Mount St. Helens and a Climate Quandary

Researchers sorting out the effects, if any, of volcanoes on long-term climate are consulting glacial ice for guidance

To most scientists, the 18 May eruption of Mount St. Helens was a scientific bonanza. To those hoping to study the link between volcanoes and climate firsthand, it was "a real dud." Mount St. Helens just did not have what it takes to thicken the light haze in the stratosphere enough, block a little more sunlight, and thus cool the air near the ground. Other volcanoes that were about as powerful and threw about as much fine ash into the stratosphere have noticeably cooled the climate of the entire globe, but little or no detectable effect is expected after the 18 May eruption of Mount St. Helens.

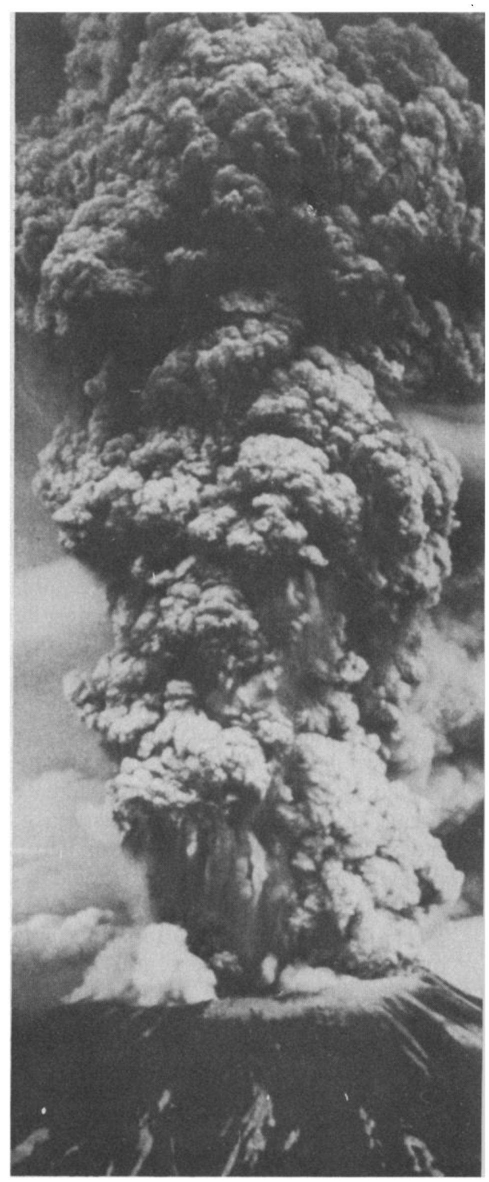
Mount St. Helens' shortcomings as a perturber of climate are apparently due more to its small production of sulfurous gases than to the amount of dust that it could throw into the stratosphere. It is these gases, when converted into droplets of sulfuric acid in the stratosphere, that would block sunlight and cool the lower atmosphere. Such a cooling of the atmosphere has been observed to persist a few years after a number of large eruptions, but some researchers believe that climatic cooling has lasted for decades and even centuries during periods of exceptionally high volcanic activity. Many of their colleagues politely disagree.

If anyone hopes to ever prove that volcanoes can cause the atmosphere to remain cooler for decades and not just a few years after an eruption, they will probably have to estimate the amount of sulfur injected into the stratosphere over the past centuries. At a recent meeting* in Washington, D.C., volcanologists warned their climatologist colleagues that no amount of study at the sites of long past eruptions will provide that kind of information. But help may be coming. Recent work suggests that glaciers have preserved for thousands of years a record of the size and frequency of volcanic eruptions measured in terms of the sulfur they produced.

By most measures, the 18 May eruption of Mount St. Helens, a lateral blast followed for 9 hours by a towering eruption plume, was sizable though not among the largest of eruptions. In all, the mountain lost 2.7 cubic kilometers of rock from its cone, according to an estimate made from aerial photographs by James Moore of the U.S. Geological Survey (USGS) in Menlo Park, California. Fine ash equivalent to about 0.2 cubic kilometer of solid rock settled from the plume on three states to the east of the mountain, according to A. M. Sarna-Wojcicki of the USGS in Menlo Park. William Rose of the Michigan Technological University in Houghton suspects that an equal amount of ash may have lightly dusted a larger area of the central United States beyond the fallout zone considered by Sarna-Wojcicki. Such ash volumes are similar to those produced during the 1963 eruption of Agung in Indonesia, according to Stephen Self of the University of Arizona. Agung, most researchers agree, was the last eruption to have a significant effect on the global climate, reducing the mean temperature about 0.2°C for 1 to 2 years.

