

CHAPTER 5

Identification of the Physical and Chemical Characteristics of Volcanic Hazards

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Introduction

Immediately after the May 18, 1980 eruption of Mount St. Helens, the public health and laboratory science communities were required to assess the likely nature and toxicity of the volcanic products. This included assessing the following volcanic products: the emissions of volcanic gases (SO_2 and H_2S), volatile organics (polynuclear aromatic and halogenated hydrocarbons), toxic inorganics (arsenic, mercury, HF, and HCl), radon gas and short-lived radiation emitted (alpha and gamma) during the decay of radon daughters, and respirable particulates (fibrous materials and free crystalline silica).

The intent of this chapter is to present the Mount St. Helens environmental sampling plan, discuss the numerous techniques available to the public health community to analyze volcanic emissions for toxic materials, and briefly outline the findings of the many analytical laboratory studies published after the May 18, 1980 eruption of Mount St. Helens.

The particular instrumentation and strategies appropriate for sampling and analysis of volcanic products (ash and gases) vary depending on the volcano being studied. For example, the concerns related to an eruption of the "effusive" volcanoes on the island of Hawaii are distinctly different from concerns related to an eruption from one of the explosive volcanoes in Washington, Oregon, Alaska, and California. The eruption of Hawaiian volcanoes (shield-type volcanoes) produce very different amounts and types of gaseous and particulate products than the Cascade volcanoes (strato-type volcanoes) (see chapter 2). It is well documented that lava flows and gaseous emission are a major concern for the Hawaiian volcanoes; however, volcanic ash, crystalline silica, and leachable toxic trace elements are the major concerns from volcanoes in the Cascade mountains of the western United States.

Sampling Strategies for Volcanic Gases and Solid Ejecta

A major concern of a physical scientist analyzing volcanic products is to ensure that the samples are pristine and not contaminated with other geologic or anthropogenic materials. If the validity of the sample is in question, then all the analytical results will be questionable. Throughout this program, careful attention was given to collecting, preparing, and analyzing samples. All procedures were carefully documented to ensure validation of results. This information helped to determine the limitations of the sampling program and what effects these limitations had on accurately assessing possible toxic hazards associated with the volcanic products.

A number of factors must be considered in selecting possible sampling sites around an active volcano. These considerations include population density, history of previous eruptions, prevailing wind direction, access to sampling sites, whether the information to be gained is for toxicological

or geologic reasons, the type(s) of samples and frequency/duration of sample collection desired, and if the site is to be manned, the health and safety of the operator must be considered. The particular information presented below is specific to our experience gained from the study of Mount St. Helens; however, the scientific approach used is of a more general nature and can be useful in monitoring the ejected gaseous and particulate products of any volcano.

Initial Sampling Program

On March 19, 1980, a series of earthquakes beneath Mount St. Helens heralded the beginning of a chain of events that eventually climaxed with the May 18, 1980 eruption. During the early period of activity from March 19 to May 14, 1980, all of the eruptions were relatively small, nonmagmatic in nature, and ejected ash to a maximum altitude of 2.5 km above the summit of Mount St. Helens impacting an area within a 50-km radius of the mountain (Figure 1). Within two weeks of the initial activity, a sampling network consisting of 10 sample sites was set up around Mount St. Helens to collect volcanic ash. The site-selection criteria were based primarily on the prevailing wind direction relative to the mountain and the relative ease of access to the site. The majority of sites were located to the northeast of Mount St. Helens. The closest site was located 9 km from Mount St. Helens and was ultimately destroyed in the May 18 eruption.

The majority of these sites were set up in locations that were impacted by most of the ash from this early phase of eruptions. This initial sampling strategy was geologically (mineralogically) oriented and operated from late March to early June 1980. The main purpose of the program was to obtain pristine sedimented ash samples, which could later be analyzed for leachable trace elements and elemental composition, and to characterize the mineralogy and morphology of the bulk ash.

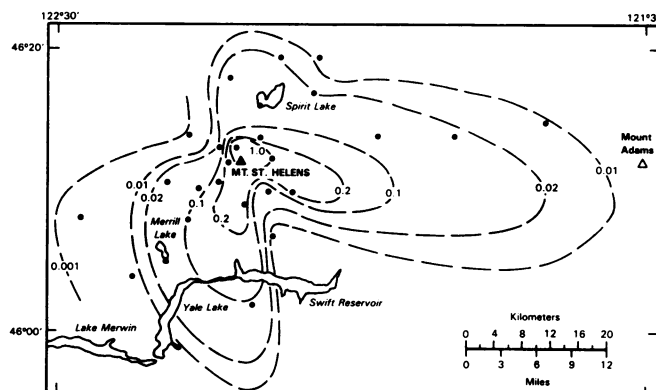


FIGURE 1—Distribution of Ash from Mount St. Helens between March 27 and April 17, 1980. (Isolines represent mass per unit area in grams per square centimeter. Sampling sites are indicated by solid circles)
SOURCE: Sarna-Wojcicki, *et al.*¹

NOTE: Author affiliations and addresses are listed on p vi.

