

A PRELIMINARY REPORT OF AIRBORNE STUDIES BY THE
UNIVERSITY OF WASHINGTON OF THE EFFLUENTS FROM THE
MT. ST. HELENS VOLCANIC ERUPTIONS

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Introduction

Mt. St. Helens ended its 123 year of dormancy on March 20, 1980 with a single small quake registering 4.1 on the Richter scale. Seismic activity increased steadily, becoming nearly continuous by March 25. The first eruption occurred on March 27 at 1236 Pacific Standard Time (PST) when a thick dark plume of ash was reported reaching 16,000 ft. The University of Washington's (UW) Cloud and Aerosol Research Group began regular airborne observations and measurements of the volcanic effluents on March 28.

In view of the considerable interest in the nature of the emissions from Mt. St. Helens, we provide here a short preliminary overview of our airborne measurements to date. These airborne measurements are continuing, with one flight a week when volcanic activity is low and more numerous flights when the activity increases. A full scientific report of our studies will be published in due course.

* Before using or quoting in publications or reports any of the scientific results reported herein, written permission must be obtained from Professor Hobbs.

Instrumentation

Measurements made aboard the UW's B-23 research aircraft are listed in Table 1. As can be seen, the instrumentation permits comprehensive measurements of the sizes, concentrations and nature of airborne particles over the size range $\sim 0.01\mu\text{m}$ — 4.5mm, and of the nature and concentrations of a large number of trace gases.

Measurement Procedures

Each flight commences in the vicinity of Mt. St. Helens and continues with measurements at increasing distances downwind in the plume of the effluents from the volcano. The altitudes of the flight paths range from about 4000 to 18,000 ft.

Measurements of the size spectra of particles, filter samples for chemical and optical analyzes, and gaseous measurements are obtained by feeding "grab" samples of air through the appropriate instruments and devices aboard the aircraft (concentrations of sulfur, nitrogen oxide and ozone are measured continuously). The "grab" samples of air (volcanic plume or ambient) are collected in a large (150 gallon) mylar bag and/or stainless steel cannisters in 5 seconds. The "grab" sample technique is desirable for two reasons. Firstly, it permits collection of sufficient samples of effluent for subsequent measurements without requiring the aircraft to be flying within the volcanic plume for long periods of time (this is necessary, for safety reasons, when the plume is very thick). Secondly, it allows acquisition of a series of essentially point samples, and each set of measurements is made on the same point sample.

TABLE 1. SPECIFICATIONS OF RESEARCH INSTRUMENTS ABOARD THE UNIVERSITY OF WASHINGTON'S B-23 AIRCRAFT USED IN THIS STUDY.

Parameter	Instrument type	Range	Principal Investigators
Size spectrum of aerosol particles	Electrical mobility analyzer	0.0032 to 1.0 μm	Profs. P. V. Hobbs and L. F. Radke
Size spectrum of aerosol particles	90° light scattering	0.3 to 12 μm	"
Size spectrum of aerosol particles	Forward light-scattering	1.5 to 40 μm	"
Size spectrum of aerosol particles	Diffusion battery	0.01 - 0.2 μm	"
Size spectrum of aerosol and cloud particles	Forward light-scattering	1.5 to 70 μm	"
Size spectrum of cloud particles and large ash particles	Diode occultation	20 to 300 μm	"
Size spectrum of precipitation particles and large ash particles	Diode occultation	300 to 4500 μm	"
Concentrations of Aitken nuclei	Rapid expansion and light transmission	10 to 10 ⁶ cm^{-3}	"
Images of cloud particles and large ash particles	Diode occultation	25 to 1000 μm	"
Images of precipitation particles and large ash particles	Diode occultation	100 to 5000 μm	"
Sizes and types of aerosol particles	Direct impaction	5 to 100 μm	"
Mass concentration of aerosol particles	Electrostatic deposition onto matched oscillators	0.1 to 3000 $\mu\text{g m}^{-3}$	"
Particulate sulfur	Pallflex filters (then flash volatilization)	0.1 to 50 $\mu\text{g m}^{-3}$	"

TABLE 1 (CONTINUED)

