UNITED STATES
DEPARTMENT
OF THE
INTERIOR
GEOLOGICAL
SURVEY

Earthquake Information Bulletin

March–April 1984, Volume 16, Number 2

UNITED STATES DEPARTMENT OF THE INTERIOR
William P. Clark, Secretary

GEOLOGICAL SURVEY
Dallas L. Peck, Director

EARTHQUAKE INFORMATION BULLETIN is published bimonthly by the U.S. Geological Survey to provide current information on earthquakes and seismologic, volcanologic, and related activities of interest to both general and specialized readers. The Secretary of the Interior has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this Department. Use of funds for printing this periodical has been approved by the Director of the Office of Management and Budget through June 30, 1987.

Henry Spall—Editor

Earthquake Information Bulletin
U.S. Geological Survey
904 National Center
Reston, VA 22092
Telephone (703) 860-6575

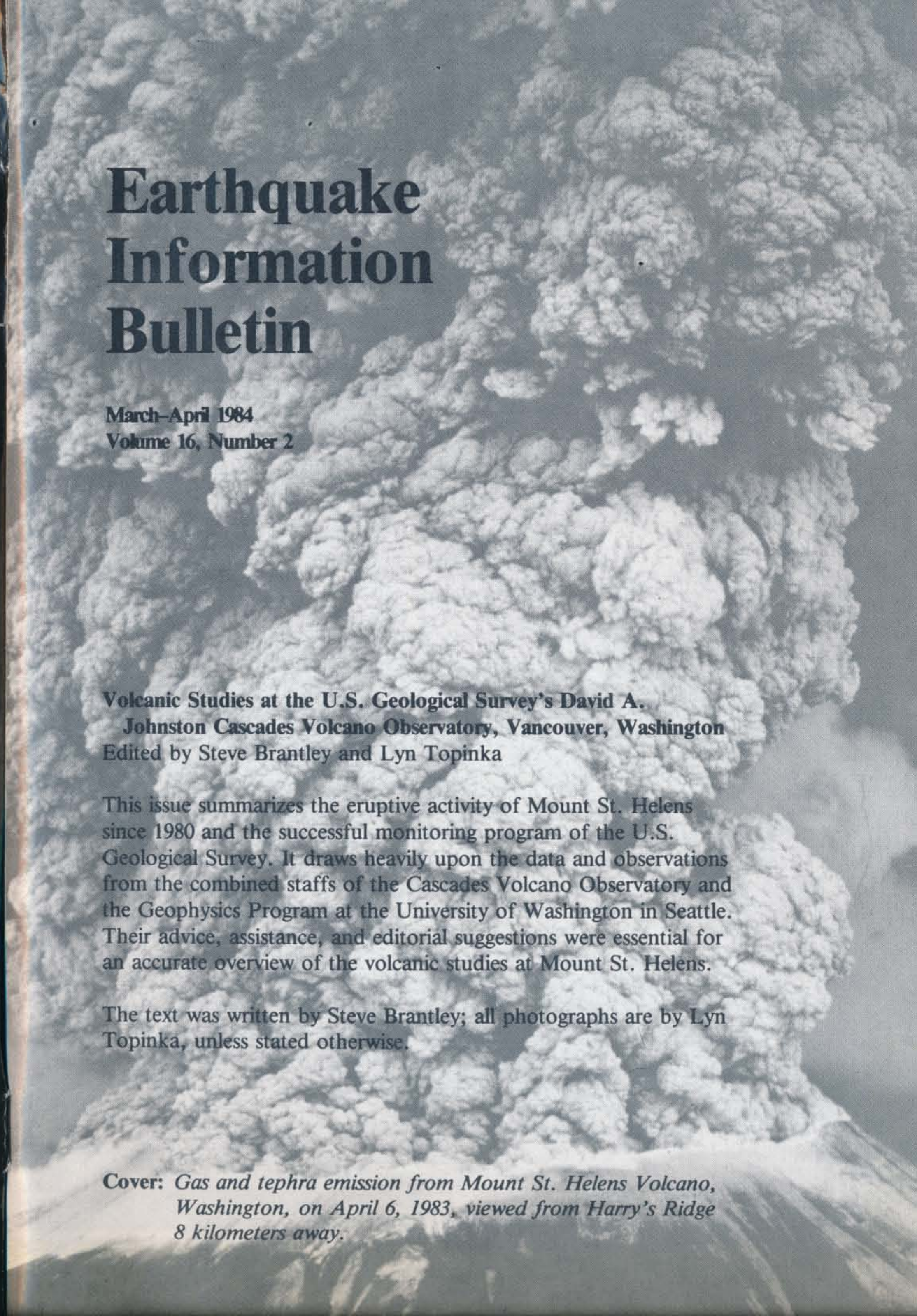
Janet Somerville Sachs—Managing Editor
Scotty Livingston—Art Editor

Subscription orders and changes of address for these should be sent to:

Superintendent of Documents
U.S. Government Printing Office
Washington, D.C. 20402
Telephone (202) 783-3238

For sale by the Superintendent of Documents. Annual subscription rate—$14.00 (domestic) and $17.50 (foreign). Make check or money order payable to the Superintendent of Documents.

Single copy rate—$4.25 (domestic) and $5.35 (foreign). Single copy rate for issues prior to Volume 15, Number 1—$2.25 (domestic) and $2.85 (foreign). Can be purchased from Branch of Distribution, Text Products Section, U.S. Geological Survey, 604 South Pickett Street, Alexandria, VA 22202 (make check or money order payable to the U.S. Geological Survey) or from the Superintendent of Documents (make check or money order payable to the Superintendent of Documents).



Earthquake Information Bulletin

March–April 1984
Volume 16, Number 2

Volcanic Studies at the U.S. Geological Survey's David A. Johnston Cascades Volcano Observatory, Vancouver, Washington
Edited by Steve Brantley and Lyn Topinka

This issue summarizes the eruptive activity of Mount St. Helens since 1980 and the successful monitoring program of the U.S. Geological Survey. It draws heavily upon the data and observations from the combined staffs of the Cascades Volcano Observatory and the Geophysics Program at the University of Washington in Seattle. Their advice, assistance, and editorial suggestions were essential for an accurate overview of the volcanic studies at Mount St. Helens.

The text was written by Steve Brantley; all photographs are by Lyn Topinka, unless stated otherwise.

Cover: *Gas and tephra emission from Mount St. Helens Volcano, Washington, on April 6, 1983, viewed from Harry's Ridge 8 kilometers away.*

Volcanic Studies at the David A. Johnston Cascades Volcano Observatory

Mount St. Helens volcano in southwest Washington transformed one of the most scenic alpine landscapes of the Cascades Range into a gray, barren wasteland in only a few minutes. A catastrophic landslide and explosive eruption on May 18, 1980, devastated 550 square kilometers of forest, sent damaging mudflows down rivers draining the volcano, and produced ash fallout hundreds of kilometers to the east. Four years after the volcano's reawakening, Mount St. Helens remains active, and the devastated landscape wrought by the May 18 eruption continues to pose flood hazards to communities downstream from the volcano.

Sixteen subsequent eruptions have taken place in the horseshoe-shaped crater formed by the May 18 eruption. No large explosive event has occurred since October 1980. The last 11 eruptions have built a lava dome to a height of 240 meters by the slow intru-

Mount St. Helens crater with its lava dome and the aftermath of a small gas and tephra emission as viewed from Spirit Lake, 2 years and 1 day after the May 18, 1980, blast. Road 100 flanks Spirit Lake on the left, and Harry's Ridge flanks it on the right. Both ridges were denuded of trees by the May 18 blast. Remains of logs are still floating in Spirit Lake.

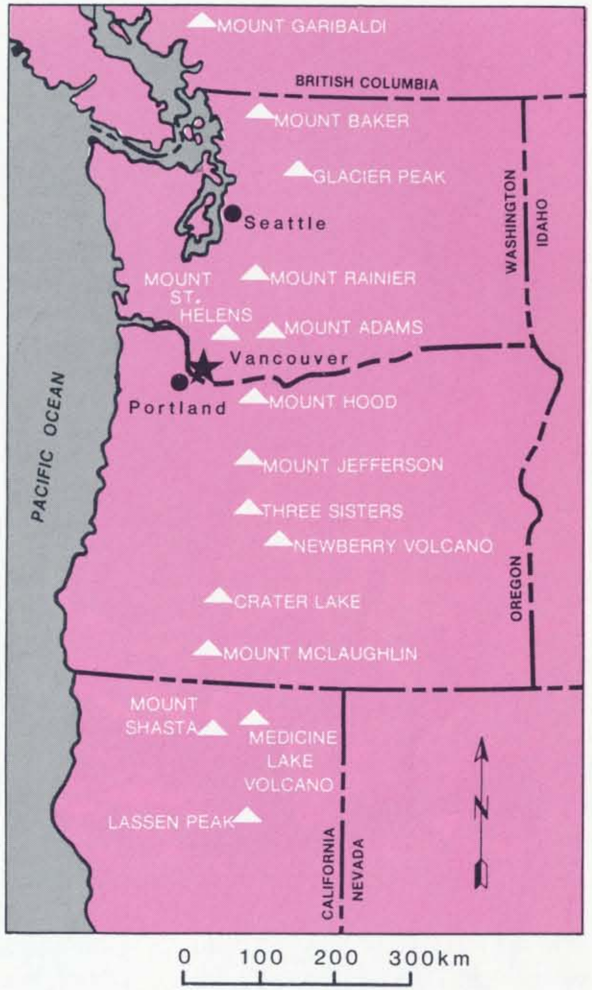
sion of magma into its interior and the extrusion of lava onto its surface; the most recent eruption of March 29, 1984, added a new stubby lava flow to the top of the dome.

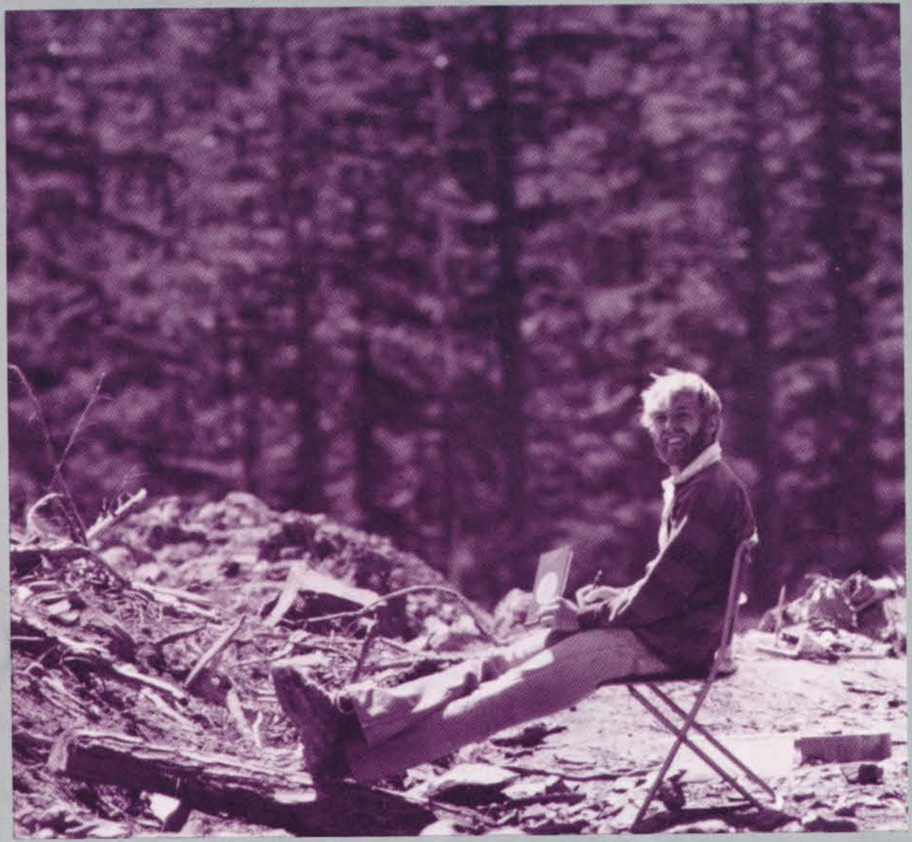
U.S. Geological Survey scientists at the David A. Johnston Cascades Volcano Observatory (CVO) in Vancouver, Washington, are studying the intermittent eruptive activity of Mount St. Helens and the hazards posed by the effects of the May 18 eruption. Many different monitoring techniques and instruments are used to record the "daily pulse" of the volcano to evaluate the chance of future eruptive activity and to investigate fundamental volcanic processes. Studies also are made of the river basins and the new lakes around the volcano and of the massive debris avalanche that slid off the mountain on May 18, 1980. These studies provide data needed to assess water-related hazards to downstream communities from increased sedimentation, erosion, and flooding along the Toutle and Cowlitz Rivers. Such hydrologic hazards likely will persist long after the decline of eruptive activity at Mount St. Helens.

CVO is supported by the Geological Survey's Volcano Hazards Program, which is responsible for providing warnings of volcanic eruptions and related hazards in the United States. Information and advice are given to Federal, State, and local officials concerning specific volcanic hazards and

Aerial view of Mount St. Helens crater, taken from rim height, April 15, 1983. To the north is Spirit Lake and Mount Rainier. The dome at the time of this photograph was approximately 230 meters high and 550 meters in diameter.

Cascades volcanoes in the Pacific Northwest.