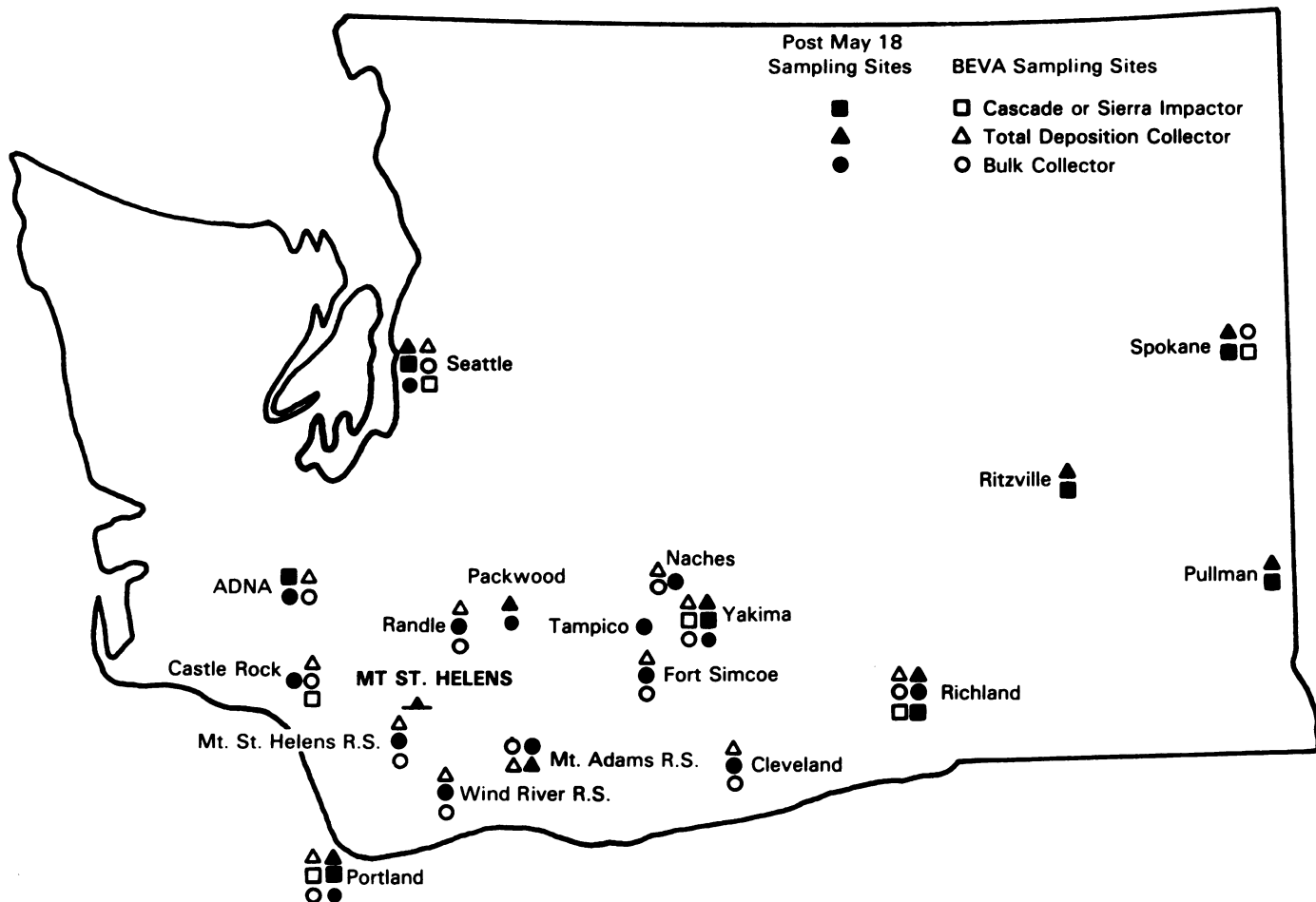


FIGURE 2—Location of sampling sites in the restructured and BEVA-supported sampling program

The sampling stations consisted of open, 30-gal plastic containers with thick (4 mil) plastic liners. The stations required no electric power and were therefore inexpensive and very reliable.

We found that the large 30-gal containers tended to accumulate debris (forest litter or trash from human sources). To eliminate the debris entering the container, a nylon mesh window screen material was secured to the top of each container. When a sample was collected, the entire liner was removed and replaced. To remove the coarser nonvolcanic material, all samples were sieved through a 20-mesh (850- μ m) screen before analysis. The sample was allowed to warm to room temperature, and the water was removed by filtering using a Buchner vacuum filter apparatus. The ash was then scraped from the filter paper if large quantities were present, or the filter paper was ashed at low temperatures (450°C) to remove the organic material if limited quantities of ash were present.

This collection and sampling technique has some limitations. The ash cannot be analyzed for leachable trace elements if water was or has been in contact with the ash. However, most of the other parameters (e.g., particle size distribution, elemental composition, and free crystalline silica concentrations) can be determined with this type of collection system.

Post-May 18 Sampling

When the initial sampling program was designed, a violent eruption of the magnitude of the May 18 eruption was not expected. After the May 18 eruption, the sampling program had to be restructured. The restructured program (June 1980 through February 1982) was designed to assess the nature and intensity of human exposure to toxicological threats from volcanic products. For Mount St. Helens, these threats primarily were from free crystalline silica in the respirable size fraction of the ash and leachable toxic elements from the bulk volcanic ash.