Parameter	Instrument type	Range	Principal Investigators
Chemical constituents of particulates (SO_4^{2-} , NO_3^- , Cl^- , Br^- , Na^+ , Ca^{++} , NH_4^+ , K^+ , PO_4^{2-} , F^- , etc.)	Ion exchange chromatograph (solution extracted from teflon filters)	Variable > 10^{-8} molar	Profs. P. V. Hobbs and L. F. Radke
Electric field	Field mill	\mp 0 to 100 kV	"
Space charge	Conductivity meter	2×10^{-9} - 10^{-15} A	
Photographs	35mm time-lapse camera	1 s to 10 min	"
Total gaseous sulfur (sequential scrubbers allow separation of SO_x , H_2S , inert gaseous species)	Flame photometric detector	0 to 10 ppm	
NO , NO_2 , NO_x (NH_3 occasionally)	Chemiluminescence (O_3)	0 to 5 ppm	"
Light-scattering coefficient	Integrating nephelometer	0 to $2.5 \times 10^{-4} \text{ m}^{-1}$ or 0 to $10 \times 10^{-4} \text{ m}^{-1}$	"
Windspeed and duration	Doppler navigator	0 to 360° , 0 to 100 m s^{-1}	"
"Inert" gaseous species (e.g. COS , CO , CO_2 , CH_4 , CS_2 , N_2O , CH_3Cl and halocarbons)	"Grab" samples with post flight analysis with multiple column gas chromatograph, mass spectrometer, and flame ionization detection	Variable	Prof. D. Cronn Washington State University, WA
Identification of elements in size segregated aerosol particles	Lundgren impactor (computer controlled). Analyzed by PIXE (18 MeV α - particles)	Variable	Prof. T. Cahill University of California at Davis, CA
" " "	Cascade impactor from "grab" sample. PIXE analysis (5 MeV protons)	Variable	Dr. A. Leslie Florida State University, FL
"Inert" gases (e.g. O_2 , Ar, N_2 , CO , CO_2 , He, H_2 , CH_4 , C_2H_6 , H_2S)	Gas chromatograph (with thermal conditioner detector)	Variable	Dr. W. Evans USGS, Menlo Park, CA
Radon Gas	"Grab" sample	Unknown	Dr. D. Douglas EPA, Las Vegas, NV
Optical Absorption of Particles	Integrating plate	Unknown	J. Ogren (U.W.)

Overview of Observations and Measurements

A very brief summary of the observations and measurements obtained on the sixteen flights that we have made to date is given in Table 2. A few further comments, and illustrations of some of the measurements obtained, will suffice to complete this preliminary report.

The emissions encountered on our first flight over Mt. St. Helens on March 28, 1980, were impressive (but fairly small compared to the emissions from the St. Augustine volcanic eruptions which we studied in 1976*). The size spectra of particles measured in the effluents from the volcano at 7 nautical miles downwind on March 28 are shown in Fig. 1. It can be seen that the concentrations of particles from ~1-10 μm , measured in a puff of ash, were up to a factor of 1000 greater than in the ambient air, but for particles $<1\mu\text{m}$ the concentrations were similar to those in the ambient air. The mass concentration of particles less than 2 μm in size in this cloud of ash and in the ambient air were ~660 and 30 $\mu\text{g m}^{-3}$ respectively. The concentrations of total sulfur gases in the plume reached values of 240 ppb and consisted mostly of hydrogen sulfide.

Between March 28 and May 17, when the volcanic activity was fluctuating, seven further flights were made (see Table 2). On April 2, April 4, April 8 and April 11 the total sulfur concentrations were in the range 15-38 ppb with fluctuations in the H_2S and SO_2 components. On May 8 however the total sulfur

* "Airborne Particle and Gas Measurements in the Emissions from Six Volcanoes" by J. L. Stith, P. V. Hobbs and L. F. Radke, J. Geophysical Research, 83, 4009-4017 (1978).

TABLE 2. CHRONOLOGY OF THE ACTIVITY OF MT. ST. HELENS
AND UNIVERSITY OF WASHINGTON RESEARCH FLIGHTS

Date (1980) Flight (times in PST to nearest hr*)	Comments
March 20	First earthquake.
March 25	Intense seismic activity.
March 27	First eruption. Ash plume reported to 16,000 ft.
March 28 1	Second eruption. Ash plumes up to 20,000 ft. Duration of ash eruptions 5-10 min with more frequent and shorter steam explosions. Aircraft followed one ash burst 55 miles east (minor activity compared to the 1976 eruptions of St. Augustine, Alaska). Total sulfur gases up to 240 ppb - mainly H ₂ S.
March 30- April 1	Infrequent ash eruptions.
April 2 2 (1000-1400)	Brief ash and steam explosions. CO ₂ concentrations in the ash plume ranged from 360-411 ppm compared to ambient levels of 320 ppm.
April 4 3 (1200-1500)	Sampled moderate volumes of ash which was rather cool (ash descended rapidly after emission). Slight H ₂ S emissions. First flight on which significant concentrations of SO ₄ ⁼ , Cl ⁻ and F ⁻ were detected. Sampled ash (mostly old lithic material) with some freshly fractured siliceous material.
April 8 4 (1300-1500)	Frequent minor ash eruptions and steam explosions. First significant concentrations of SO ₂ measured (since March 28 eruption).
April 8- April 10	Minor activity. Bulge on upper north flank of mountain confirmed.
April 11 5 (1200-1400)	Geyser-type steam explosion with water in crater draining into vent and then exploding up to ~500 ft above mountain top. Minor sulfur gas emissions (~50% SO ₂).
April 12- April 22	Activity continued to decline
April 23 6 (1000-1300)	Lowest level of activity observed on flights so far. Very slight particle and gas emissions.
April 24- May 6	Activity continued to decline.

* All times in this report are given as Pacific Standard Time (PST). After April 27, local time is obtained by adding 1 hour to the stated PST times.