David A. Johnston Cascades Volcano Observatory

On the morning of May 18, 1980, volcanologist David A. Johnston was alone at the Coldwater II observation station, 9 kilometers from the Mount St. Helens volcano. As one of the first members of the U.S. Geological Survey monitoring team to arrive at Mount St. Helens after the volcano's reawakening in March, Johnston was observing its activity when he was swept away by one of the most devastating explosive eruptions of modern history.

The U.S. Geological Survey officially dedicated the David A. Johnston Cascades Volcano Observatory in Vancouver, Washington, in 1982. The observatory serves as headquarters for more than 60 resident scientists, technicians, and support personnel from the Geologic and the Water Resources Divisions. CVO works closely with the Geophysics Program of the University of Washington in Seattle to maintain the seismic network around the volcano and to monitor earthquake activity. Scientists from around the world also visit the observatory to learn of its monitoring activities and of the eruptions at Mount St. Helens.

the implementation of emergency-response plans. Activities designed to inform people of volcanic hazards include research on volcanic processes, monitoring active and potentially hazardous volcanoes, and mapping the types and the extent of volcanic deposits of past eruptions.

The goal of the monitoring and research activities of CVO is to give timely warnings of eruptive and related hydrologic hazards at Mount St. Helens. Three types of written public statements about volcanic activity are issued by CVO to provide hazard information to the public and to governmental agencies:

- A *factual statement* describes current conditions of the volcano but does not anticipate future events; such statements are revised when warranted by new developments.
- A *forecast* is a comparatively nonspecific statement about volcanic activity to occur weeks to decades in advance. A forecast is based on projections of past eruptive activity or is used when monitoring data are not well understood. This kind of statement is particularly useful for land use planning and development of emergency response plans.
- A *prediction* is a comparatively specific statement giving place, time, nature, and, ideally, size of an impending eruption. Correct predictions were made of all 14 eruptions at Mount St. Helens from June 1980 to the end of 1982.

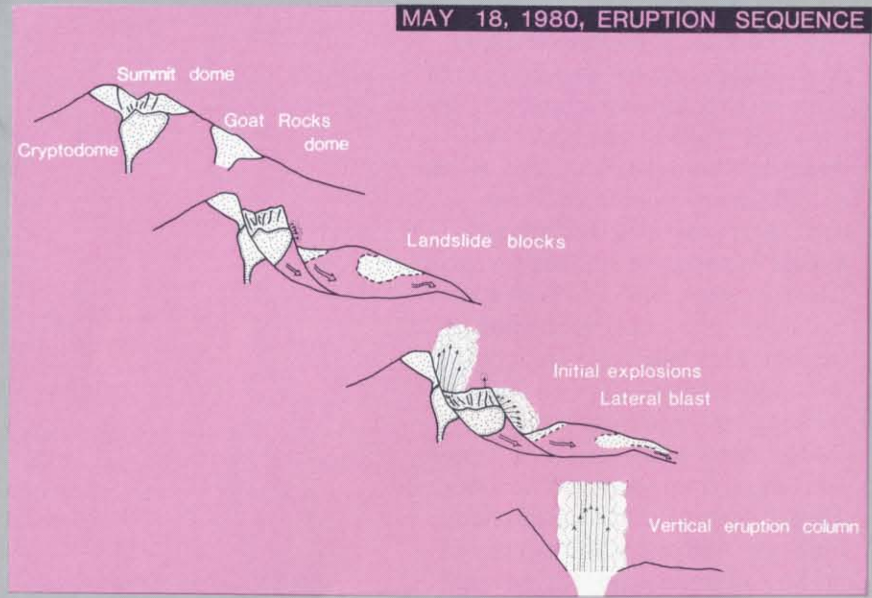
Water-related hazard information is provided to the National Weather Service and other Federal, State, and local agencies involved in flood mitigation planning.

Before and after; Mount St. Helens from Coldwater II on May 17, 1980, and on September 9, 1980. The Coldwater II instrument-observation station was located 9.2 kilometers north-northwest of Mount St. Helens. U.S. Geological Survey scientist David A. Johnston was manning the station on the morning of May 18, 1980, when the eruption devastated the area. The station was used for electronic distance meter measurements to the "bulge" and also as a site for time-lapse photography. (Photographs by Harry Glicken.)

Eruptive Activity of Mount St. Helens: March 1980 March 1984

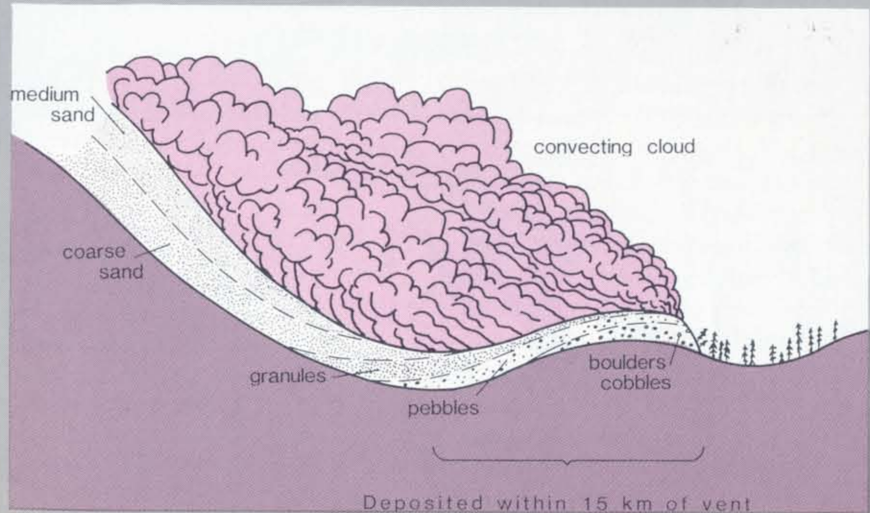
The present activity of Mount St. Helens began in March 1980. A magnitude 4.0 earthquake on March 20 was followed by 2 months of intense seismicity and phreatic "steam-blast" eruptions. These events accompanied the intrusion of viscous magma into the volcano, shoving the north flank outward more than 100 meters and creating the famous "bulge."

On May 18, a magnitude 5.1 earthquake shook loose the steepened north flank, resulting in the largest known landslide in historic time. Removal of 2.3 cubic kilometers of material released pressure on the hydrothermal and magmatic system within the volcano and triggered a devastating lateral blast to the north. Within minutes, an ash-laden eruptive column rose more than 20 kilometers above the volcano. Melting snow and ice formed mudflows and floods that raced down almost all the valleys draining the volcano. The largest and most destructive mudflow originated from water-saturated parts of the debris avalanche in the North Fork Toutle River Valley.



The sequence of events that followed a magnitude 5.1 earthquake on the morning of 18 May, 1980. A large landslide triggered a devastating lateral blast to the north which in turn exposed the eruptive vent that produced an eruptive column more than 20 kilometers above the volcano. The "bulge" formed on the north flank of the cone from the intrusion of magma into the volcano, creating a cryptodome (hidden dome).

The lateral blast sweeping northward from the volcano. The figure shows both the debris transported along the ground and the ash convecting upwards from the blast. It also gives a sense of the movement along the leading edge.



Mount St. Helens erupted explosively five more times during 1980. None of these eruptions were as large as the events on May 18, but each eruption produced ash columns that rose 8 to 14 kilometers above sea level and hot, dry pyroclastic flows of pumice and ash that swept down the north flank as fast as 100 kilometers per hour. These pyroclastic flows deposited ash and pumice fragments in fanlike patterns of sheets, tongues, and lobes in an area extending up to 8 kilometers north of the vent. Individual pyroclastic flow units were generally less than 5 meters thick, and maximum temperatures recorded several hours after their deposition ranged from about 300° to 730°C. The thickness of airfall deposits ranged from one-third to one-fortieth that of the May 18 airfall deposit at a given distance from the volcano.

U.S. Geological Survey scientist Pete Rowley sampling a day old pyroclastic flow near Mount St. Helens on October 17, 1980. Pyroclastic flows which are mixtures of hot gas, rock, and ash, were associated with the six major 1980 eruptions (May 18, May 25, June 12, July 22, August 7, and October 16–18). The flows on May 18, 1980, were the largest. (Photograph by Terry Leighley, Sandia Labs.)

Mount St. Helens Eruption Summary
Post-May 18, 1980

Date	Explosive activity	Pyroclastic flows	Dome-building activity
1980:			
May 25	X	X	
June 12	X	X	X
July 22		X	
August 7	X	X	X
October 16	X	X	X
December 27			X
1981:			
February 5			X
April 10			X
June 18			X
September 6			X
October 30			X
1982:			
March 19 (minor explosion, including mudflows)			X
May 14			X
August 18			X
1983:			
February 2 (minor explosions)			X
Continuous dome-building activity from February 1983 to February 1984			
1984:			
March 29			X

Lava extruded from the vent and formed lava domes within a few days after the June 12, August 7, and mid-October explosive eruptions. The June and August domes were blown away by subsequent explosive eruptions, but the October dome survived to form the core of the still-growing dome. Domes are formed by thick, pasty masses of lava too sticky to flow very far from the vent. Lava of the Mount St. Helens dome is dacite that contains a higher percentage of silica than the Hawaiian basalts and is about 1 million times more viscous.

Aerial view of the October 1980 dome, viewed from the northwest. (Photograph by Terry Leighley, Sandia Labs.)

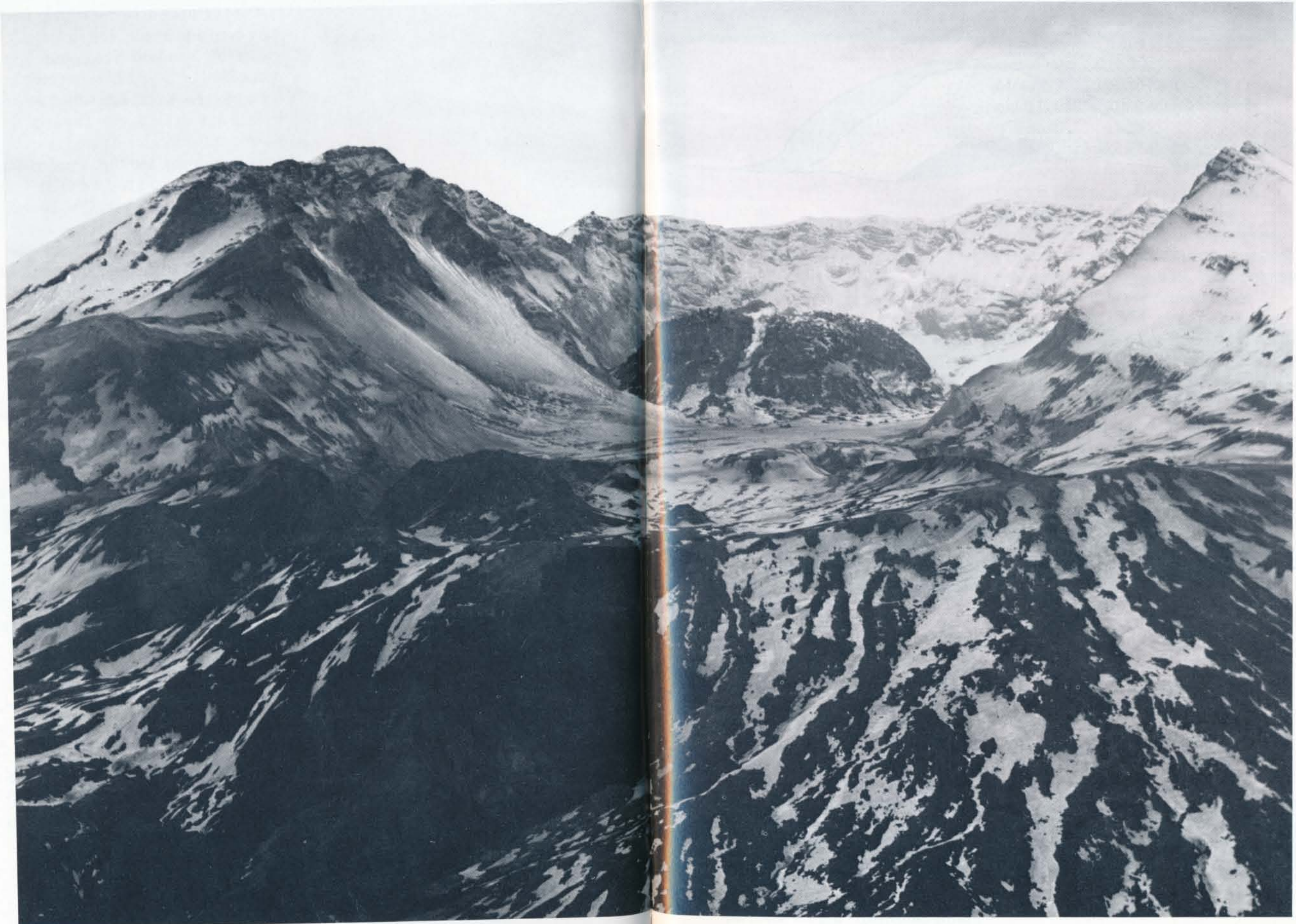
Aerial view of the December 1980 lava flow, viewed from the south. (Photograph by Donald A. Swanson.)

Aerial view of Mount St. Helens dome, from the northeast, showing the September 1981 lobe.