During the period following the May 18 eruption of Mount St. Helens, the number of sampling sites was expanded (Figure 2). However, many times the distribution of ashfall was limited and completely missed our sampling sites. In this situation a number of interesting techniques were developed to sample sedimented ash. Personnel were dispatched to the impacted areas, and samples were collected by removing the top few millimeters of snow (and ash), brushing the surface of automobiles in new car lots, or sweeping picnic tables and tennis courts. These techniques, although not ideal, provided investigators with reasonably pristine ash samples. Care was taken to document the source of the sample and prevailing environmental conditions so that any analytical anomalies could be evaluated.

To determine possible health risks associated with air-

borne particles of ash in the respirable size fraction ($<10 \mu\text{m}$), Cascade impactors or Sierra High Volume separators were placed in seven population centers of Washington and Oregon (Portland, Seattle, Yakima, Spokane, Richland, Ritzville, and Pullman). These systems are capable of fractionating particles according to their aerodynamic size during periods of new ashfall and episodes of resuspension. Both of these "active" collection devices work on the principle of inertial impaction of airborne particles onto a filter media. If a stream of air laden with particles is directed at a surface, particles of sufficient inertia will impact on that surface, and the smaller particles will remain in the airstream. When the plates are arranged in a series of stages (cascade), the aerosol stream is passed from stage to stage with continually increasing particle velocities and decreasing particle cut-off sizes (D_{50}). The D_{50} is defined as a cut-off size of a stage at which 50 per cent of the particles within that size range are removed from the airstream.²

The two systems used on this program were a five-stage Sierra High-Volume Cascade Impactor with a preseparator and an Andersen 2000 four-stage separator with backup filter. These devices may be used for active collection of area samples, but not for personal, breathing-zone sample collection. The particle size fractionation for the Sierra system was greater than $5.5 \mu\text{m}$ for the preseparator and greater than $7.2 \mu\text{m}$, 3.0 to $7.2 \mu\text{m}$, 1.5 to $3.0 \mu\text{m}$, 0.95 to $1.5 \mu\text{m}$, and 0.49 to $0.95 \mu\text{m}$ for stages one through five respectively, operated at 40 standard cubic feet per minute (scfm). The effective cut-off diameters for the Andersen 2000 impactor were greater than $7.0 \mu\text{m}$, 3.3 to $7.0 \mu\text{m}$, 2.0 to $3.3 \mu\text{m}$, 1.1 to $2.0 \mu\text{m}$, and less than $1.1 \mu\text{m}$ for stages one through four and backup filter, respectively, operated at 20 scfm (Figure 3). These systems have disadvantages because they require electricity, an operator to turn the system on during an ashfall, and immediate removal of the sample after sampling. The merits of this type of system are that samples of airborne materials may be collected, their airborne concentration measured and related to human breathing rates, and their mineralogical and toxicological properties analyzed. Collection of samples in this manner can then be related to the hazards associated with inhalation of a specific volume of air contaminated with this material.

The advantage of an active sampling network compared to the previously used passive network is that the active system allows accurate estimations of: 1) particle concentrations per unit volume of air at ground level near the breathing zone of exposed individuals; and 2) airborne concentrations of free crystalline silica during periods of ashfall and resuspension episodes. The passive network was only able to collect pristine samples of sedimented ash. Comparison of the active and passive network capabilities in predicting toxicological hazards to the public shows that samples gathered using the passive collection techniques allow us to predict the potential for hazardous exposure from particulate material (e.g., crystalline silica) whereas those from active systems allow us to actually measure concentrations of contaminants in air in that particular sampling area. Large errors can be expected in attempts to extrapolate concentrations of crystalline silica in breathing-zone air from the percentage of free crystalline silica in sedimented ash sampled from the same area.

BEVA Sampling Program

In early March 1982, Battelle, Pacific Northwest Laboratories (Battelle-Northwest) became an active participant of