TABLE 2. (CONTINUED)

Date (1980) Flight (times in PST to nearest hr)	Comments
May 7	Ash and steam eruptions resumed.
May 8 7-8 (1000-1300)	Ash and steam eruptions sampled from aircraft (somewhat smaller than those of April 2).
May 8 (1400-1600)	Sulfur gas emissions back to several hundred parts per billion (ppb) with mostly H ₂ S but occasionally significant SO ₂ . Peak altitude of eruptions ~13,000 ft. MSL.
May 9- May 16	Ash and steam eruptions continued with decreasing frequency.
May 17	Activity nearly ceased.
May 18 9 & 10 (1000-1500) (1600-2000)	<u>First major explosive eruption</u> at 0732 PST. North face of mountain collapsed. Many hot avalanches (nuée ardentes). Eruptions reported to reach altitudes in excess of 60,000 ft. UW flight out to ranges of 240 nautical miles downwind. Sulfur gas emissions very low (near ambient levels) except in a single area near the top of the plume late in the day when 1 part per million (ppm) of H ₂ S was measured. High particle mass loadings measured throughout both flights.
May 19 11 (1100-1400)	Eruptions continued with heavy ash deposition to the east but at a much reduced rate. H ₂ S emissions high in most samples (~0.5 ppm). SO ₂ concentrations in plume near ambient.
May 20- May 22	Eruption activity continued but at much reduced rates.
May 23 12 & 13 (0800-1200) (1300-1400)	Measurements similar to May 19 but quantity of ash much reduced. Airborne measurements extended to Eastern Washington with emphasis on measurements of particles resuspended (blown up) from ground. Visibility very poor in blowing ash.
May 25 14 (0800-1300)	<u>Second major explosive eruption</u> . Ash reported to altitudes of ~40,000 ft. Ash deposited in Western Washington and Oregon (Portland). Airborne samples consisted mainly of old lithic silicious rock with no fresh glassy materials. Some elevated Cl ⁻ (HCl?). Gaseous sulfur generally less than 100 ppb and mostly H ₂ S.

TABLE 2. (CONTINUED)

Date (1980) Flight (times in PST to nearest hr)	Comments
May 26- May 29	Declining volcanic activity. Amounts of ash in each explosive pulse also less.
May 30 15 (0900-1300)	Heavy steaming and very light ash to 11,000 ft. Incandescent lava reported in crater but discounted by our observations. Sulfur gas ~0.5 ppm (mostly H ₂ S).
May 31- June 3	Activity similar to May 30.
June 4 16 (1000-1300)	Visually similar activity to May 30 but sulfur gas contained 30% SO ₂ with observations of SO ₂ up to 200 ppb (the highest yet observed). Particles in airborne effluents rich in Cl ⁻ , F ⁻ , Br ⁻ and SO ₄ ⁼ .