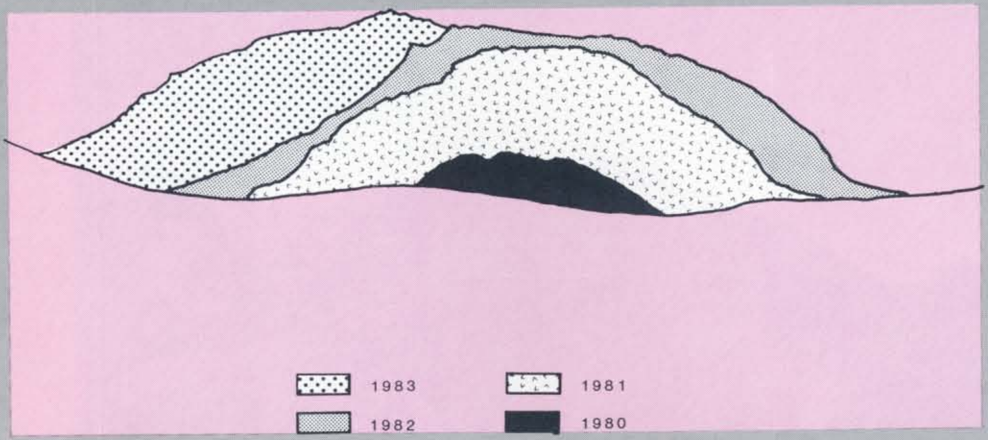
Aerial view of Mount St. Helens dome from the northeast, May 26, 1983.

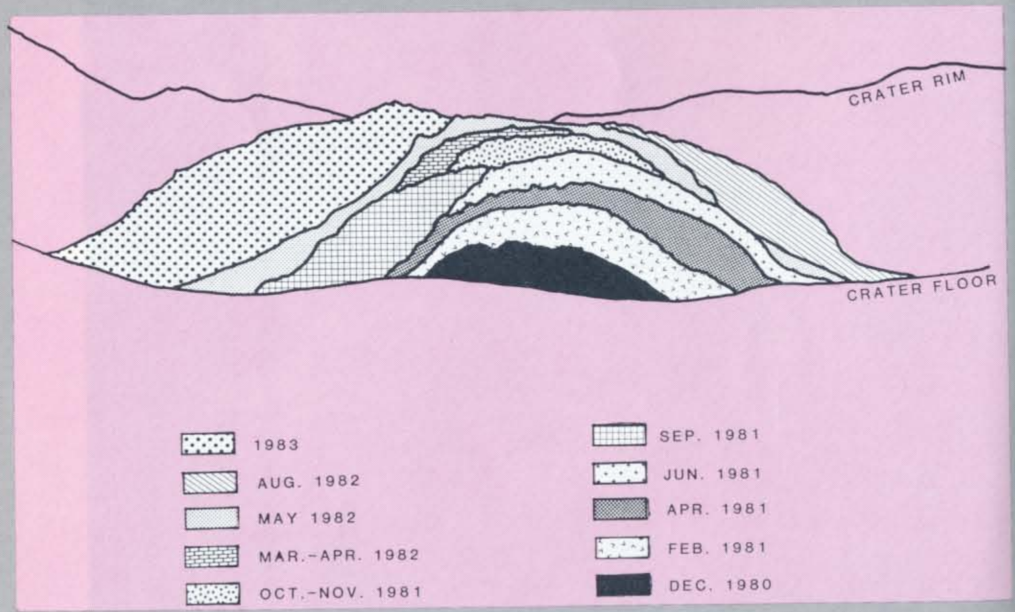
The 11 eruptions since October 1980 have been dominantly nonexplosive events that have built a composite lava dome 750 × 675 × 240 meters high in the crater. Each eruption added a stubby lava flow to the dome. The lava flows commonly are extruded near the top of the dome, and over a period of several days, creep 1 to 5 meters per hour down one side; usually a few million cubic meters of new lava is added to the dome during one of these episodes. The dome-building eruptions in 1981 and 1982 were episodic and occurred every 1 to 5 months. Beginning in February 1982, the dome grew continuously by the intrusion of magma into it and the extrusion of lava onto its surface; the most recent lava extrusion occurred in late March 1984. At the current rate of dome growth, about

U.S. Geological Survey scientist and Mount St. Helens dome, southeast side, May 26, 1983.



A recent aerial view of Mount St. Helens crater from the northwest, January 9, 1984.





1 million cubic meters per month, it would take 150 to 200 years to build Mount St. Helens to its former height, but it is unlikely that such a scenario will occur.

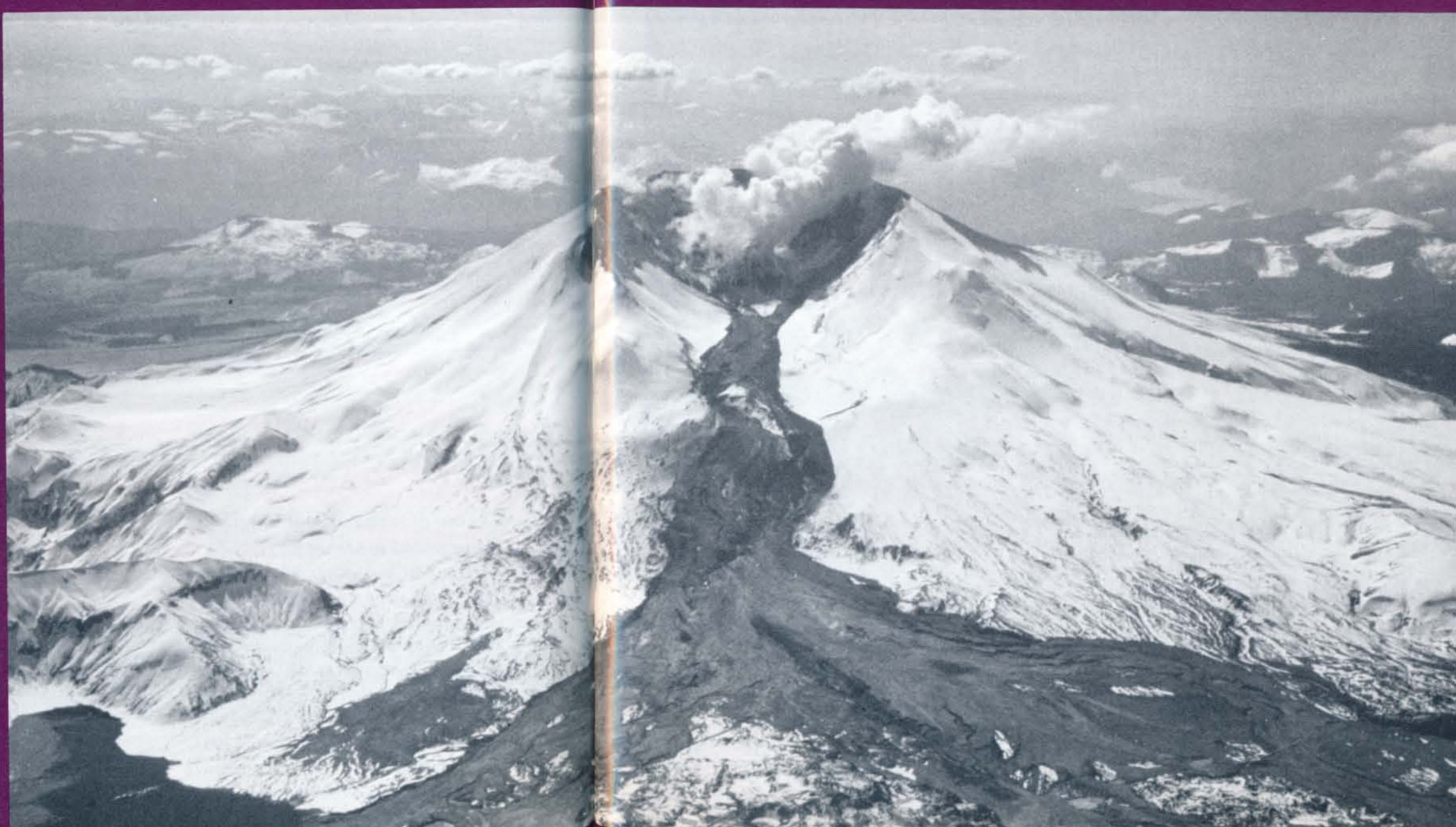
Small explosions sometimes precede or accompany the dome-building eruptions at Mount St. Helens; if they occur when snow mantles the crater floor, then they can produce mudflows (lahars) and snow avalanches. The explosive onset of the March 19, 1982, eruption hurled hot pumice and dome rocks against the 640-meter-high south crater wall, dislodging snow and rock that avalanched through the crater and down the north flank of the volcano. Deep snow in the crater melted quickly from the volcanic heat, forming a small lake from which a destructive flood swept down the north flank and into the North Fork Toutle River. About a day later, new lava erupted on the southeast flank of the dome.

The two diagrams are profile views of dome growth at Mount St. Helens sketched from photographs taken at a photo station approximately 1.0 kilometer north of the dome. The diagram above represents the yearly increase in dome profile between 1980, 1981, 1982, and 1983. The diagram below represents the increase in the profile after each dome-building eruption. During 1983, the dome was in a "continuous growth" phase. The 1983 profile increase was sketched from an October photograph, although the dome did continue to grow.

A rock avalanche from the dome on February 3, 1983, formed a notch on the east flank and caused a snow avalanche from the crater wall. (Photograph by Richard B. Waitt.)

Mount St. Helens dome, with the February 1983 spine viewed from the south.

Closeup of the February 1983 spine. (Photograph by Donald A. Swanson.)



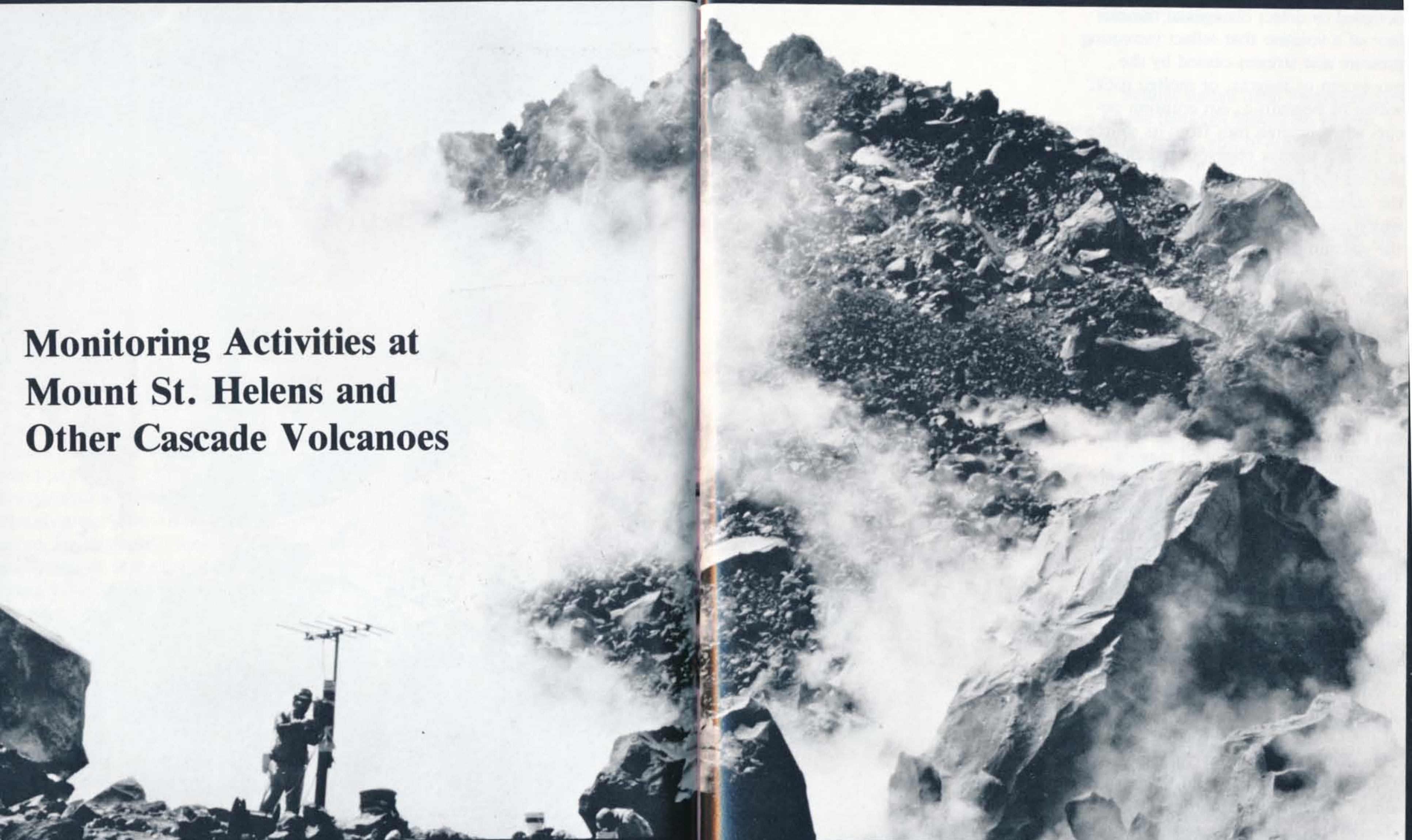
The March 19, 1982, lahar from the crater of Mount St. Helens, viewed from the north. Extremely rapid snow melt from a lateral explosion resulted in the first major lahar down the Toutle River since May 18, 1980. Within minutes of the explosion, snow in the water melted, forming a temporary lake from which a lahar swept down the north flank of the volcano. The flow picked up loose snow and rock, eroded deeply into the ravines below the crater, and became a debris flow by the time it reached the pumice plain. Peak discharge reached at least 14,000 cubic meters per second. Part of the lahar went into Spirit Lake (lower left) while the major portion flowed down the Toutle River channel. Five hours later, the flood, reached the Cowlitz River. (Photograph by Tom Casadevall.)