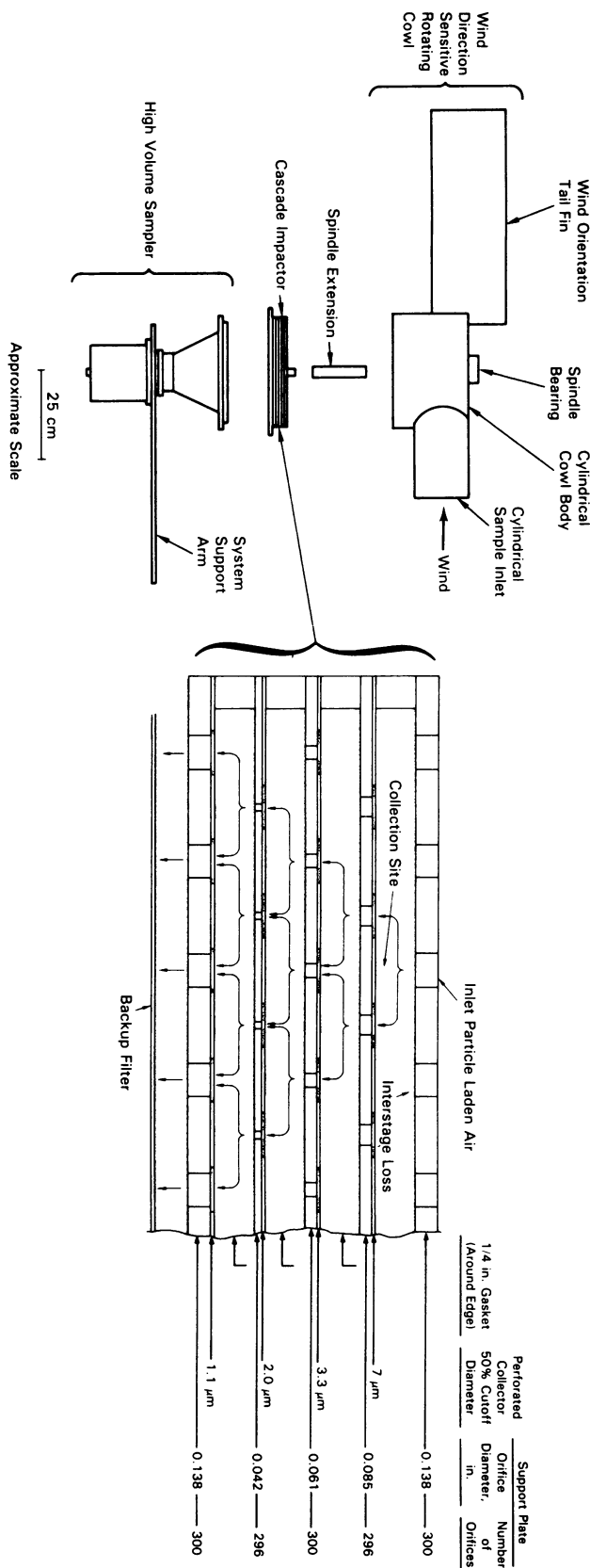


FIGURE 3—Diagram of high-volume Cascade impactor system with exploded view of particle impactor plates
SOURCE: Schmel GA.³

the Oregon Health Sciences University Study Center for the Biological Effects of Volcanic Ash (BEVA). Through this affiliation and under BEVA direction, the sampling sites were consolidated into 12 total sites (Figure 2). Sites located in Richland, Portland, Castle Rock, Seattle, Yakima, and Spokane were equipped with active pump-operated collection devices (Cascade impactor or Sierra five-stage separators), as well as passive collection devices (30-gal plastic container with clear plastic liners and flat clear plastic tarpaulins of known dimensions). The clear plastic tarpaulins could collect relatively large amounts of ash compared to the 30-gal containers. In addition, the use of flat tarpaulins with known dimensions permitted accurate estimates for total quantities of sedimented ash per unit area. The remaining six sites, classified as passive sites only, were equipped with 30-gal plastic containers and tarpaulins of known dimension. This type of sampling network would have enabled us to gather pristine samples of sedimented ash, estimate the airborne concentrations of ash per unit volume of air collected, and obtain sized airborne ash near major population centers. However, since the initiation of this project, no other major eruptions have occurred and only a few minor ashfalls have been reported, mainly within 50 km of Mount St. Helens.

Other Air Sampling Programs

Most of the air sampling during periods of major ashfall was carried out by federal, state, and local air pollution agencies in Washington, Oregon, Idaho, and Montana. These institutions used existing equipment, located at rooftop sites meant for monitoring compliance with industrial pollutant standards, to sample newly fallen and resuspended volcanic ash. Three general types of sampling apparatus were used: the high-volume samplers, high-volume cascade separators, and/or the dichotomous air samplers (Dichot). The high-volume sampler draws air through a filter media at 20 to 40 scfm. A system in this configuration is unable to differentiate particles of varying diameters and, therefore, provides only the concentration of total suspended particulates (TSP) per unit volume of air. The Dichot air sampler can discriminate between particles according to aerodynamic particle size, usually between the less than 15- μm and the greater than 15- μm size fraction. Using this existing network at the time of the May 18 eruption, the US Environmental Protection Agency estimated that in some areas of the northwest US, concentrations of TSP were as high as 35 mg/m^3 during periods of peak ashfall (Figure 4).⁴ Concentrations of airborne particles on the Hanford site, 211 km east of Mount St. Helens, reached a maximum concentration of 2.6 mg/m^3 of which 1.43 mg/m^3 was less than 5.5 μm in diameter. The respirable content of the total airborne solids was 55 per cent by weight.⁵

Characterization of Volcanic Products

Many of the very large volcanic eruptions of the more recent past (Tambora, 1815; Krakatoa, 1883; Katmai, 1912; Quizapu, 1932; Bezymianny, 1956; Hekla, 1974; Souffriere, 1979; and El Chichón, 1982) occurred on islands, peninsulas, or adjacent to ocean areas where the ash cloud was carried out to sea. The proximity of Mount St. Helens to a major population center of North America and the prevailing wind patterns of this area provided ample opportunities for observation and study. Large volumes of information were gathered on the behavior of the volcano and the products of its