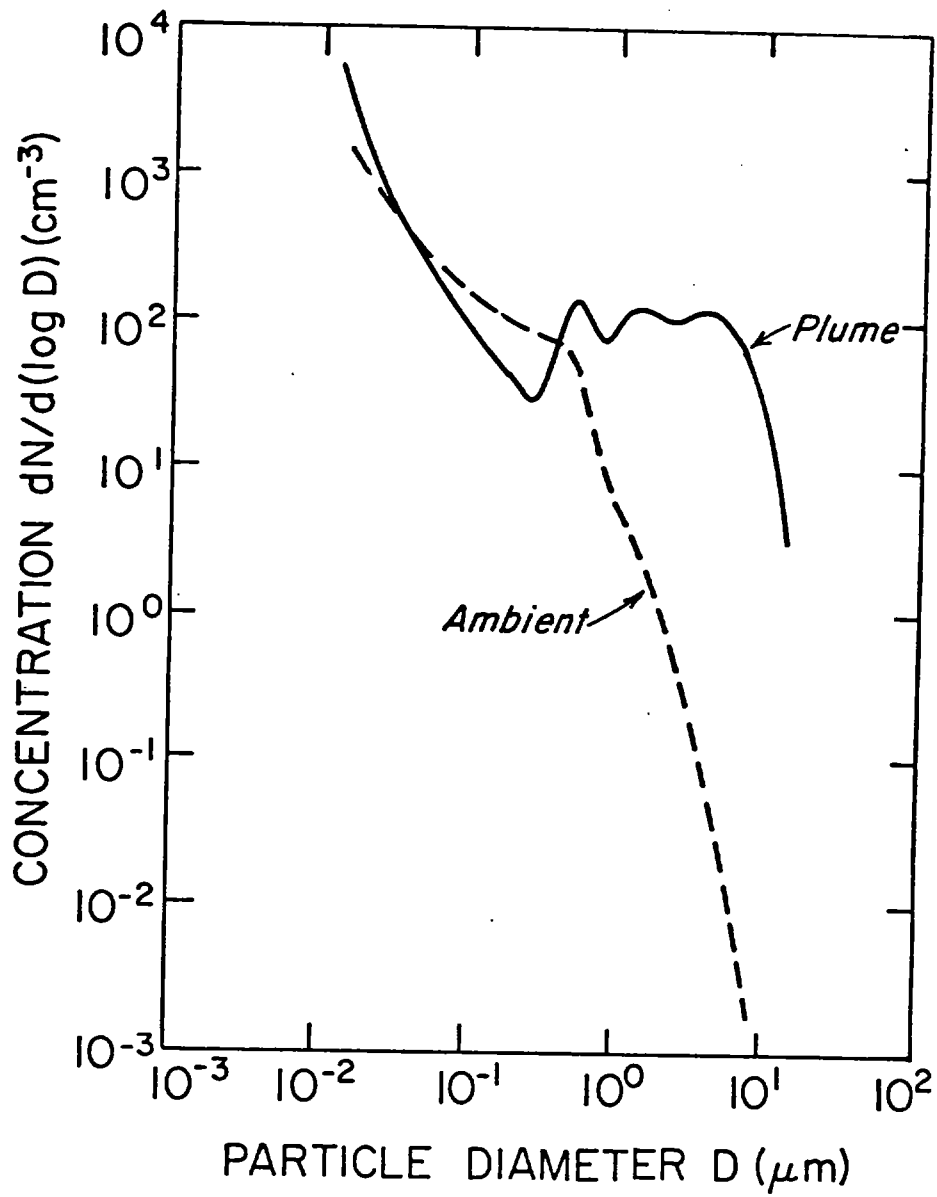


Fig. 1. Particle size distributions at 10,000 ft altitude and 7 nautical miles downwind of Mt. St. Helens at 1439 PST on March 28, 1980: (a) in the emitted ash (solid line) and (b) in the ambient air (dashed line).

concentrations had returned to values similar to those measured on March 28 with 230 ppb of H₂S and 53 ppb of SO₂.

By May 18, seismic and visible activity had virtually ceased when, without warning, a major eruption occurred at 0732 PST*. The north face of the mountain collapsed in avalanches and pyroclastic flows, devastating a wide area north and east of the mountain. The explosive eruptions ejected material to an altitude of over 60,000 ft. and ash was carried eastward over Washington, Idaho and Montana within a few hours (Fig. 2).

The UW research aircraft was in the air in the vicinity of Mt. St. Helens by ~1100 PST on May 18. The dark black cloud of ash over and downwind of Mt. St. Helens was the largest we have seen in all of our volcanic studies and was much too thick to penetrate. However, measurements were obtained at the peripheral edges of this ash cloud using the "grab" sample technique. Shown in Fig. 3 is one set of measurements of particle size spectra obtained at a distance of 5 nautical miles downwind of Mt. St. Helens about 4½ hours after the start of the major eruption. It can be seen that the concentrations of particles in the ash cloud varied from about a factor of 4 to over 1000 times greater than in the ambient air. For particles less than 2 µm in diameter, the mass loading in the periphery of the ash cloud was ~93 µg m⁻³ while in the ambient air it was <0.1 µg m⁻³. The concentrations of sulfur gases, nitrogen oxides and ozone measured in the periphery of the ash cloud were not significantly different from the concentrations in the ambient air.

* 0832 local time.