In addition to the dome-building eruptions, vigorous emissions of gas and tephra have occurred from fractures and small craters on top of the dome since late 1980. These periodic outbursts usually last several minutes, occasionally sending ash plumes as high as 5 to 6 kilometers above the volcano. Most of the tephra consists of fragmented pieces of dome rock, not new liquid magma, in contrast to the more hazardous magmatic explosions of 1980.

The eruptive activity of Mount St. Helens presents unique opportunities for geologists to observe the formation of different types of volcanic deposits. Geologists typically study rocks and deposits that are thousands to millions of years old. By observing eruptive activity that occurs in the present, geologists are better able to recognize deposits preserved in the historic record. For example, a large hummocky deposit at the base of Mount Shasta Volcano in northern California has characteristics similar to those of the 1980 debris avalanche deposit at Mount St. Helens. Based on detailed studies of the Mount St. Helens debris avalanche, geologists now can infer with greater confidence that a large landslide also produced the deposit near Mount Shasta. Stratigraphic studies at Mount St. Helens include studies of the debris avalanche, the lateral blast, mudflows, pumiceous pyroclastic flows, airfall tephra, and lava domes.

Gas and tephra emission, Mount St. Helens, viewed from the north on May 19, 1983. Numerous gas and tephra emissions have occurred on Mount St. Helens since 1980. There is very little warning before the bursts occur. Large bursts have reached 6,096 meters, and minor ones barely clear the dome. Their origin is as yet uncertain, but it is believed to be either a result of ground water reacting with the hot dome, pent up gases being released, or a combination of the two.

Monitoring Activities at Mount St. Helens and Other Cascade Volcanoes



eismic station near Mount St. Helens dome on the north side, May 12, 1981. The data from a network of seismometers encircling Mount St. Helens are telemetered back to the University of Washington in Seattle, Washington. Deep earthquakes, shallow earthquakes, and surface events (such as rockfalls) can be identified. Shallow earthquakes are observed in increasing numbers up to 1 to 2 weeks before dome-building eruptions and increase abruptly hours before the eruption begins. The life span of instruments in the crater area is usually short; within a month of this photograph, a large boulder from the dome had destroyed the seismometer.

The continuing eruptions of Mount St. Helens provide an unusual opportunity for scientists to study volcanic activity and to devise and test methods for predicting eruptions. Many successful predictions have been issued for eruptions since June 1980. Eruption prediction and information about volcanic activity at Mount St. Helens provide the basis for hazard warnings of eruptive activity to the public and local governments.

Volcano monitoring involves a vari ty of measurements and observations designed to detect changes at the surface of a volcano that reflect increasing pressure and stresses caused by the movement of magma, or molten rock, within or beneath it. An eruption occurs when magma rises from its source or from a storage reservoir and finally reaches the Earth's surface. As it rises, the magma fractures overlying rocks, which causes earthquakes, and parts of the volcano deform as magma approaching the surface makes room for itself.

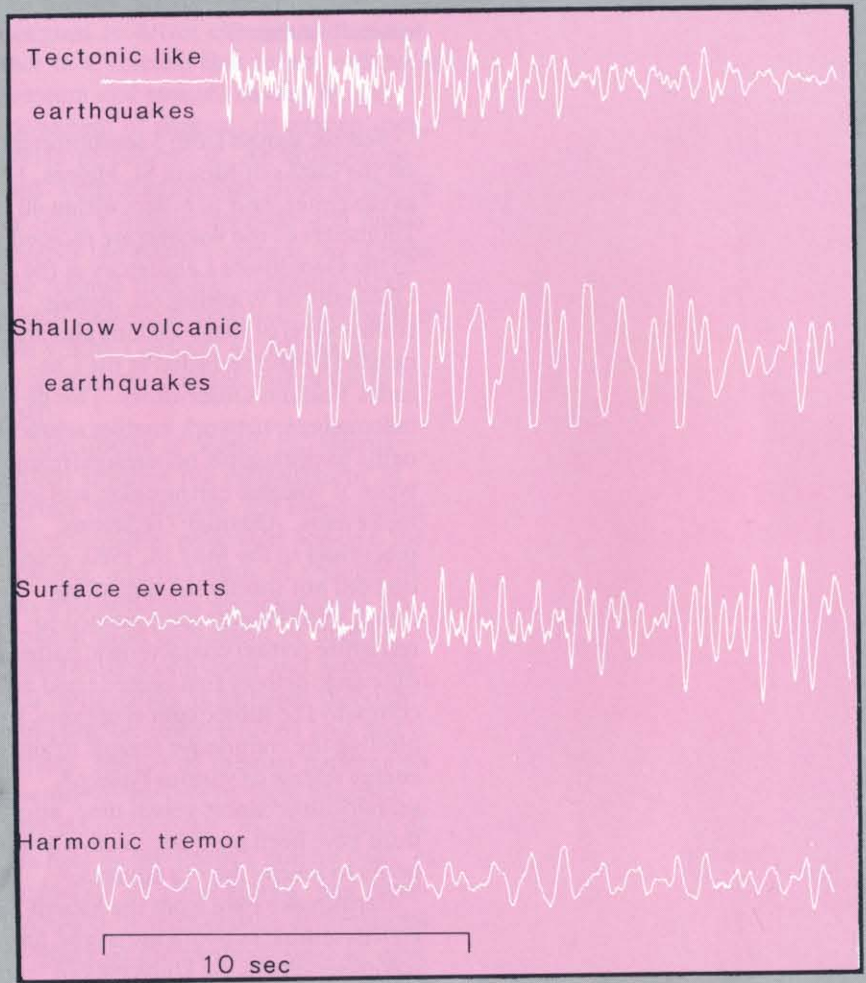
Monitoring at Mount St. Helens chiefly involves the measurement of surface deformation, the investigation of earthquakes generated beneath the volcano, and the study of changes in gas emission rates accompanying the underground movement of magma. Additional geophysical and geochemical information is gathered through sampling of newly erupted lava and tephra, studies of thermal patterns on the dome, surveys of local electrical and magnetic fields, measurements of changes in the Earth's gravity field, examination of photographs, and measurements of temperature at fumaroles.

Many of the methods used to monitor Mount St. Helens were developed at the U.S. Geological Survey's Hawaiian Volcano Observatory where the activity of Kilauea and Mauna Loa shield volcanoes is monitored. Although the techniques are similar, their application and interpretation have been modified and adapted to Mount St. Helens and other stratovolcanoes of the Cascades Range.

Seismic Studies

Seismic signals from 5 seismometers on the flanks of Mount St. Helens, 1 in the crater, and 10 others within 40 kilometers of the volcano are radioed to the Geophysics Laboratory at the University of Washington. Signals from several of these stations also are radioed to and recorded at the Cascades Volcano Observatory. This detailed seismic network enables seismologists to distinguish between different types of volcanic earthquakes and surface events. Although the seismic precursors to the May 18, 1980, eruption did not specify the time of its onset, seismologists have learned to recognize certain characteristic patterns of seismic activity that precede and accompany the subsequent eruptions. By plotting the cumulative seismic strain energy release of various types of seismic disturbances versus time, eruptions have been predicted from a few hours to several days in advance.

Earthquake data from the Mount St. Helens seismic network are stored on computer files at the University of Washington in Seattle. Seismologists review and classify the seismograms, or "seismic signatures," from several local stations each day; during periods of high earthquake activity, seismologists monitor the records 24 hours a day.



Four major types of seismograms, or "seismic signatures," are recognized from seismometers in the vicinity of Mount St. Helens. Seismologists review and classify the seismic records daily.

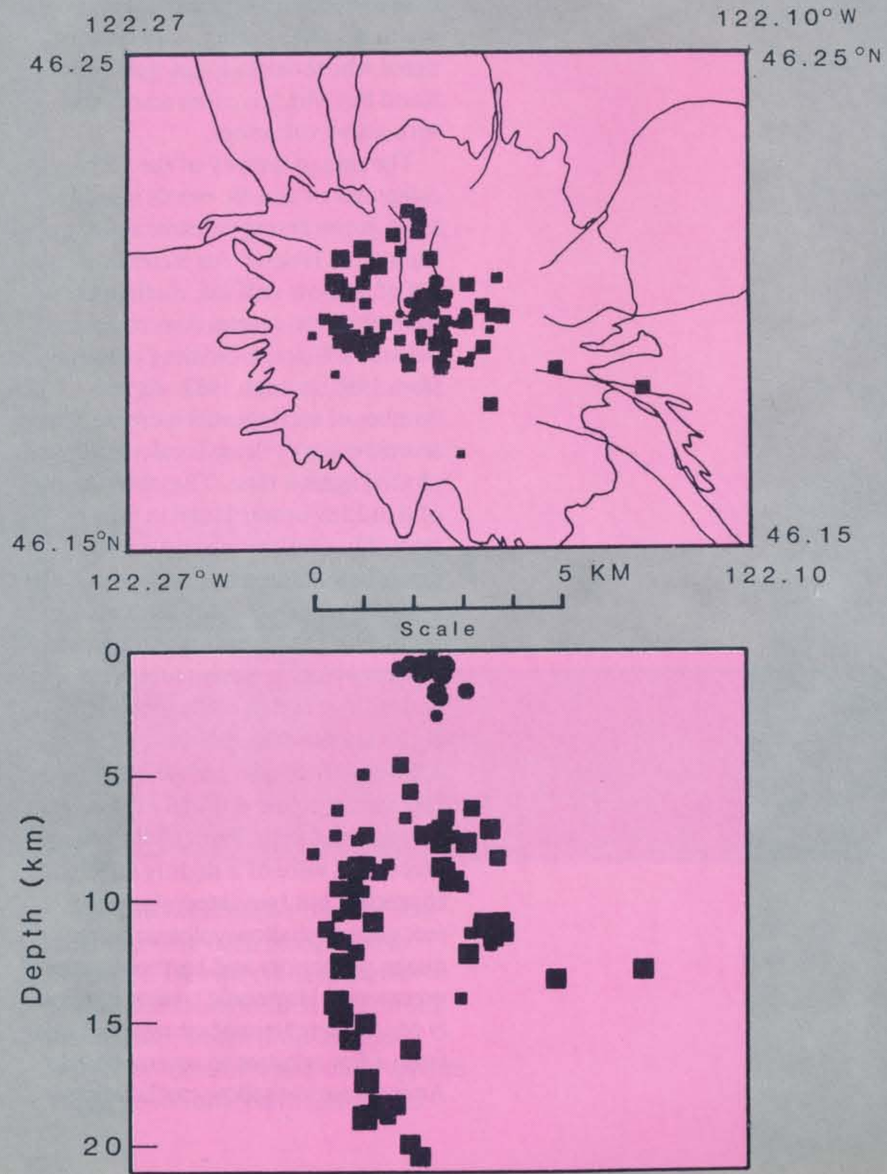
The following major types of seismograms have been recognized at Mount St. Helens: (1) deep earthquakes and those located away from the volcano, which produce high-frequency signatures and sharp arrivals similar to tectonic earthquakes, (2)

shallow earthquakes, located under the dome at depths of less than 3 kilometers, which produce medium- to low-frequency seismic arrivals, (3) surface events, such as gas and tephra events, rockfalls associated with dome growth, and snow and rock avalanches from the crater walls, which produce complicated signatures with no clear beginning or end, and (4) harmonic tremor, which is a long-lasting, very rythmic signal whose origin is not well understood but which is often associated with active volcanoes.

The rate of activity of the various categories of seismic events is used to assist in predicting volcanic activity at Mount St. Helens. An increasing number of shallow volcanic earthquakes were observed several days to 2 weeks before each dome-building eruption from 1980 through 1982. As the number of earthquakes increase, total seismic energy release is calculated and plotted against time. The observation of a sudden upward turn in this smoothly accelerating curve a few hours before the eruption begins is the basis for relatively short-term predictions. Once the eruption is underway, shallow volcanic earthquakes cease, and surface events from rockfalls dominate the records.

Increased seismic activity also preceded the post-May 18 explosive eruptions of 1980. Each of the seismic precursors were of a slightly different character, but two categories were recognized: shallow volcanic earthquake precursors and harmonic tremor precursors. Harmonic tremor is a nearly continuous train of vibrations lasting from a few minutes to several hours. An increase in shallow earthquakes

The hypocenters of earthquakes associated with volcanic phenomena. Circles are for the 30 best-recorded precursory earthquakes that preceded the March 19, 1982, eruption. Squares are for the 90 best-recorded earthquakes immediately following the explosive eruptions of 1980. The east-west cross section has a 2:1 vertical compression.



preceded the July and October 1980 eruptions when a lava dome was present in the crater. Harmonic tremor preceded the May 25, June 12, and August 7, 1980, eruptions when the vent was open and no dome existed. Having learned from the seismic buildup preceding the May 25 explosive eruption, seismologists were able to issue warnings of the subsequent explosive events by at least 2 hours.