Mount St. Helens, like Agung, not only produced a significant amount of ash but was powerful enough to carry large amounts of it into the stratosphere. Reaching those high altitudes is important because ash that does not reach the relatively tranquil stratosphere can be rapidly washed out of the atmosphere by precipitation. Mount St. Helens' billowing plume of hot gases and ash broke through the bottom of the stratosphere 9 kilometers above the mountaintop and rose another 10 kilometers into the thin, cloud-free air. No one directly measured the amount of volcanic debris that entered the stratosphere, but Murray Mitchell of the National Oceanic and Atmospheric Administration in Silver Spring, Maryland, guesses that the amount reached about 5 metric tons. That would be about one-half the mass injected by Agung and about one-tenth that of Krakatau in 1883, he says.

Despite this respectable size, the 18 May eruption has had only a minor effect on the stratosphere. In contrast to the relatively large amount of material carried into the stratosphere, a disproportionately small amount has stayed there long enough to have any effect at all on climate. Patrick McCormick of the National Aeronautics and Space Administration's (NASA's) Langley Research Center, Hampton, Virginia, reported at the Washington meeting that the mass of stratospheric aerosol, the submicron particles making up the haze, more than doubled in the Northern Hemisphere after the eruption. But that doubling amounted to only 0.44 or 0.64 million



Austin Post, U.S. Geological Survey

*Symposium on Mount St. Helens Eruption: Its Atmospheric Effects and Potential Climatic Impact, Washington, D.C., 18-19 November 1980, sponsored by the National Aeronautics and Space Administration.

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tons, depending on the assumptions McCormick made in his calculations. He arrived at these figures by compiling ground-based and airborne observations from around the world made by light detection and ranging systems (LIDAR). These are instruments that determine the altitude and concentration of particles on the basis of the way that they scatter the light of a laser.

Geoffrey Kent of the Institute for Atmospheric Optics and Remote Sensing in Hampton reported that the Stratospheric Aerosol and Gas Experiment (SAGE) satellite observed similar increases (0.28 to 0.39 million tons). Orbiting once every 1.5 hours, this satellite measures the attenuation of sunlight after it passes through the upper atmosphere during about 30 sunrises and sunsets each 24-hour day.

A fraction of a million tons of material lingering in the stratosphere, it seems, is not enough to block much sunlight and cool the climate. Estimates of the long-term increase in stratospheric aerosols after the Agung eruption vary between 10 and 30 million tons, at least 20 times more than after the Mount St. Helens eruption. Whereas Agung lowered the mean temperature a few tenths of a degree, Mount St. Helens could probably lower the mean by only a few hundredths of a degree, Mitchell estimates.

The explanation for this large difference in the effects on climate, despite comparable injections of ash, is that most volcanic dust falls out of the stratosphere too quickly to cool the entire globe. Within the past few years, researchers have realized that the strongest link between volcanoes and climate change is not always dry, dusty ash; rather, it is often an aerosol of submicron droplets of concentrated sulfuric acid derived from sulfurous volcanic gases. While most of the ash is rapidly falling out of the stratosphere, the accompanying sulfur dioxide and other sulfur-containing gases are converted into sulfuric acid droplets small enough to stay in the stratosphere for years. This conversion is slow enough to prolong the effect of the additional aerosol beyond the time required for a droplet to be removed naturally.

What is needed, Mitchell says, are data that take into account the conversion of sulfur gases into acid aerosol.

Atmospheric scientists watched this conversion of gases into particles as the debris from Mount St. Helens began to circle the world. The SAGE satellite detected about four times as much new aerosol over the Northern Hemisphere in August as it did in late May, Kent notes. The most likely explanation, he says, is that gases already in the atmosphere in late May produced the new aerosols seen in August. McCormick says that researchers using LIDAR saw a change within the first month in the light-scattering characteristics of stratospheric material. That change would be consistent with a shift from an aerosol dominated by relatively large, ashlike particles to one consisting of small, liquid particles, he says. James Rosen of the University of Wyoming found on the basis of particle size alone that the shift from ash to acid over Wyoming may have occurred within a few days.

Once worldwide observations became available, it was obvious that Mount St. Helens had been a minor source of gaseous sulfur in the stratosphere. The eruption had been energetic, but the magma that erupted as ash had contained a relatively small concentration of sulfur, according to analyses of magmatic glass by William Melson of the Smithsonian Institution. Self suggests that Agung achieved its greater effect on the stratosphere, and thus climate, because its eruption happened to be both powerful and rich in sulfur. The usual trend, he notes, is for more sulfurous magmas to produce less powerful, less explosive eruptions. Agung seems to have struck a balance between the amount of sulfur available and its ability to carry it into the stratosphere so that the climatic effect was maximized. Rose adds that the amount of sulfur released during an eruption may also depend on the amount of magma that gives up its sulfur as gas but is never erupted from the volcano.