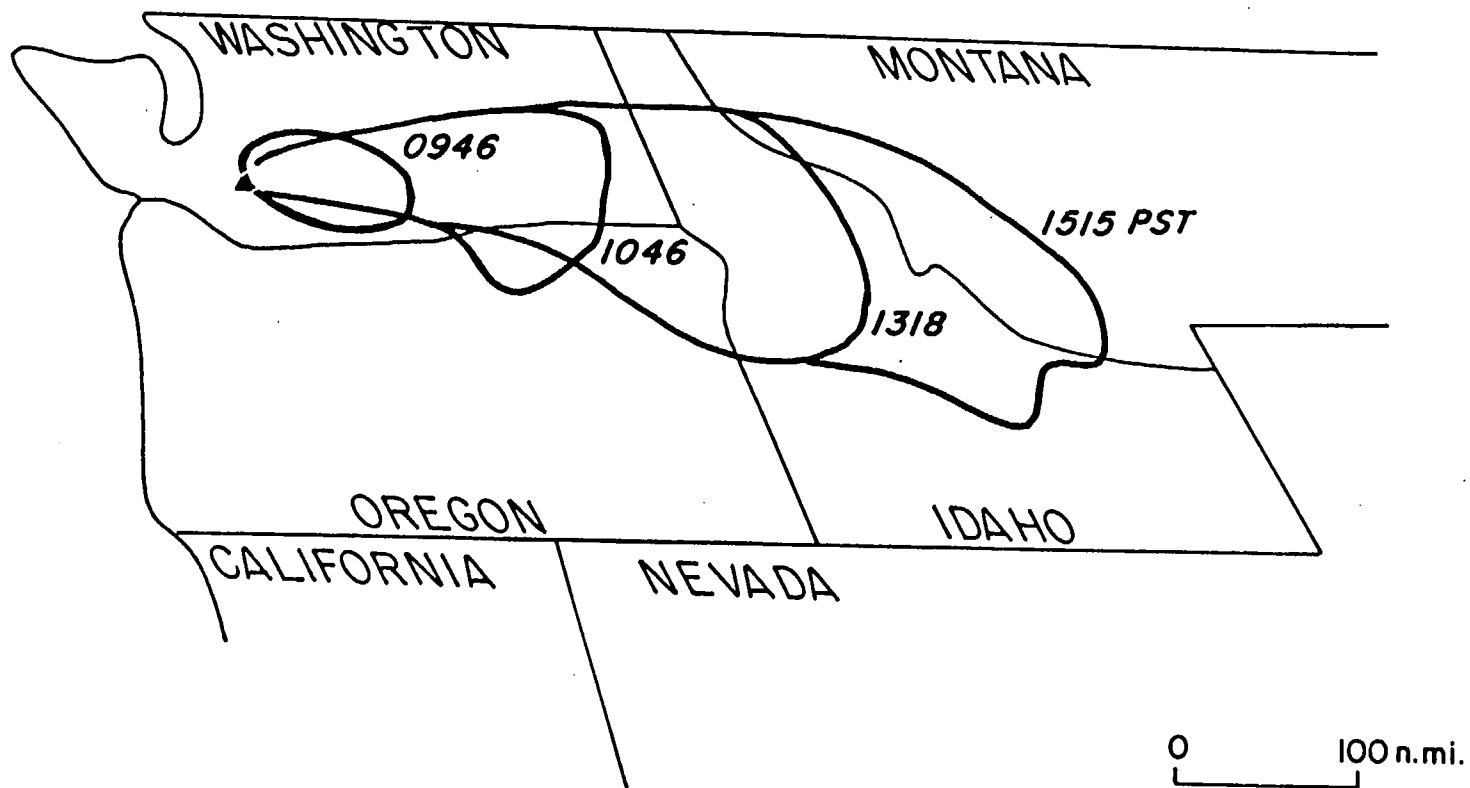


Fig. 2. Spread of the emissions from the explosive eruption of Mt. St. Helens on May 18, 1980, as deduced from satellite observations. (Note: local time is obtained by adding 1 hour to the PST times shown.)

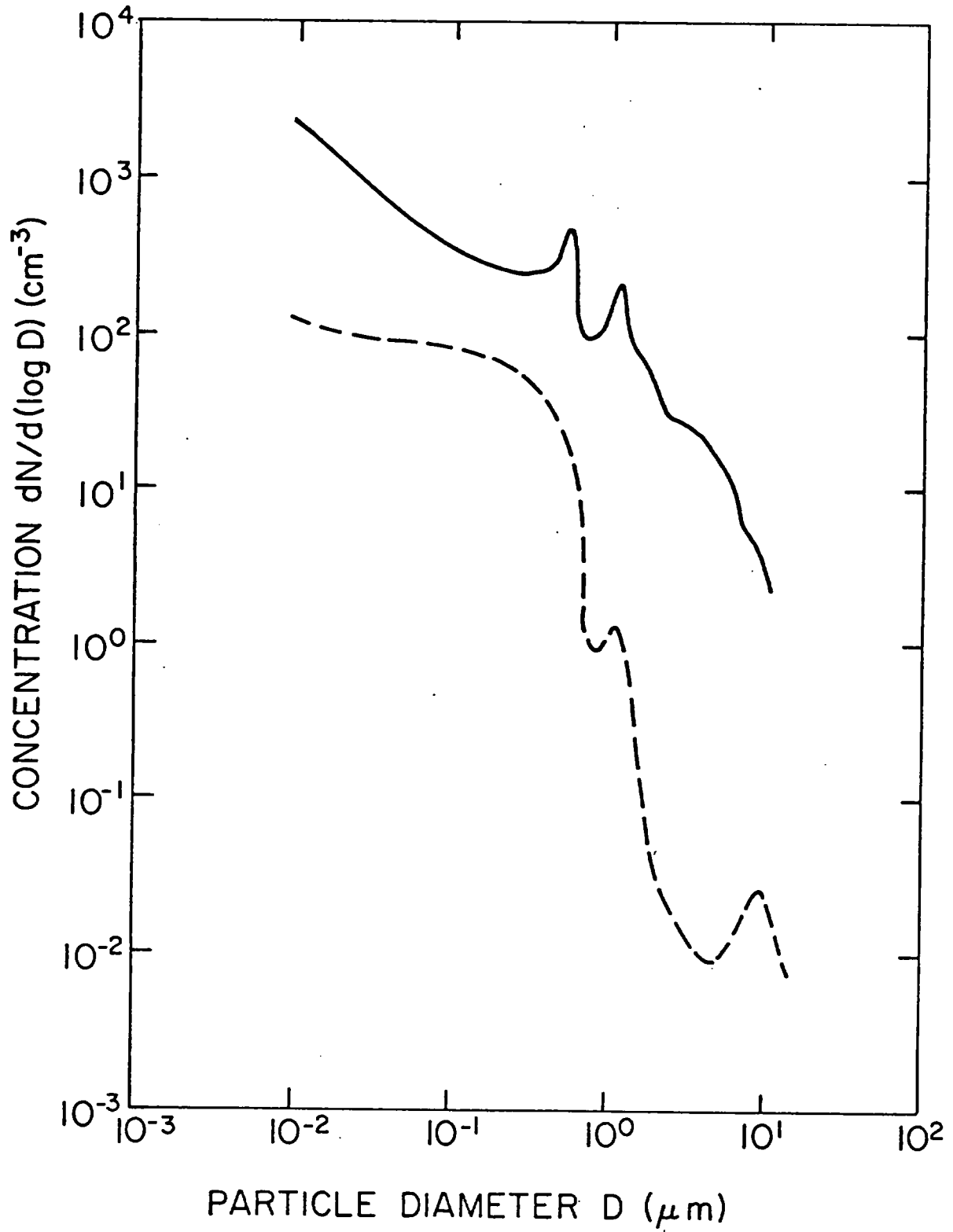


Fig. 3. Particle size distributions at 9700 ft altitude and 5 nautical miles downwind at 1209-1227 on May 18, 1980: (a) at the periphery of the main ash cloud (solid line) and (b) in the ambient air (dashed line).