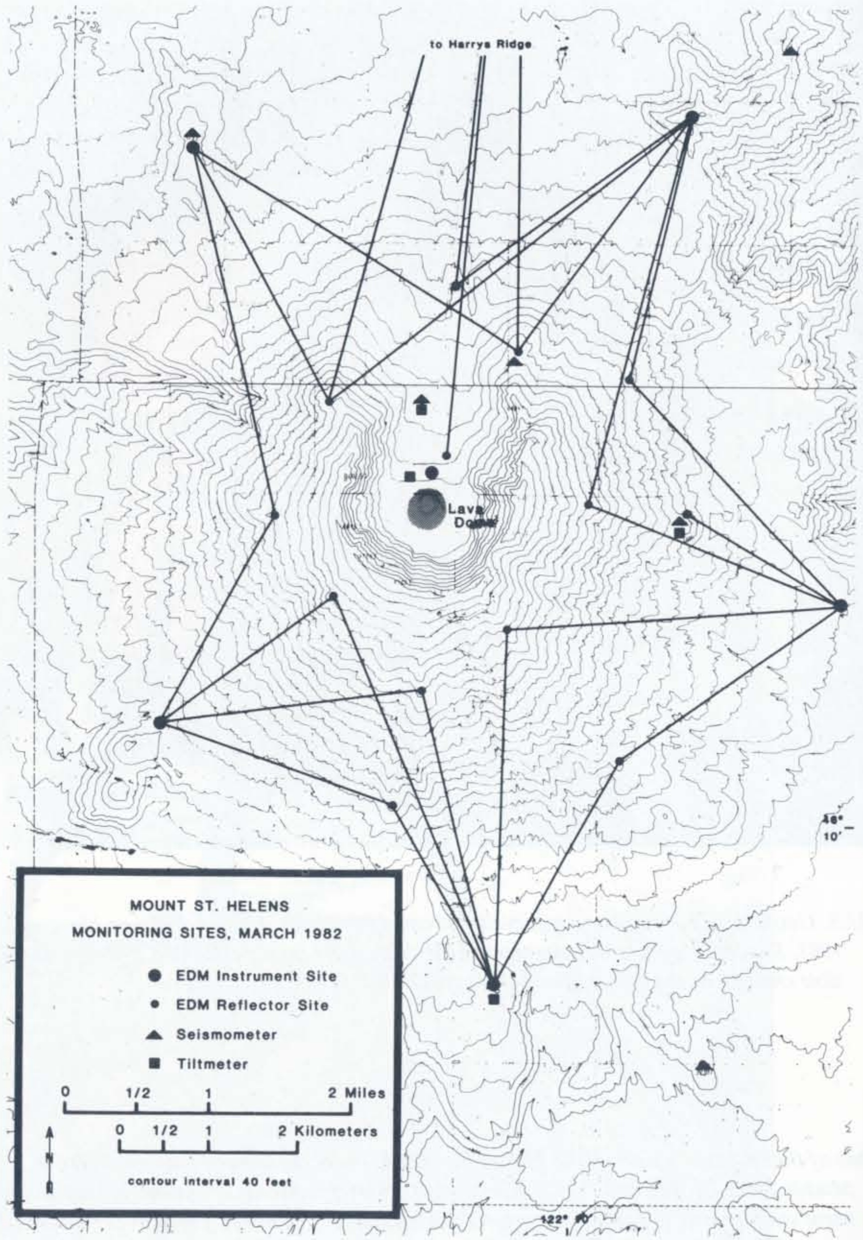
Although a characteristic pattern of seismic activity has accompanied most eruptions, there have been departures from the pattern. The explosive eruptions of 1980 were followed by swarms of deep earthquakes (deeper than 5 kilometers). In contrast, none of the subsequent dome-building eruptions were followed by deep earthquakes that could be related to the eruptions. The March 19, 1982, dome-building eruption began with an explosion and was preceded rather than followed by both deep and shallow earthquakes. The continuous dome-growth eruption that began in early February 1983 was preceded by an unusually small increase in shallow earthquake activity. Earthquakes and surface events occurred daily reflecting the continuous dome-growth activity in 1983.

Deformation Studies

Shortly after the May 18, 1980, eruption, geologists reestablished a surveying network on the volcano to measure changes that might signal additional eruptive activity. Glass prisms atop heavy steel towers on the volcano's upper flanks were surveyed with an electronic distance meter and theodolite from instrument towers

U.S. Geological Survey personnel leveling around Mount St. Helens dome on November 6, 1981. Repeated leveling circuits around the dome have been performed to determine possible changes of the crater floor before eruptions.

◀ *One of the stations/towers of the Mount St. Helens outer deformation network, from Muddy River, November 2, 1982. Currently the outer deformation network has 6 instrument stations and 13 permanant prism towers circling the flanks of Mount St. Helens. The network is occupied approximately once a month when possible, and both distance and vertical and horizontal angles are read. The U.S Geological Survey scientists are watching for swelling of the flanks of Mount St. Helens, which is a possible precursor to volcanic activity. So far, no significant changes have occurred.*



Monitoring sites at Mount St. Helens as of March 1982.

placed at the base of the volcano. Frequent measurements showed small movements during the summer of 1980, some of which may have indicated swelling before the explosive eruptions. No systematic deformation of the outer flanks of the volcano has been detected since 1980.

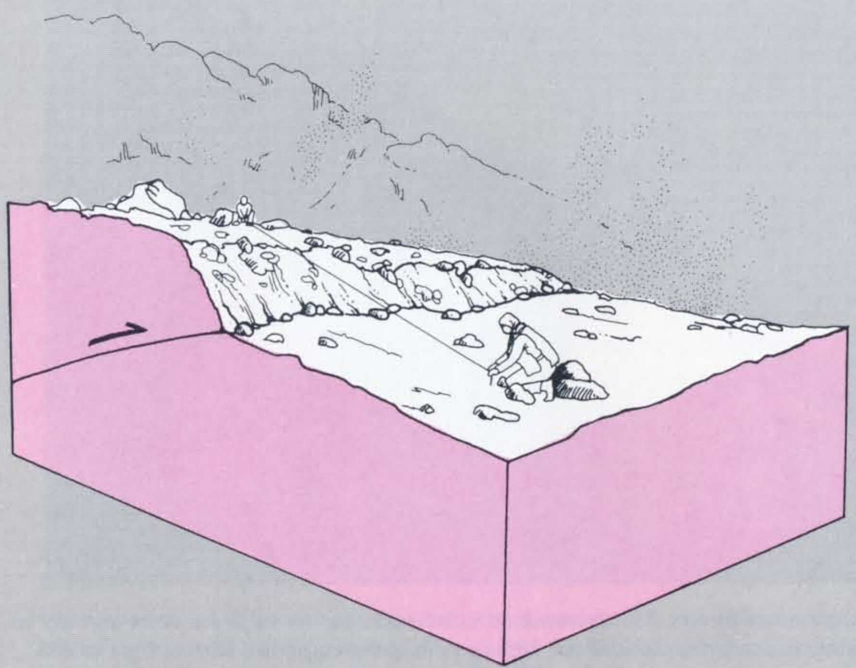
The largest changes measured in 1980 were inside the new crater near the eruptive vent. As a consequence of these observations, monitoring has been focused inside the crater since fall 1980. Geologists visit the crater several times each week to measure deformation of the crater floor and the lava dome before eruptions. At the end of each field day, total measured displacements of ground cracks, thrust faults, and the dome are plotted against time. The observation of a gradual and then a rapid change in the curves a few days to several weeks before an eruption begins is the basis for relatively long-term predictions.

Ground-Crack Measurements

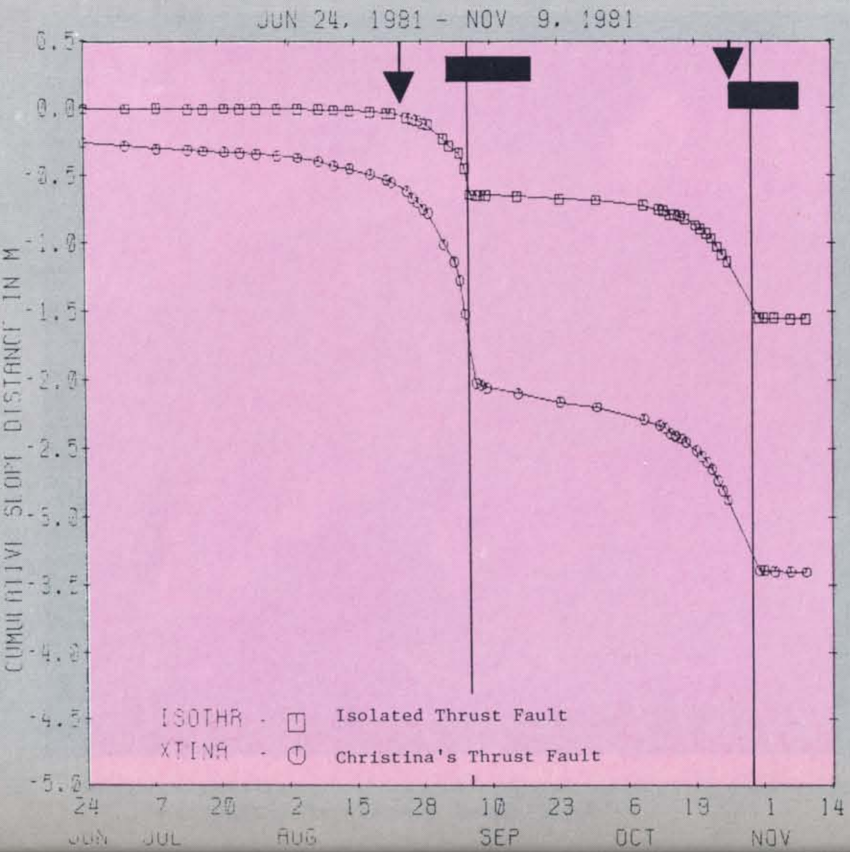
New ground cracks appeared on the crater floor from several days to 2 to 4 weeks before all the 1980 to 1982 eruptions. The cracks, commonly tens of meters long and tens of centimeters wide, extended outwards from the dome like spokes from the hub of a wheel. Incandescent rock was visible in some cracks, and temperatures of escaping gas were measured as high as 840°C. Measured with a steel tape, the cracks commonly showed continual widening that accelerated before eruptions. Such accelerated movement was used to predict several eruptions in 1981 and 1982.

Steel tapes stretched between fixed points which are used to measure changes in radial cracks and on thrust faults. A network of three stations is used with measurements made between all points of the triangle at each radial crack or thrust fault station. Before an eruption, radial cracks were found to widen several tens of centimeters, and thrust faults often moved several meters. Measurements of radial cracks and thrust faults were extremely important in predicting the 1981 and 1982 dome-building eruptions, but, during the 1983 "continuous eruption," the dome became too large, and talus from the dome covered the crack and thrust areas.

Taking measurements across a thrust fault in the crater of Mount St. Helens, August 26, 1981. (Photograph by Terry Leighley, Sandia Labs.)



One of the thrust faults on the crater floor. The upper portion (left block) of the thrust fault is pushed over the lower portion before eruptions shown in the preceding photograph. Movement of the thrust fault is measured with a steel tape across the leading edge. (Diagram by Bobbie Myers.)

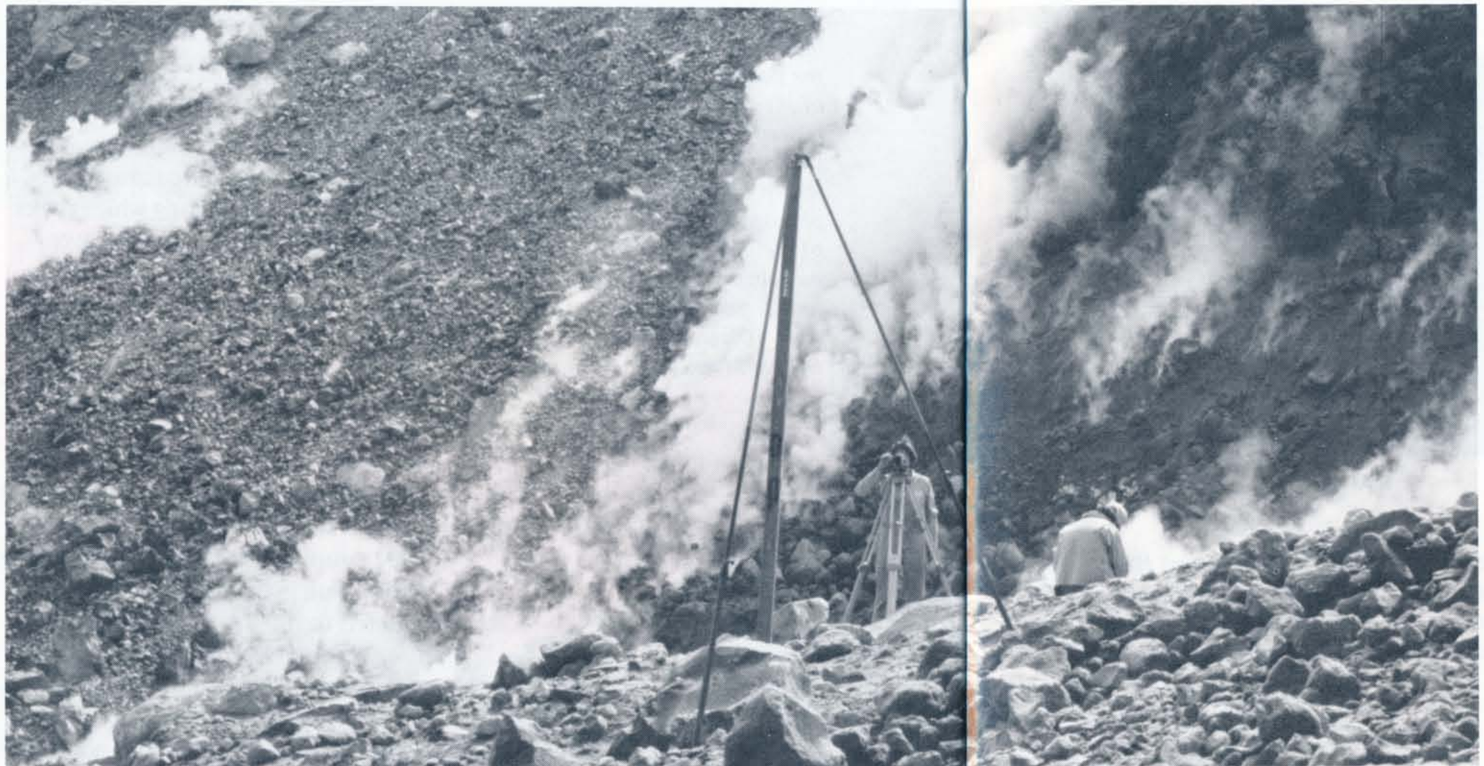


Cumulative contraction of taped distance across the leading edge of two thrust faults before the September 6, 1981, and October 30, 1981, eruptions. (The two arrows are dates on which the long-term prediction was issued; the bars are periods within which the eruption was predicted to occur; the solid lines are dates eruption began).