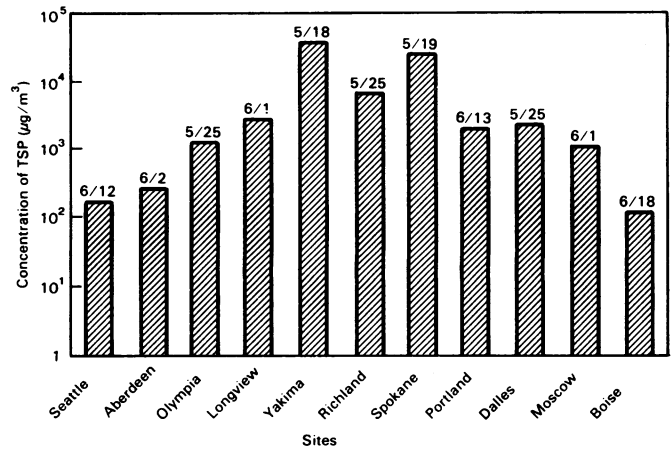


FIGURE 4—Highest concentrations of total suspended particulates measured between May 18 and June 18, 1980, by the EPA Region 10 volcano particulate network. Peak concentrations for Olympia, Yakima, and Spokane represent sampling intervals less than 24 h. NOTE: Information provided by Jon Schweiss and Bill Schmitt US EPA Region 10, Seattle, WA

eruptions. Since 1980, more than 400 papers have been published in the open literature. These include 130 relating to biological topics, 140 on chemical topics, and approximately 140 discussing the results of meteorological studies. Obviously, it is beyond the scope of this chapter to discuss or cite all of these; however, many papers relating to parameters evaluating health hazards of volcanic ash are briefly discussed. More in-depth information can be obtained directly from these articles cited.

Ash from the early eruptions was analyzed at Battelle-Northwest using x-ray fluorescence to determine the major elemental composition of the ash. Concurrently, many other institutions carried out independent research to analyze this ash. A comparison of these results is discussed briefly in the latter part of this chapter. Immediately after the May 18, 1980 eruption of Mount St. Helens, numerous sedimented ash samples from this eruption were received for analysis from throughout Washington, Idaho, and Montana.⁶ Six major ash eruptions occurred in the period between May 18 and October 18, 1980 (May 18, May 24–25, June 12–13, July 22, August 7, and October 16–17). Ash samples from these eruptions were collected and analyzed. The techniques described in the section on sampling were acceptable for determining free crystalline silica concentrations in the respirable fraction of the bulk ash samples, a major concern of the public health agencies, even though the sampling strategy was originally intended for collection of samples for geologic analysis.

Elemental Composition

The elemental composition of volcanic ash is important to the volcanologist or geologist in determining what occurs during a volcanic eruption. Elemental composition is used to determine the mineralogical classification of the ash (i.e., basalt, andesite, dacite, and rhyolite). Knowing the characteristics of the volcanic material is helpful in predicting the likelihood of free crystalline silica in the ash (basalt and andesite have little possibility for containing any free crystalline silica; see chapter 2 and the section below on Morphology, Mineralogy, and Free Crystalline Silica).

Many techniques and instruments are available that can determine elemental composition of volcanic ash. They

include direct techniques such as x-ray fluorescence, instrumental neutron activation analysis, prompt gamma activation analysis, proton-induced x-ray emission analysis, and x-ray photoelectron spectroscopy.⁷⁻¹⁴ All of these techniques require minimal sample preparation. More laborious techniques are required when samples are analyzed using atomic absorption or plasma emission spectroscopy.^{6,12,15} These type of analyses require sample dissolution by fusion or acid digestion techniques.

The papers cited above generally agreed that the ash consisted of 60 per cent to 65 per cent silicon-containing compounds expressed as SiO₂. It is important to note that this is not free crystalline silica; most of this SiO₂ represents silicates in the form of complexes with aluminum, iron, calcium, and/or magnesium, or other cations in the ash. Volcanic ash with this amount of SiO₂ is classified as dacite. Comparing the ashes from the May 18, May 25, June 12, July 22, and August 7 eruptions of Mount St. Helens showed that no obvious trends developed and little difference was observed in their compositions.¹⁵

Water-Soluble Constituents from Mount St. Helens Ash

Immediately after the May 18 eruption of Mount St. Helens, public health agencies questioned whether the ash contained any soluble toxic cations or anions, primarily heavy metals, fluorides, and/or chlorides. These concerns related to earlier documentation from the Icelandic volcano, Hekla, which erupted in 1947 through 1948 and again in 1970. Ash from Hekla was found to contain large amounts of leachable fluorides causing fluorosis in farm animals and sheep.¹⁶⁻¹⁸

The concentration of fluorides in Mount St. Helens ash was considerably lower than that observed in ash samples from the Icelandic volcano.¹⁹ Concentrations of leachable fluorides in solution from Mount St. Helens ash ranged from 0.56 to 0.94 mg/l. These values were determined with a 10:1 water/ash ratio. These solution values were indicative of leachable fluoride concentrations in the dry ash of 5.6 to 9.4 ppm, which compared well with those values determined by Taves.²⁰ The study by Taves also revealed that most of the fluoride associated with the ash was not biologically available and that the smaller particle size fraction had significantly higher concentrations of fluoride. This trend was observed by Fruchter, *et al*, for chlorides, nitrates, and sulfates.⁶ These data imply that the ash may have acted as nucleation sites for the adsorption of gaseous precursors of these constituents.