In addition to the very black ash cloud, smaller outlying "whitish" looking clouds of effluents were observed on May 18. These clouds were sufficiently small that they could be penetrated completely by the UW aircraft and measurements obtained in their interiors. Particle size measurements obtained in such a cloud are shown in Fig. 4. It can be seen that the concentrations of particles less than about $0.1 \mu\text{m}$ were no higher in these clouds than in the ambient air, but for particles from about 0.1 to $30 \mu\text{m}$ the concentrations were up to 100 times greater than in the ambient air. The mass concentrations of particles less than $2 \mu\text{m}$ in the "whitish" clouds and in the ambient air were about 31 and $5.5 \mu\text{g m}^{-3}$, respectively. The concentration of sulfur gases in these clouds was at least 13 ppb (compared to ambient concentrations of 6 ppb) and was primarily SO_2 . Nitrogen oxide and ozone concentrations in the "whitish" clouds were similar to those in the ambient air.

Late in the evening, as the volcanic activity declined, our final measurements were taken near the top (17,000 ft) of the main visible plume from the volcano. These samples proved very rich in sulfur gas, about 1 ppm of mostly hydrogen sulfide.

Another flight was carried out the following day (May 19). Emissions were still considerable, but much less than on May 18. Particle concentrations measured in the periphery of the main ash plume and in the ambient air, 12 nautical miles downwind of Mt. St. Helens, are compared in Fig. 5. At this range, mass loadings for particles less than $2 \mu\text{m}$ in the plume and in the