A researcher wishing to study the connection between past volcanic eruptions and climate thus faces a quandary. He knows that sulfur in the form of acid droplets, not ash, often has the greatest effect on climate, yet estimates of sulfur output during past eruptions are even

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Ancient Cut Marks Reveal Work of Prehuman Hands

Fossil bones on archeological sites have long been regarded as important but frustratingly mute evidence of early human activity. But it turns out that petrified bones as old as 2 million years bear previously unnoticed telltale signs of the use of stone tools.

Working with a selection of fossils from Olduvai Gorge in Tanzania, Patricia Shipman of Johns Hopkins University and Richard Potts of Harvard have developed an electron microscopic technique that clearly reveals the shallow cut marks in the surface of fossil bone that were made by the edge of a stone flake wielded by prehuman hands.

Alan Walker, of Johns Hopkins University, reported the preliminary results from Shipman and Potts's work. He said, "some of the marks on fossil bones were made by carnivores, and these appear as long smooth U-shaped valleys under the electron microscope." The marks made by stone flakes are distinctive, however, because "running along the bottom of the valleys are sets of 'tram-lines' that were made by the many jagged facets on the edge of the flake."

Shipman and Potts have submitted a paper to *Nature* on this intriguing new discovery, as has Henry Bunn who works with Glynn Isaac at Berkeley. "Henry Bunn has detected distinct marks of tool use on a 1.5-million-year-old pygmy hippo bone from East Turkana in Kenya," reported Isaac, leader of the archeology work in the area. "This is an important extension of archeological sites," he claimed, "because if we find cut marks on bones that are not directly associated with stone tools we still have a clear indication of prehuman activity that wasn't previously available."

The discovery of this new evidenc of early human tool use initiated wh one worker called "cut mark fever Researchers began looking for, ar finding, cut marks on all kinds of fossi bones. The work is still in its early stages, but it is already giving a profitable new perspective through the archeological window. "Shipman and

The American Association for the Advancement of Science held its annual meeting from 3 to 8 January in Toronto.

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poorer than those of ash. Over recent decades, measurements of the amount of sunlight reaching the ground give some idea of the varying concentrations of stratospheric aerosols. Before about 50 years ago, such observations become sparse and less reliable. For those times, eruptions have been classified on the basis of their reported violence, estimated ash volumes, and visual effects on the sky. A widely referenced measure of volcanic inputs to the stratosphere, the dust veil index, even includes apparent climatic coolings as a measure of the volcanic "dust" that persisted in the stratosphere after a known eruption. Such questionable approaches, Mitchell says, are typical of "all the incredible uncertainties involved in estimating volcanic loadings." What is needed, he says, are data that take into account the conversion of sulfur gases in the stratosphere into acid aerosol.

Researchers are hopeful that samples taken from deep within great glaciers will provide that kind of information. In the course of the most recently reported study of deep ice cores,† C. U. Hammer, H. B. Clausen, and Willi Dansgaard of the University of Copenhagen measured the changes in the conductivity of the ice along a 404-meter-long core from Crête in central Greenland. Conductivity, they found, is a measure of the amount of acid in the ice. The amount of acid in an annual layer of ice, which can be dated with an uncertainty of only 1 to 3 years back to A.D. 553, seems to depend on the amount of acid-producing sulfur injected into the atmosphere that year by distant volcanoes. The major known eruptions north of 20°S, such as those of Agung (1963), Katmai (1912), Krakatau (1883), and Tambora (1815), appear as sharp spikes of acidity as far back as the Eldgja eruption of A.D. 934 (± 2 years) in Iceland. Between known eruptions, acidity varies from year to year as well as over periods of centuries. A similarly analyzed 1390-meter core from Camp Century in northwest Greenland recorded major eruptions back to 10,000 years ago, including one identified as the 4400 B.C. eruption that destroyed Mount Mazama and created Crater Lake in Oregon.