Many observers reported that the ash was mildly corrosive to metal surfaces; however, equilibrium pH values in solutions of bulk ash ranged from 5.5 to 6.8.^{6,20} It has been postulated that the surface of the ash particles may have been acidic as a result of nitric, hydrochloric, hydrofluoric, and/or sulfuric acid condensate. With the addition of significant amounts of water, a rapid reaction may have occurred with constituents in the bulk ash neutralizing the surface acids.

Another concern was determining possible long-term effects of leachable elements from the volcanic ash on drinking water quality, fisheries, and the aquatic environment. Two studies determined that the leachable elements associated with the ash should not present any unusual biological hazards to the ecosystem impacted by ash fall.^{6,21} Table 1 contains a comparison of the US Environmental Protection Agency drinking water limits with the average concentration of numerous metals from a 10:1 water/volcanic ash slurry solution.

Leachable elements were determined in these studies by

TABLE 1—Comparison of Selected Components in Volcanic Ash Leachate Solutions to USEPA Drinking Water Standards

	10:1 Water/Ash Leachate from May 18, 1980 Ash ^(a)	EPA Drinking Water Standard ^(b)
	(ppm)	(ppm)
F ⁻	0.64 ± 0.20	1.4 - 2.4 ^(c)
NO ₃ ⁻	1.94 ± 1.47	10.0
As	<0.3	0.05
Cd	<0.01	0.01
Cr	<0.01	0.05
Pb	<0.03	0.05
Hg	0.00002 ^(d)	0.002

(a) Mean and standard deviation from 6 sites located 98-644 km from Mt. St. Helens

(b) Code of Federal Regulations Title 40, 141.11 July 1, 1984

(c) Dependent on temperature

(d) Single sample analysis from Richland, Washington

either direct current plasma or inductively coupled argon plasma spectroscopy. Atomic absorption is a suitable alternative to these techniques. Ion chromatography or specific ion electrodes were used to determine F⁻, Cl⁻, SO₄²⁻, and NO₃⁻.

Particle Sizing

Particle sizing was used to separate the respirable (less than 10 μm) from the nonrespirable size fraction of the bulk ash. The respirable size fraction was then analyzed for free crystalline silica concentrations. Studies on Mount St. Helens ash have determined that greater than 90 per cent, by count, consisted of particles in the respirable size range.^{6,19} In general, the mean particle size diameter decreased with increasing distance from the volcano. However, the relative amounts of ash (by weight) in the 3.5-20-μm fractions remained relatively constant in samples collected from 98 to 644 km from Mount St. Helens.⁶

Particle size distribution in bulk sedimented Mount St. Helens ash was determined using two analytical methods: dry sieving in conjunction with aerodynamic particle size separation and scanning electron microscopy. The first method determines particle size distribution by weight and the latter by count or volume. In dry sieving, a series of Tyler Standard Screens are used to segregate the ash according to size. The final size fraction by dry sieving was limited to the less than 45 μm particle size. Further separation by aerodynamic particle fractionation techniques was required to collect the respirable size fraction.²² Size distribution by scanning electron microscopy was determined by quantitative image analysis. Profile measurements were made with a Quantimet. All data were normalized to compensate for different areas included at each magnification.⁶ In general, the analytical results from the dry sieving and electron microscopy agreed. Ninety per cent of the ash particles were smaller than 10 μm, and accounted for approximately 10 per cent of the total ash by weight.⁶

Morphology, Mineralogy, and Free Crystalline Silica

Morphology is the determination of the size and shape of volcanic ash particles. The morphology of the ash from the May 18 eruption of Mount St. Helens was determined using the method described by Heiken.²³ Samples were collected from 98 to 644 km downwind of Mount St. Helens and then analyzed. The ash consisted of material ranging from 0.5-mm

porous pumice to submicron-size fragments of glasses, plagioclase, and magnetite.⁶ Ash from the premagmatic stages of eruption (March 19 to May 14, 1980) were studied by Sarna-Wojcicki, *et al.*¹ Sarna-Wojcicki also performed similar analyses of ash from the May 25, June 12, July 22, and August 7 eruptions.^{15,24}

The importance of morphology to the public health officials is related to the presence or absence of respirable-size fibrous minerals and the quantity of respirable-size free silica in the bulk ash. Although fibrous minerals were not a significant problem in ash from Mount St. Helens, electron microscopic examination of several ash samples submitted to the National Institute of Safety and Health (NIOSH) by the US Department of Agriculture (USDA) from the 1982 eruption of El Chichón tentatively identified the presence of fibrous minerals (aspect ratios of 5:1 to 15:1). Apparently, the ash samples were collected near a road that may have been contaminated by asbestos from automobile brake linings (personal communication from R. S. Bernstein, NIOSH). At the request of NIOSH and USDA, Battelle-Northwest scanned numerous ash samples collected subsequently from varying distances downwind of El Chichón and found no fibrous minerals. The concern for the presence of fibrous minerals in volcanic ash relates to the potential carcinogenicity of this material to humans when inhaled. This effect appears to be caused in part by the size, shape, and biological persistence of the particle, not necessarily the type of material constituting the particle in the lung.²⁵ This example of possible contamination of sedimented volcanic ash with commercial asbestos exemplifies the importance of collecting pristine ash samples and documenting where the sample was collected.