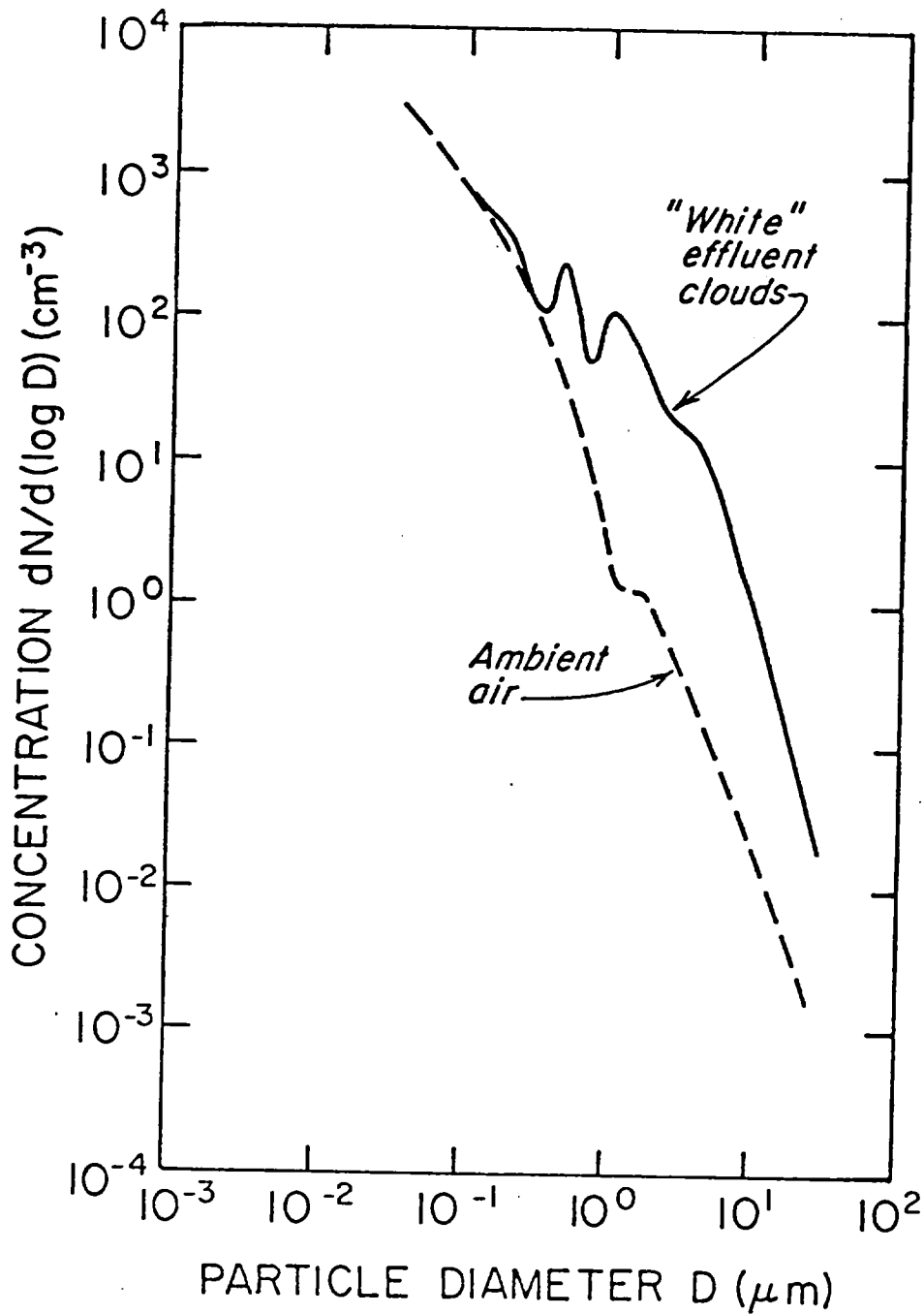


Fig. 4. Particle size distributions at 10,500 ft altitude and 70 nautical miles downwind at 1830 - 1842 PST on May 18, 1980: (a) in the "whitish" effluent clouds (solid line) and (b) in the ambient air (dashed line).

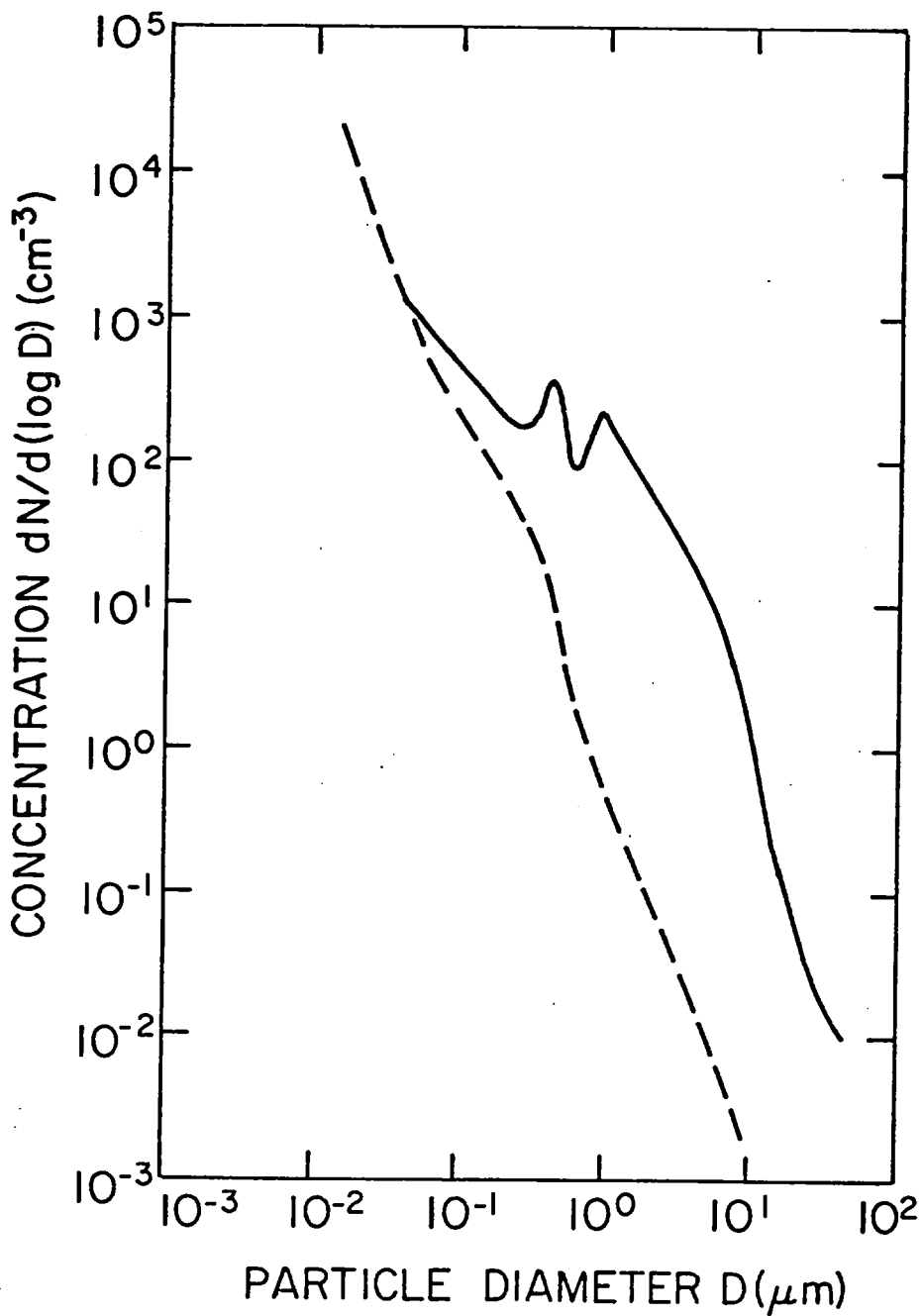


Fig. 5. Particle size distribution at 8900 ft altitude and 12 nautical miles downwind of Mt. St. Helens at 1338-1340 PST on May 19, 1980: (a) on the periphery of the main ash cloud and (b) in the ambient air (dashed line).

ambient air were 63 and $5 \mu\text{g m}^{-3}$, respectively. Hydrogen sulfide concentrations in the plume were high (about 0.5 ppm) but SO_2 concentrations were near ambient values.