Thrust-Fault Measurements

From 1980 to 1982, parts of the crater floor became slightly wrinkled several weeks before eruptions. A few wrinkles developed into thrust faults, a low-angle fracture, along which rocks above the fracture are pushed over rocks below the fracture. By summer 1981, a complex system of thrust blocks had disrupted much of the southwestern part of the crater floor. The thrust faults formed as rising magma forcefully ruptured the crater floor, shoving parts of it upward and outward from the vent toward the rigid crater walls. Before the August 18, 1982, eruption, the leading edge of one thrust fault grew from less than 30 centimeters to roughly 5 meters high a few days before the eruption.

Movement along the faults was monitored by repeated measurements between benchmarks on either side of the fault by using a steel tape and by level-



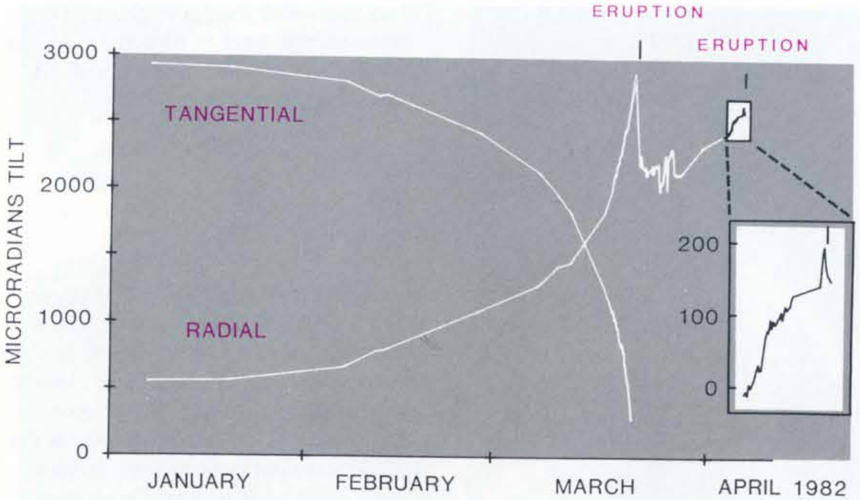
Tilt station which used spirit-levels for measurement, next to Mount St. Helens dome, May 20, 1982. (Photograph by Donald A. Swanson.)

ing between points on the upper and lower plates. The rate of movement accelerated before eruptions, and this provided the most consistent and reliable relatively long-term (1-3 weeks) predictive tool at Mount St. Helens during 1981 and 1982. Rockfalls from the dome and crater walls have buried some major thrust faults under rock debris; others have been overridden by the dome itself; but new thrust faults occasionally appear, as in October 1983.

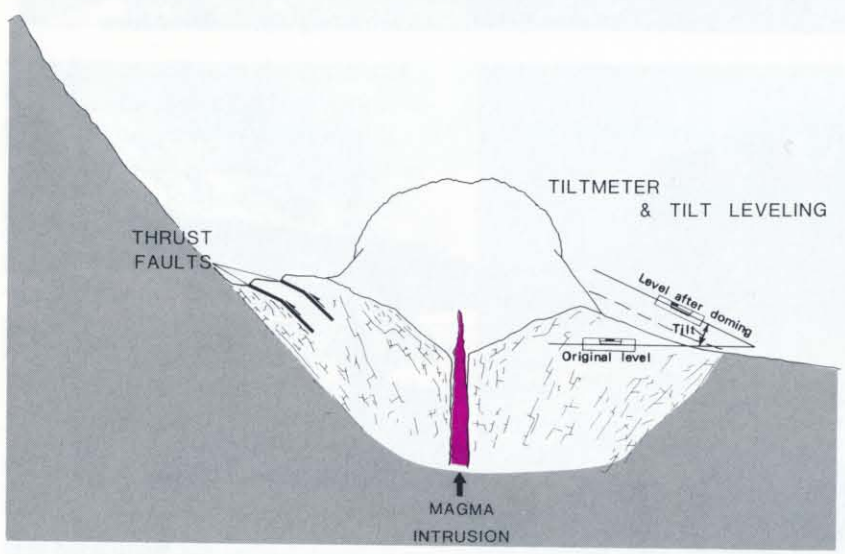
Tilt Measurements

In addition to cracking and faulting, the crater floor tilts before eruptions. Electronic tiltmeters, which are widely used in Hawaii, measure changes in

Electronic tiltmeter site, north of dome, April 1981. Tilt measurements record changes in the inclination of the ground surface on the crater floor and around the dome. A network of electronic tiltmeters and spirit-level stations in the crater has been used to help monitor deformation before and during eruptions. These records of changes in the inclination of the ground have been useful for predictions; electronic tiltmeters installed on the crater floor detect changes several weeks before an eruption, and the rate of change begins to accelerate rapidly several hours to several days before an eruption. (Photograph by Terry Leighley, Sandia Labs.)



Tiltmeter data from a station north of the dome for the eruption of March to April 1982. Radial uplift began in mid-January and accelerated sharply on March 16; rapid subsidence began 30 minutes before the explosive onset of the March 19 eruption. Uplift resumed in late March and then reversed again to subsidence 36 hours before a second lava flow was erupted on April 5.



The operation of a tiltmeter bubble level and the tilt that occurs when magma rises in the vent under the dome. Thrust faults also formed on the crater floor before eruptions in 1981 through 1982.

slope or inclination of the ground surface. Tiltmeters specifically designed for use at Mount St. Helens have been installed on the crater floor tens to several hundred meters from the dome. Tilt data contributed to accurate predictions for eruptions during 1981 and 1982.

The tiltmeters, which employ two sensitive bubbles mounted at right angles on a 15-centimeter base plate, measure tilt of the crater floor in two directions. The direction of tilt is generally outward from the dome but is sometimes complicated by nearby cracks or faults. Amount of tilt is expressed in microradians, which is the angle turned by a 1-kilometer-long rod if one end is raised 1-millimeter. Although these tiltmeters are capable of measuring one-tenth of a microradian, precision is limited to 5 to 10 microradians in the crater because of surface thermal effects. Data from the crater tiltmeters are radioed directly to CVO in Vancouver and are stored in computer files. Tiltmeters provide the only realtime information about crater deformation and are, therefore, especially valuable when field work is impossible because of poor weather or hazardous volcanic activity.

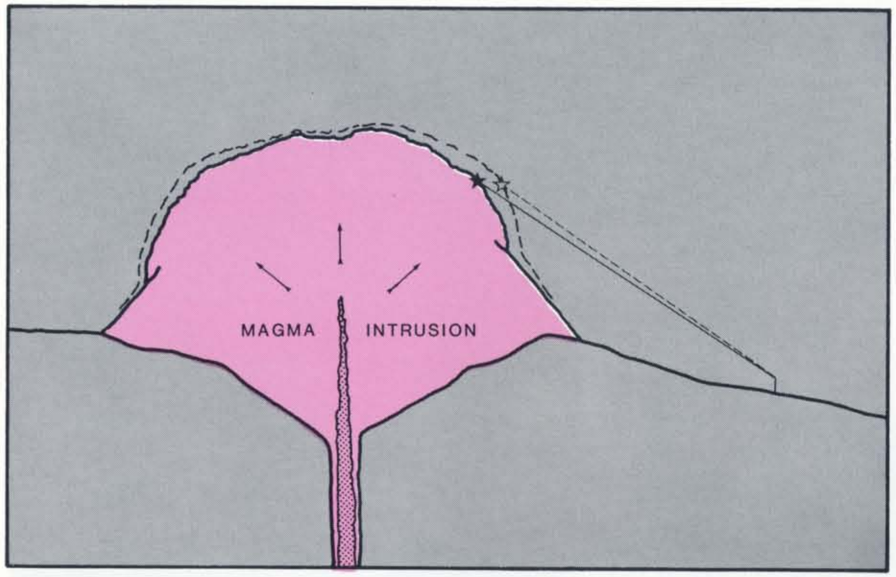
Tilting of the crater floor began several weeks before each eruption in 1981 and 1982, accelerated a few days before, and, on several occasions, abruptly reversed direction minutes or hours before the eruption began; for example, tilt before the March 19, 1982, eruption at one station increased from about 14 microradians per day 3 weeks before the event to 360 microradians per day on March 19. The tilt reversed direction about 30 minutes before the eruption began.

Winter monitoring of Mount St. Helens dome on March 22, 1983. Note that the 1.5 meters of snow almost obscures the theodolite. Slope distance and vertical angle measurements to targets and prisms on the dome are made every other day all the year round (weather permitting) to determine whether any part of the dome is swelling. Before the August 1982 lobe appeared on the surface, measurements to the dome showed that the west and southwest sides of the dome were growing upward and outward at rates of as much as 22 meters per day. These measurements are made from numerous sites circling the dome. Although many instrument stations are not habitable during the winter months, generally one or two stations can be dug out and occupied.

Lava-Dome Measurements

Measurements show that the dome expands as magma moves up into it before eruptions. Repeated surveys using an electronic distance meter and theodolite between points on the crater floor and targets placed on the dome reveal movements that speed up as the eruption nears. A target on the west

U.S. Geological Survey scientists making deformation measurements, north side of Mount St. Helens dome, August 17, 1982.

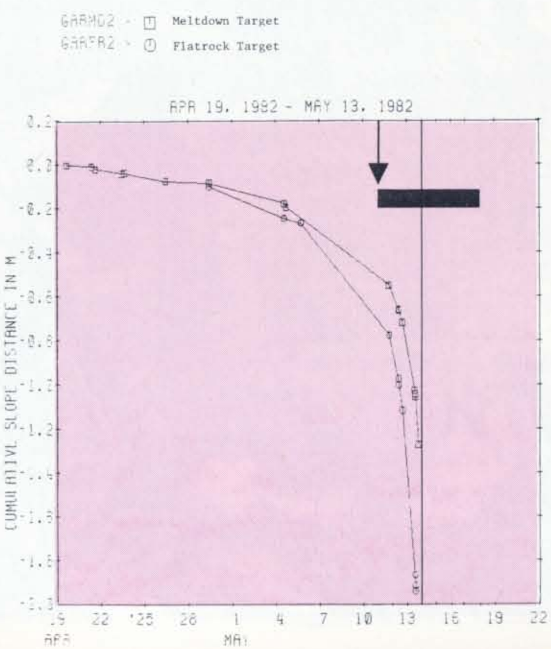


Expansion of the lava dome before eruptions is measured by surveying targets on the dome from instrument stations on the crater floor. Vertical angles are surveyed with a theodolite, and slope distance is measured with an electronic distance meter.

side of the dome was moving roughly 2 centimeters per day 2 weeks before the May 14, 1982, eruption; this movement increased to about 200 centimeters per day by May 13. Such accelerations were frequently used to predict eruptions in 1982.

Generally, all sides of the dome were monitored in 1981 and 1982 from four to five stations on the crater floor. Experience has shown that the dome deforms differently at each of the stations, thus making it necessary to monitor more than one side for reliable predictions. During the winter months, one and sometimes two sides of the dome can be monitored; it is no longer possible to monitor the east sector of the dome because of hazardous rockfalls from the dome and the east crater wall. This technique has become essential for predicting the most recent eruptions because most of the ground cracks and thrust faults have been buried by the dome and associated rockfall debris. This type of measurement also documents movements of the dome during prolonged eruptions, such as that of 1983, and is used to foretell significant changes in such continuous activity.

Cumulative contraction of slope distance between targets on the dome and an instrument station on the crater floor north of the dome before the May 14, 1982, eruption. (Arrow is date on which the long-term prediction was issued; bar is period within which the eruption was predicted to occur; solid line is the date the eruption began).



U.S. Geological Survey scientists measuring the plume's sulphur dioxide level with the correlation spectrometer on Sugar Bowl, northeast side of Mount St. Helens, October 21, 1983.