The mineralogy of Mount St. Helens ash was determined by using optical microscopy, scanning electron microscopy with energy-dispersive x-ray (SEM/EDX), and x-ray diffraction (XRD).^{4,6,10} Generally, the ash contained varying quantities of plagioclase feldspar (andesine), orthopyroxene (hypersthene), titanium-bearing magnetite, glass, and trace quantities of hornblende and biotite. Samples of ash collected from eastern Washington (Spokane and Pullman) and western Montana (Missoula) contained approximately 80 per cent glass, with the remaining 20 per cent consisting of feldspar and pyroxene.⁶

Free crystalline silica in volcanic ash is directly related to the chemical composition of the volcanic magma from which it is derived. However, crystalline silica particles provide little information to the volcanologist or geologist, regardless of the size distribution of the particles, because they reveal few of the characteristics of the volcano or its eruption. Before the eruption of Mount St. Helens, there was little interest in the respirable free crystalline silica content of volcanic ash. Until questions were raised by public health officials about the potential for chronic ash inhalation to cause silicosis (see chapter 6), little interest was expressed by the geological community.

Radioactivity in the Ash

There is radioactivity associated with all terrestrial matter. Four of the most common radioactive isotopes present in geologic material are ⁴⁰K, ²³⁸U, ²²⁶Ra, and ²³²Th (primordial radionuclides). Concentrations of ⁴⁰K, ²²⁶Ra, and ²³²Th in the bulk ash from the May 18 eruption ranged from 6.06 to 10.3 pCi/g, 0.314 to 0.552 pCi/g, and 0.067 to 0.116 pCi/g, respectively.^{6,26} When ²²⁶Ra decays, a transition occurs from a solid to a noble gas, ²²²Rn (radon). Average

concentrations of radon in marine air range from 0.5 to 1.0 pCi/l. However, in the Colorado Plateau region of the United States where considerable mining operations for uranium take place, radon concentrations of 4 to 5 pCi/l have been measured in ambient air. The half-life of ²²²Rn is 3.8 days. It decays through a series of short-lived alpha-emitting "daughters" to ²¹⁰Pb, an isotope with a relatively long half-life of 22 years. The first daughter of radon is ²¹⁸Po, a solid; the transition involves an alpha decay that leaves the ²¹⁸Po atom charged for a very short time. It is during this period that the polonium has great affinity for any particles in air and will ultimately attach itself to that particle. Any further decay of the polonium generally occurs while attached to the particle surface of the successive radon daughters, ²¹⁴Pb, ²¹⁴Bi, ²¹⁴Po, and ²¹⁰Pb.

During the ashfall immediately after the May 18, 1980 eruption of Mount St. Helens, the presence of radon daughters was detected on the ash using a Ge(Li) gamma ray detector.⁶ At that time, there was some uncertainty as to the source of these radon daughters. Two hypotheses were advanced. One was that the volcano emitted considerable radon into the ash plume, whereupon the particulate attached ²¹⁸Po subsequently decayed to other short-lived radon daughters. The second involved the scavenging of atmospheric radon daughter particles by the ash particles which carried a static charge as evidenced by numerous reports of lightning discharge in the ash cloud. To test the theory that excess radon was emitted by the volcano, two experiments were performed. A high-altitude flight by a WB-57 aircraft was used to sample the volcanic ash cloud 50 and 75 hours after the May 18 eruption.^{8,27} These findings indicated that only one out of eight air samples collected contained radon levels slightly above background concentrations. A second experiment found that the plume was not enriched in ²¹⁰Pb, which would be expected if large quantities of radon were emitted from Mount St. Helens. Thus, it was ultimately concluded that the radon daughters on the ash were scavenged from the air column by the falling ash.

Volatile Volcanic Emissions

The most common magmatic volatile outgassed by volcanoes is water, often comprising 90 per cent or more of the total volatile phase. This is closely followed by CO₂ with lesser quantities of H₂S, SO₂, volatile inorganics (e.g., HCl, HF, Hg, and As) CO, H₂, He, radon, and volatile organics (e.g., halogenated hydrocarbons, CH₃X X=F,Cl,Br,I). Many of these gases are of particular concern around shield-type volcanoes (e.g., those in Hawaii and Nicaragua). Sampling techniques for volcanic gases at these types of volcanoes can be found in articles written by Greenland,²⁸ Gerlach,²⁹ and Giggenbach.³⁰ However, Mount St. Helens required a different approach because of its tendency to erupt violently and propel volcanic gases high above the "stack" height of the crater. This type of behavior rarely results in ground level fumigation by volcanic products. However, in some cases, if the gas accompanies a pyroclastic flow or surge, significant ground level fumigation can occur.