Exactly one week after the first explosive eruption of May 18, a second violent eruption occurred. This eruption, which began at 0132 PST on Sunday May 25, sent an ash-rich cloud to 45,000 ft. by 0145 PST. Despite poor visibility and rain showers (some ash-laden), our airborne measurements began in the eruption cloud by 1000 PST. Particle size measurements in the ash plume (Fig. 6) were similar to those obtained on May 18. However, unlike May 18, we detected fairly high levels of total sulfur gases in most of the ash clouds: 6-110 ppb (compared to 6-14 ppb in the ambient air), with 13-95 ppb of hydrogen sulfide and 3-6 ppb of inert sulfur species.

Measurements on May 30 and June 4 showed the gaseous emissions to be continuing while the amount of ash declined. A significant fraction of the smaller particles now appeared to be condensed soluble material, with quantities of $\text{SO}_4^{=}$, Br^- , F^- and Cl^- .

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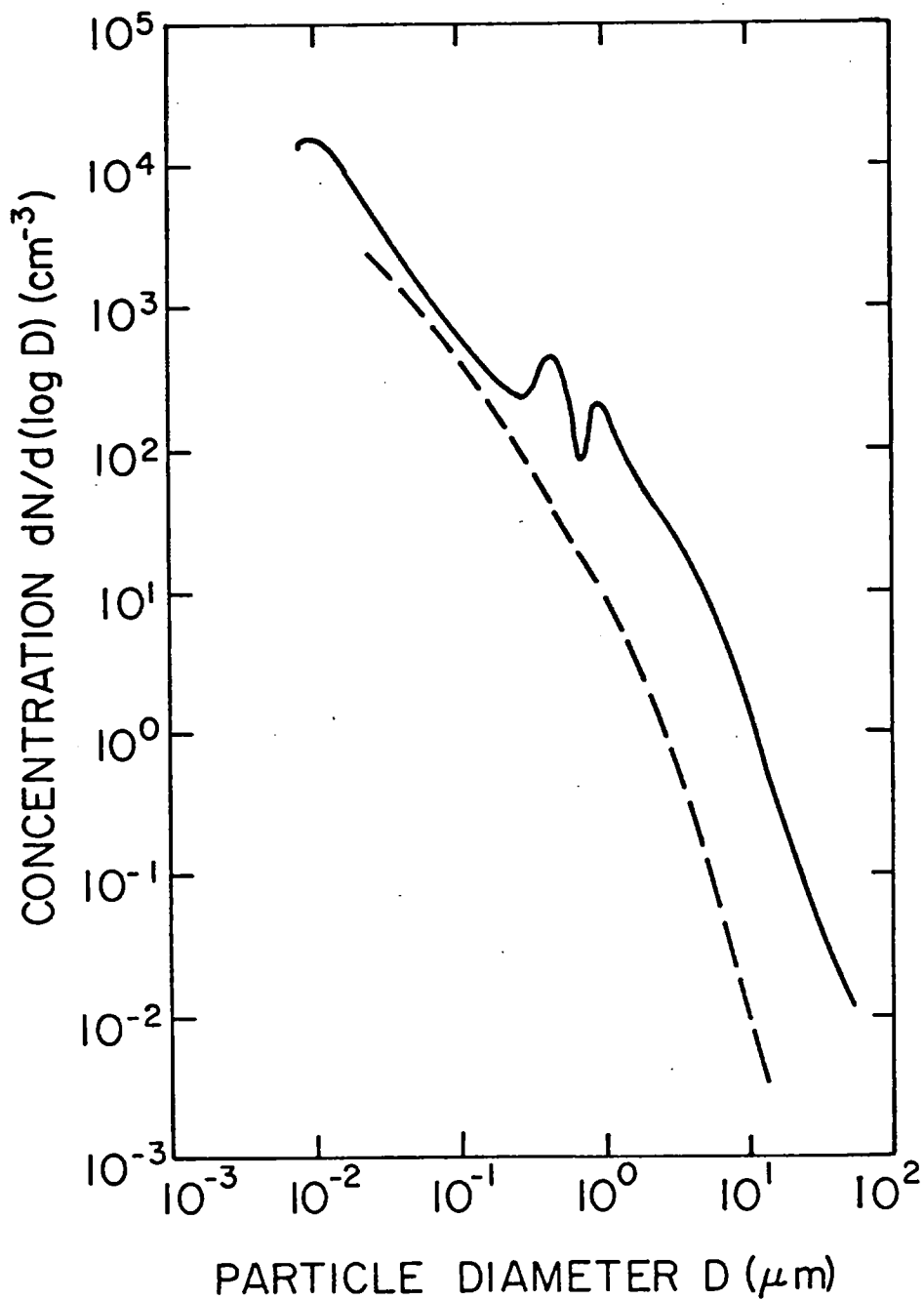


Fig. 6. Particle size distributions at 11,400 ft altitude and 5 nautical miles downwind of Mt. St. Helens at 1029 PST on May 25, 1980: (a) in the ash cloud (solid line) and (b) in the ambient air (dashed line).