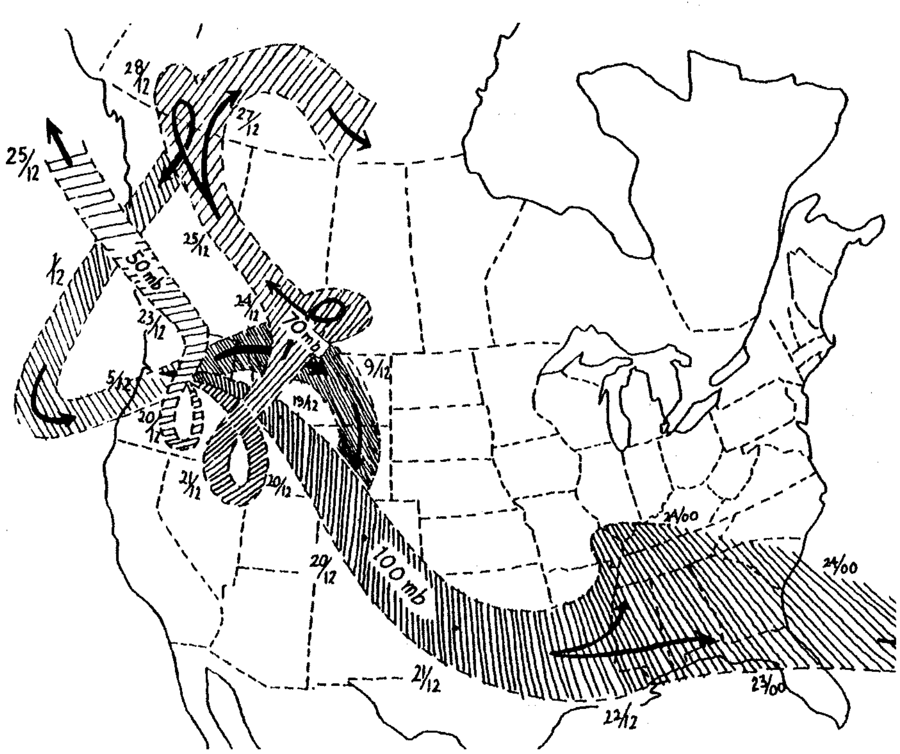
†*Nature* **288**, 230 (1980).

The Danish group attempted to "roughly estimate" the amount of acid that fell to the ground over the entire globe from a single eruption by using the amounts that fell in central Greenland. Because the latter amount would depend on the latitude of the eruption relative to the latitude of Greenland, they used the observed patterns of fallout from appropriately located atmospheric nuclear weapons tests to calibrate the Greenland record. The 1815 eruption of Tambora, the proposed cause of New England's "year without a summer," weighed in at 150 million tons of acid, Krakatau at 55 million tons, and Agung at 20 million tons. These estimates "could easily be wrong by a factor of 2," they say.

Although both volcanologists and those studying ice cores are encouraged by these and other early results, they echo the reservations of the Danish group about the present reliability of acid production estimates. One problem, the Danes point out, is that the acid is not always perfectly preserved in the ice. Soil dust containing carbonate minerals can neutralize all or part of the acid and under some conditions the acid generated by atmospheric carbon dioxide can also alter the ice record. The record also varies from place to place, Lonnie Thompson of Ohio State University points out. All cores taken from the same region will record the major events, but they may differ in details, he says. And modest, nearby eruptions can appear as massive as a large, distant one because some of the acid will travel through the lower atmosphere as well as the stratosphere.

Most of these problems appear to be surmountable. The key, Thompson believes, will be the analysis of numerous cores from both hemispheres—Arctic and Antarctic regions as well as isolated glacial ice closer to the equator. Analysis of both acidity and the accompanying insoluble particles, some of which are volcanic, should help distinguish between acid from nearby eruptions and truly global fallout, he says. Once those kinds of studies are made, researchers who see a link between volcanoes and long-term climate change may have a good chance of finally settling the question.

—RICHARD A. KERR



Dispersal of Mount St. Helens debris in the stratosphere

Trajectories for air masses that were at various altitudes over Mount St. Helens on the morning of 18 May 1980, as calculated by Edwin Danielsen of NASA's Ames Research Center. Air at about 16 kilometers above sea level (100 millibars—"100 mb" on the map—of atmospheric pressure) moved steadily toward the southeast. At 20 kilometers (50 mb), the debris drifted southward, then came back and headed to the northwest. LIDAR and SAGE satellite observations followed material above 20 kilometers to the west during a complete circuit of the globe, the reverse of the path followed below the stratosphere. The complex meanderings at about 18 kilometers (70 mb)—looping to the southeast, then to the northeast, splitting over northwest Canada, swooping back over the mountain from the west by 5 June, and then approaching Wyoming from the north after 9 June—resulted from a temporary stagnation at that level of the stratosphere that occurs each year. The calculation of this trajectory from weather observations was prompted by University of Wyoming researcher James Rosen's detection of anomalously high aerosol concentrations at 18 kilometers over Wyoming at a time when Mount St. Helens debris was not expected. Labels are day/hour in Universal Time. [*Source: Edwin Danielsen*]