In general, most gas sampling around Mount St. Helens required the use of aircraft.^{6,31-34} Typical sampling procedures call for collecting the sample in stainless steel cylinders, gas collection bottles, plastic or Teflon bags, or cryogenic collectors. These types of samples (grab samples) measure parameters only for that discrete time and location. To obtain integrated values, numerous samples or sampling with real-time instruments (continuously) is required. After

collecting the grab samples, various analytical techniques can be used for analyses. Usually gas chromatography is used with a variety of column packing materials to separate out particular components of a complex gas mixture. These columns can be coupled to a wide selection of detectors: flame ionization (for hydrocarbons), flame photometric (for sulfur containing compounds), electron capture (for halogen containing compounds), photoionization, or a mass spectrometer.^{28,31-34}

Additional results of papers concerning the volatile products of Mount St. Helens eruption included the observation that ash from the May 18 eruption outgassed large amounts of carbonyl sulfide (COS) and carbon disulfide (CS₂) upon standing at room temperature. These findings suggest that the sulfates in the stratosphere may be carried directly to the upper atmosphere as carbonyl sulfide or carbon disulfide.³¹ In a publication by Hobbs, *et al*, H₂S concentrations on May 19 were reported to be approximately 0.5 ppm.³³ This agrees well with the 0.5-ppm value found by Fruchter, *et al*.⁶ Hobbs also reported that on a single occasion after the third violent eruption (June 13), NO₂ concentrations approached 400 ppb, 8 km downwind of Mount St. Helens.

A very extensive sampling and analytical program for trace gases was undertaken by Cronn and Nutagul.³⁴ More than 50 whole-air samples were collected in numerous plumes from Mount St. Helens from March through June 1980. Four research aircraft were used to collect samples, which were analyzed by five analytical methods for 14 trace gases. They concluded that COS, CS₂, CH₃Cl, CO₂, CO, N₂O, C₂H₆, and C₂H₂ were found in elevated amounts in the volcanic plume gases. Carbonyl sulfide was determined to be a substantial fraction of the sulfur-containing gases during the May 18 eruption, although SO₂ and H₂S still predominated. A publication by Pereira, *et al*, reported the presence of several polycyclic aromatic hydrocarbons in the methylated extract of ash from the May 18 eruption collected in Richland, Washington.³⁵ These compounds were phenanthrene derivatives. The most probable source is from pyrolysis of plant materials because of the presence of fatty acids, dicarboxylic acids, phenolic acids, and aromatic aldehydes.^{36,37}

Through sampling, analyzing, and reviewing the data, these volatile species were determined to be of no major toxicological concern to the general population around Mount St. Helens. However, it is important that these facets be considered by the public health community after each volcanic eruption to properly assess possible hazardous effects to the general population.

Unanswered Analytical Questions

A major problem that still remains unsolved is that of a method to analyze free crystalline silica in a matrix of amorphous silicates on small, personal-dosimeter, air filter samples. During the sampling period, in the breathing zone of exposed individuals, a filter may accumulate a few milligrams of total material. If 5 per cent of this material is crystalline silica, this will result in only micrograms of free silica. These quantities of crystalline silica are very difficult to determine accurately by any method currently available to the scientific community. Development of a valid and reliable method for analyzing low-level concentrations of free silica in personal air-samples contaminated with non-toxic silicates would also be useful for industrial hygiene and regulatory monitoring in industries such as mining, smelting, quarrying, and road construction.

Interaction of the Physical Scientist with the Public Health Community

Immediately after the eruption of Mount St. Helens, many decisions and subsequent public health announcements were made based on the toxicity of the volcanic ash as assessed by physical scientists. Some of these decisions were based on inaccurate scientific information, resulting in conflicting recommendations for the protection of the health and safety of the general populace. The prime example of this was the controversy concerning the concentration of respirable-size crystalline silica in the ash. In this situation, no standard methods had been specified for analysis of crystalline silica in the volcanic ash so that geologists and environmental health scientists, using their respective routine methods of analysis, were in apparent conflict over the presence and quantity of this toxicant in the ash. This confusion clearly did not reassure the general public immediately after the eruption. In retrospect, it is obvious that the laboratory methods used by physical scientists (e.g., geologists) to assess the composition and nature of the volcanic products must be guided by the public health community and its concern over the ways in which such products may adversely affect human health.

To prevent such confusion from recurring, we must document the reasons for shortcomings encountered during this episode. In areas where premonitory volcanic activity occurs, it is important to understand the characteristics and the history of this volcanic activity. For example, the public health community in Hawaii need not be concerned with the dispersion of volcanic ash or crystalline silica; however, they must be concerned with increasing H₂S and SO₂ gas emissions and lava flow during episodic eruptions. The history of Mount St. Helens and other volcanoes in the Cascade Range clearly demonstrates their potential for explosive volcanic eruptions.³⁸ Similar documentation is available for most volcanic regions in the "Ring of Fire" around the Pacific and in other volcanic hot spots. To prepare for a possible eruption, it would be wise to identify possible human and technical resources that can be relied on to provide technical guidance concerning seismic and other hazards. Prime sources are local universities or government agencies (as was the case with the May 18, 1980 eruption of Mount St. Helens).

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