U.S. Geological Survey scientists sampling gases in a fumarole, near Mount St. Helens dome in 1981. The monitoring of gas emission from Mount St. Helens includes frequent airborne measurements of sulfur dioxide in the volcanic plume and periodic sampling of gases from the crater fumaroles. Data on the chemistry and on the emission rates of the gases are used in issuing predictions of eruptions. Approximately five airborne traverses are made beneath the plume during a single flight to calculate the emission rates. A correlation spectrometer measures the amount of solar ultraviolet light absorbed by sulfur dioxide in the plume, compares it to a standard, and, thus, measures the amount of sulfur dioxide.

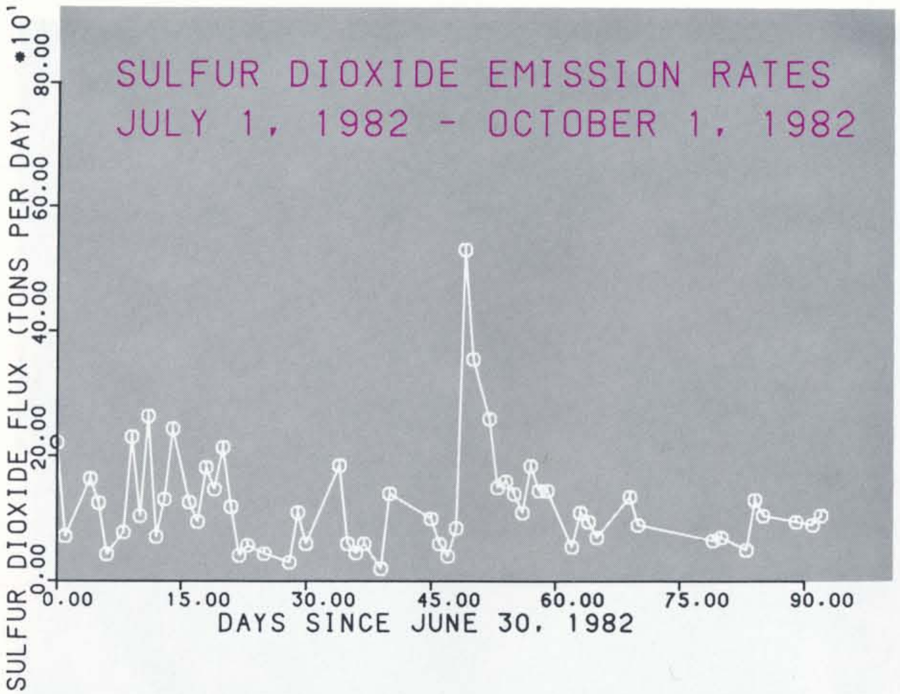
Gas Emission Studies

Gas emissions are measured regularly in conjunction with seismicity and ground deformation to monitor eruptive activity. Mount St. Helens continuously emits volcanic gas from fumaroles on and around the dome. Most of the gas emitted by the volcano is water vapor, but emissions also include sulfur dioxide, carbon dioxide, hydrogen, and lesser amounts of helium, carbon monoxide, hydrogen sulfide, and hydrogen chloride.

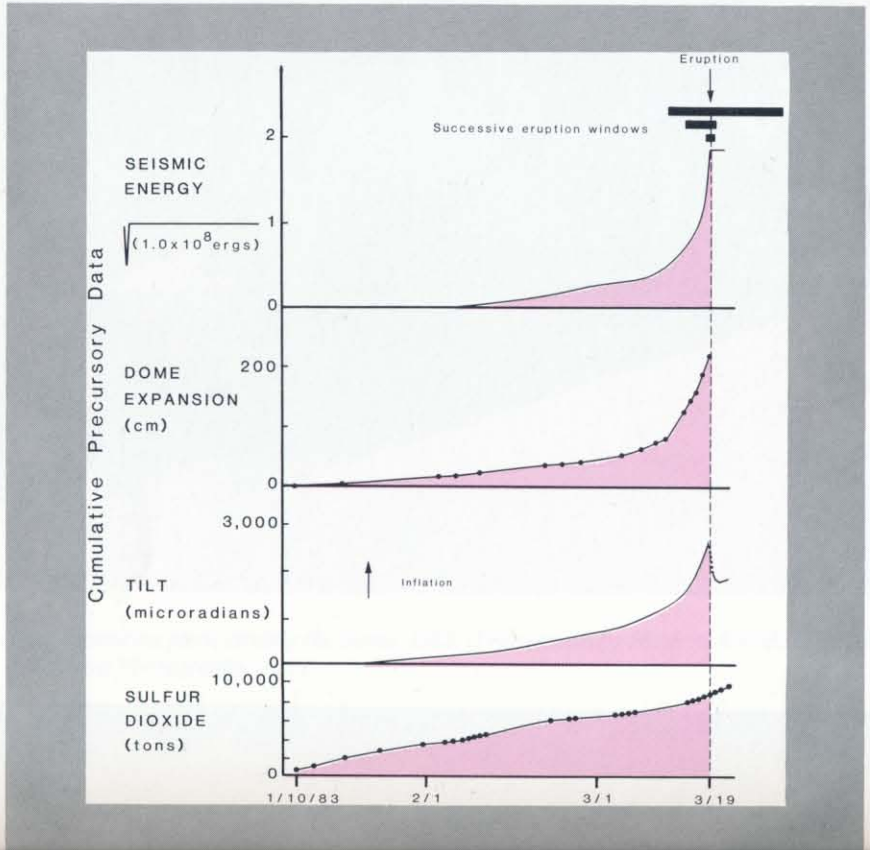
Gas studies include (1) frequent airborne measurements of sulfur dioxide and, in 1980 and 1981, carbon dioxide in the plume and (2) less frequent sampling of gases from crater fumaroles. The emissions of sulfur dioxide are measured in the plume by a correlation spectrometer (COSPEC) designed originally for pollution studies. The instrument measures the amount of solar ultraviolet light absorbed by sulfur dioxide in the plume and compares it with an internal standard. Three to six traverses are made beneath the plume at right angles to the plume trajectory several times each week to calculate daily emission rates.

The emission rates of sulfur dioxide peaked during summer 1980 at about 1,500 tons per day, decreased rapidly in late 1980, and remained low at about 100 tons per day through 1983. Emission rates of carbon dioxide decreased rapidly in late 1980 until they were below the detection limit of 1,000 tons per day. These patterns correspond generally to a change in eruptive style from the explosive activity of 1980 to the now predominantly nonexplosive activity. The patterns suggest steady outgassing of a single batch of magma under the volcano to which no

A gas-measuring plane circling the dome, 1982. (Photograph by Hugh Ackroyd, copyright Ackroyd Photography, Inc.)



Sulfur dioxide emission rates (tons per day) before and after the August 18, 1982, eruption. Emission rates peaked on the morning of August 18 and then returned to preeruption levels within a few days. Increased rates of sulfur dioxide emissions prior to the eruption are interpreted as the result of the degassing of a batch of magma as it rises toward the surface.



Precursory data plotted against time for the March 19, 1982, eruption. Curves for seismic energy release, dome expansion, and tilt show gradual increases in slope 3 weeks before the eruption and then rapid change within a few days of the eruption. Tilt reverses direction about 30 minutes before the small explosive onset that marks the beginning of the eruption. (Solid bars: three predictions were issued before the eruption; each one successively narrowed the time within which the eruption was expected to occur.

significant new magma has been added since mid-1980.

Increased rates of sulfur dioxide emissions measured before several nonexplosive eruptions are interpreted as the result of accelerated degassing of a small volume of magma as it moved toward the surface. During the nonexplosive eruptions, gas emissions remained elevated during the active extrusion of lava and generally dropped to preeruption levels once extrusion stopped. The occasional outbursts of gas and tephra are accompanied by brief, sudden increases in the emission rate of sulfur dioxide, water vapor, and probably other gases as well. It is not known whether this increase in gas is derived directly from magma within the dome or released during periodic, geyserlike flashing of a shallow hydrothermal system.

Dome Composition

Since October 1980, each eruption has added a new flow of viscous dacitic lava to the dome. Chemical and mineralogic analyses of dome samples show that lava composition throughout successive eruptions has remained nearly constant. This suggests that the magma feeding the eruptions has not undergone any significant changes and is consistent with the model of a single, shallow magma reservoir supplying the eruptions. Whether the chemical composition of future extrusions remain the same or show systematic changes, new analyses must be interpreted in the light of all other observations to help anticipate the character of future behavior.

Thermal Observations

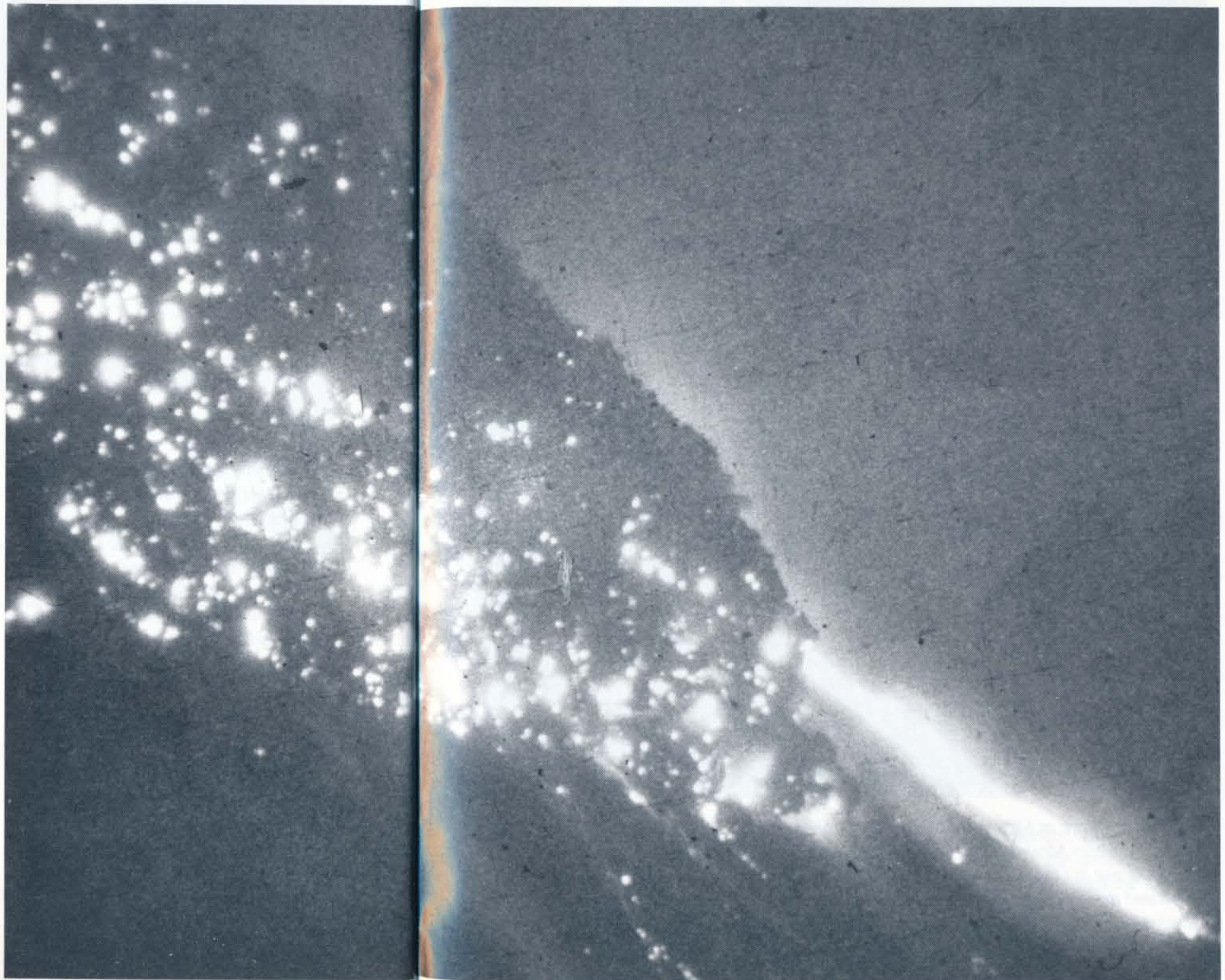
Nighttime aerial observations of the lava dome also have been useful in monitoring volcanic activity. An image intensifier attached to a 35-millimeter or video camera can detect hot spots on the dome that are not visible to the naked eye. The intensifier magnifies the glowing spots 20,000 to 40,000 times. Increased visible glow is sometimes observed a few days before an eruption. This technique, currently under development, shows promise for monitoring the dome should work in the crater be curtailed for any reason.

