscles of dystrophic chickens (*2*), the physiological basis of the righting difficulty is unknown. One possibility is that skeletal muscle rigidity, such as that found in myotonia congenita (*3*), prevents successful righting. This hypothesis is supported by the facts that dystrophic chicken muscle fibers have increased transmembrane resistance (*4*) and continue to fire abnormally in response to mechanical stimulation after neuromuscular blockade by *d*-tubocurarine (*5*). Both of these electrophysiological abnormalities are also found in myotonic mammalian muscle fibers (*6*). One might then expect an improvement in righting ability of dystrophic chickens after administration of diphenylhydantoin (DPH), a clinically useful antimyotonic drug (*7*). We have found that DPH dramatically improves the righting ability of dystrophic chicks and partially corrects abnormalities of acetylcholinesterase (AChE) (E.C. 3.1.1.7) and fiber morphology in posterior latissimus dorsi (PLD) muscles of dystrophic chicks.

The study was begun with 1-day-old New Hampshire chicks from normal line 412 and the related, homozygous dystrophic line 413 (*8*). Four groups of chicks were used. Group 1 included normal, untreated chicks; group 2, dystrophic, untreated chicks; group 3, dystrophic, exercised chicks; and group 4, dystrophic, DPH-treated, exercised chicks. Chicks were injected intraperitoneally with either diluent (group 3), or DPH, 20 mg/kg (group 4), twice daily at 12-hour intervals (*9*). The dose of DPH (20 mg/kg) was calculated from the mean body weight of chicks in group 4. The concentration of the stock DPH solution was increased as needed to deliver the 20 mg/kg dose in an injection volume of 0.1 to 0.25 ml. Chicks in groups 3 and 4 were "exercised" immediately before each injection by placing each chick on its back until it could no longer right itself. The number of consecutive times a chick could right itself was termed the exhaustion score. Exhaustion scores of chicks in groups 3 and 4 were determined just before the second daily injection on days 1 to 40 after hatching. Exhaustion scores of untreated chicks in groups 1 and 2 were determined at 5-day intervals in order to minimize the effects of exercise. Student's *t*-test was used to determine statistically significant differences in mean exhaustion scores.

Table 1 shows that untreated normal and dystrophic chicks differed greatly in their exhaustion scores from days 13 to 35 after hatching (*10*). Chicks in group 1 (normal) righted themselves an average of 19.5 times during each test period, whereas chicks in group 2 (dystrophic) averaged only 1.8 times. Injections of DPH had a dramatic effect on exhaustion scores. Chicks in group 4 (DPH-treated, exercised) had scores that were not statistically different ($P > .1$) from those of group 1. Chicks in group 3 (exercise alone) also showed improved exhaustion scores, but the mean score for this group was significantly lower ($P < .001$) than that for group 4. Regardless of how exhaustion scores were averaged (that is, whether as means of all chicks in a group at a specific test period or as means of single chicks for the entire experimental program) only the chicks in group 4 performed as well as normal chicks. In another experiment dystrophic chicks injected with DPH, but not exercised, had

Table 1. Effects of DPH and exercise on exhaustion scores of normal (line 412) and dystrophic (line 413) chicks. Test periods indicate the number of times each chick was exercised to exhaustion during days 13 to 35 after hatching. Exhaustion scores are grand means (± standard deviation) of the average score for each bird in the group. The number of birds per group is shown in parentheses.

Line	Group	Test periods	Exhaustion scores
412	1	5	19.5 ± 1.9 (12)*
413	2	5	1.8 ± 2.0 (16)†
413	3 (exercise)	46	8.9 ± 2.8 (15)*†
413	4 (exercise plus DPH)	46	20.3 ± 3.8 (11)*

*Statistically different from group 2 ($P < .01$). †Statistically different from group 1 ($P < .01$).