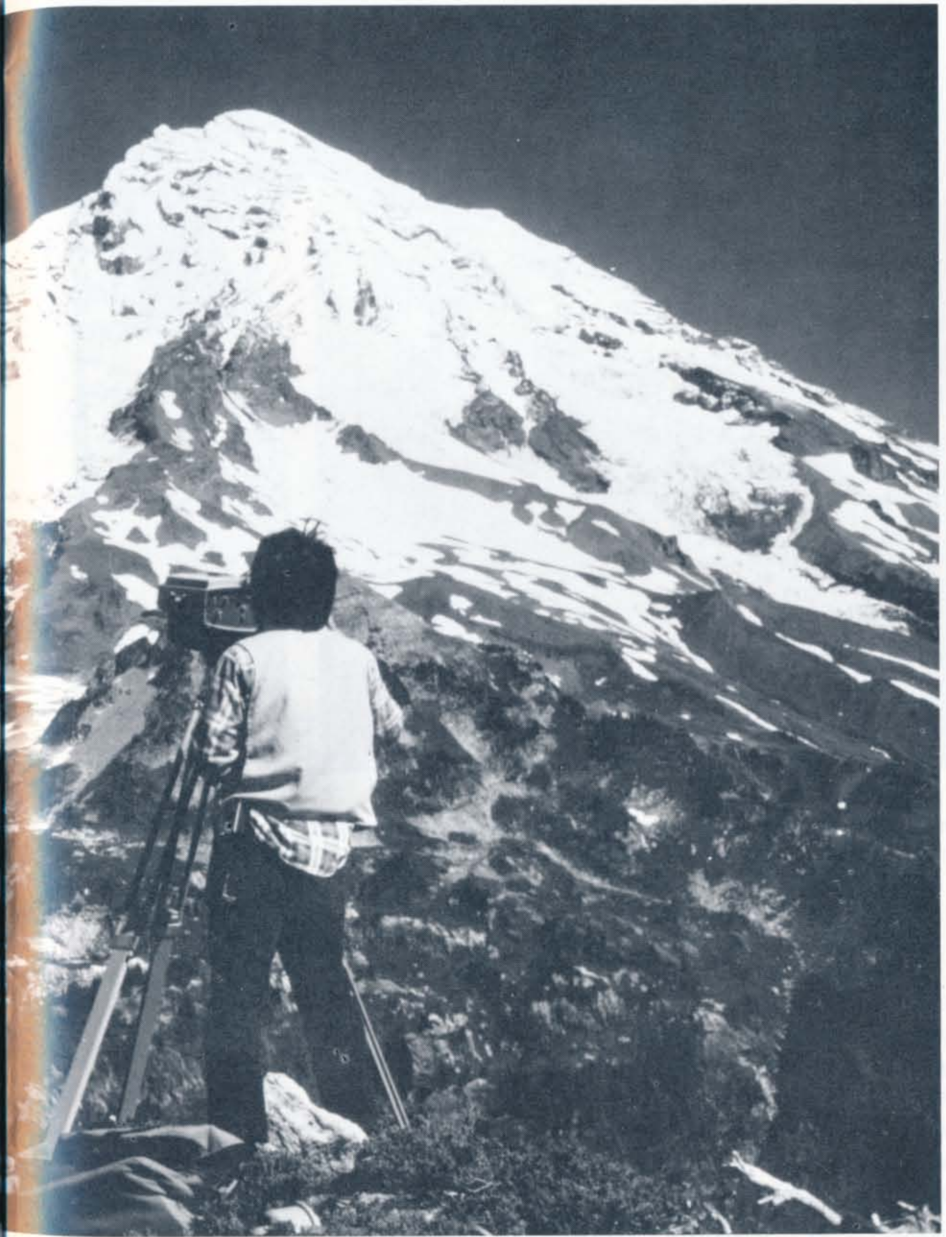
Other Volcanoes

Survey networks and tilt stations have been established on other volcanoes of the Cascade Range: Mount Baker and Mount Rainier in Washington, Mount Hood and Crater Lake in Oregon, and Mount Shasta and Lassen Peak in northern California. Current plans are to remeasure these networks every 3 years, unless conditions, such as increased seismicity, warrant more frequent monitoring. Earthquake activity is continuously monitored at these volcanoes. Monitoring earthquakes and ground movements on these volcanoes will probably record changes before future eruptive activity, but it is unlikely that the monitoring will define the exact time or type of an eruption as precisely as is currently possible at Mount St. Helens.

The drama of the May 18, 1980, eruption of Mount St. Helens captured the attention of people throughout the world to a degree matched by few natural events in recent decades. However, the energy and volume of this eruption were exceeded considerably by several other eruptions elsewhere in the world during the past century. Even so, the fact that a great natural disaster occured in one of the highly developed countries has brought volcanoes in general and Mount St. Helens in particular a degree of recognition and

Night observation of the August 1982 lobe. This 8-second time-exposure photograph, taken from Harry's Ridge, 8 kilometers north of Mount St. Helens, is a nighttime photograph of a slowly spreading lava flow; incandescent spots show through its darkening crust. Most of the spots are too dim to be seen with the naked eye but are revealed here through the use of a visual image intensifier, an instrument that amplifies the light intensity 20,000 to 40,000 times. (Photograph by Robin T. Holcomb.)





Deformation work at Mount Rainier on September 13, 1983. The Cascades Volcano Observatory monitors Mount Baker and Mount Rainier in Washington State, Mount Hood and Crater Lake in Oregon, and Mount Shasta and Lassen Peak in California. Both deformation and dry tilt measurements are made, giving the U.S Geological Survey baseline measurements at these peaks for future reference. Repeat measurements will be made every few years to help determine the possibility of volcanic activity. In the photograph, distance measurements are being taken to prisms set up on Mount Rainier; at the same time, the helicopter flies between the instrument site and the prism site taking atmospheric temperature and pressure readings.

Donald W. Peterson, scientist-in-charge, Cascades Volcano Observatory, accompanies visiting geologists from the Geological Surveys of New Zealand and Australia. This photograph shows the group on Harry's Ridge, 8 kilometers north of Mount St. Helens.

visibility not previously achieved. Systematic observations and monitoring of the activity since its beginning in 1980 probably have exceeded those associated with any major eruption elsewhere, thus providing both an opportunity for education on a worldwide scale and a responsibility for disseminating the lessons learned.

Scientists and public officials from at least 25 countries have visited CVO and Mount St. Helens and have gained improved insights into volcanic processes and into how society interacts

Richard J. Janda, chief of the Water Resources Division Cascades Volcano Projects, explains the events of the May 18, 1980, eruption to a group of visiting engineering hydrologists from the Peoples' Republic of China.

with natural disasters. In turn, scientists of the U.S. Geological Survey's Volcano Hazards Program have participated in monitoring active volcanoes in other countries, including Indonesia, Papua New Guinea, and New Zealand, and have visited areas of active volcanism in several other countries and have consulted with their scientists. This kind of interaction is of immeasurable value in helping the international community of volcanologists to deal with the vital goals of improving the ability to predict volcanic eruptions and to mitigate volcanic risks.

The Changing Hydrology at Mount St. Helens

The effects of the May 18, 1980, eruption of Mount St. Helens significantly increased the threat of flooding along rivers draining the volcano, especially the Toutle and lower Cowlitz Rivers. The erosion of unconsolidated volcanic debris around the volcano and the possible failure of debris dams impounding Spirit, Coldwater, and Castle Lakes pose hazards to communities downstream from the volcano. Steps have been taken by the U.S. Army Corps of Engineers to reduce the threat of flooding, and discussion is currently underway to implement long-term solutions. Data collected by U.S. Geological Survey hydrologists from the Cascades Volcano Observatory and from Tacoma, Washington, are given to Federal, State, and local officials who are responsible for flood-mitigation and emergency-response plans.

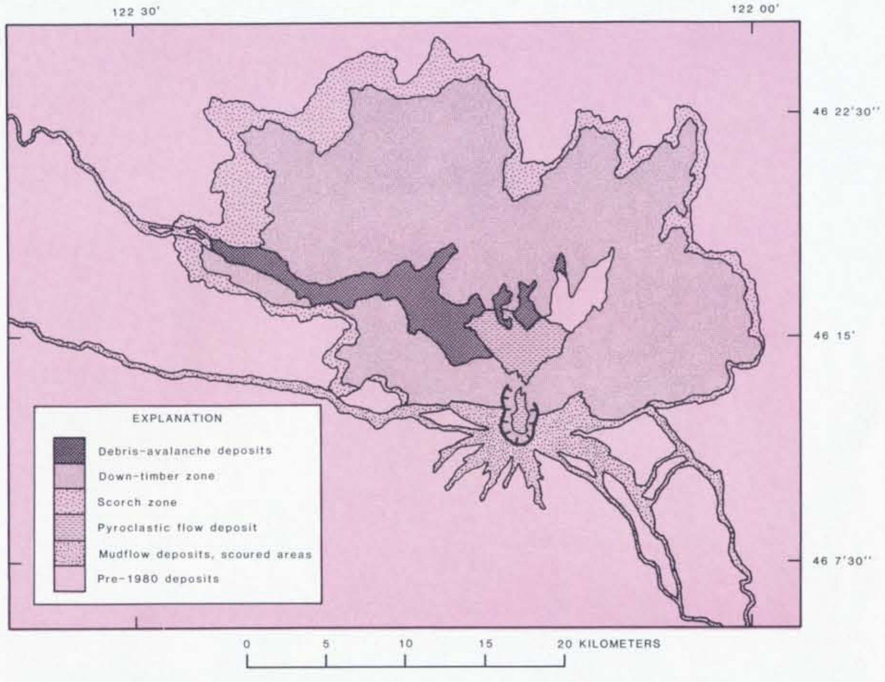
Hydrologic Monitoring

Erosion of Volcanic Deposits

The May 18, 1980, eruption significantly increased the rate of surface runoff during storms and the availability of readily erodible sediment by destroying vegetation and by depositing loose debris over a wide area north of the volcano. The directed lateral blast stripped trees from most hillslopes within 11 kilometers north of the volcano and leveled nearly all vegetation as far as 20 kilometers in a 180-degree arc north of the mountain.

Tree blowdown at Elk Rock, about 18 kilometers from Mount St. Helens.

Tree blowdown on Smith Creek. (Note the two people in the lower right.)



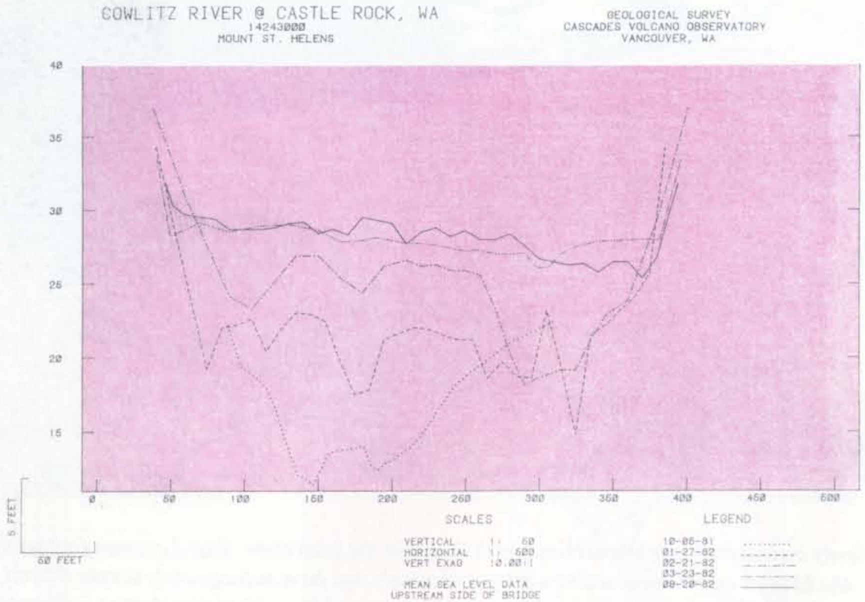
The effects of the May 18, 1980, eruption.

The blast deposited blocks, smaller rock fragments, and organic debris over the 550-square-kilometer area in layers to more than 1 meter in thickness. Surrounding this zone of toppled vegetation is a narrow 100-square-kilometer band of scorched, but standing, timber in which sandy deposits are as thick as 8 centimeters.

Rivers with headwaters in the blast area have a rapid streamflow response to rainfall, owing to reduced infiltration rates on hillslopes and low roughness along channels. Streams now respond more quickly to a given amount of rainfall and produce higher peak flows as rainfall is quickly flushed through the drainage system. Greater streamflow increases the erosion and transportion of sediment from hillslopes and river channels; deposition of this debris in the lower reaches of the Toutle and Cowlitz Rivers reduces

Newly incised drainage channel on Smith Creek in the blast zone. Rapid erosion following the May 18 eruption carved new stream channels that have subsequently deepened and widened. This channel, for example, was 25 meters wide and 6 meters deep in September 1980; 1 year later, the channel was almost 60 meters wide and 11 meters deep. Note the remains of trees in the channel, and the people shown for size.

Mudflow line on Muddy River on October 23, 1980. During the May 18, 1980, eruption, numerous lahars were generated on the upper western, southern, and eastern flanks of Mount St. Helens. Nearly 20 bridges were destroyed, and several kilometers of road were buried. The lahars were dense, viscous slurries of poorly sorted gravel, sand, mud, and water. Trees were bent in the direction of the flow and stripped of their bark. Mudlines were left on standing trees. Note the height of the mudlines as compared to the scientist, top right.



Cross sections of the Cowlitz River at Castle Rock gage immediately downstream from the confluence of the Toutle River. Between October 1981 and September 1982, the channel progressively filled with sediment. The U.S. Army Corps of Engineers has periodically dredged the channel to reduce potential flooding.

channel depths, thereby increasing the possibility of flooding. Flood levees, channel dredging, and debris-retention structures built by the U.S. Army Corps of Engineers have thus far prevented serious flooding to communities along the Toutle and Cowlitz Rivers.

Lahars, or mudflows, and floods accompanying the May 18 eruption rushed down nearly all the streams draining the volcano and spread over valley floors, raised channel beds, and destroyed roads, bridges, and homes. Lahars formed during the initial blast, and pyroclastic flows occurred in the Smith, Pine, and Muddy River drainages on the east flank of the cone and in the South Fork Toutle River on the west flank. The most voluminous and destructive lahar originated by the slumping and flowing of water-saturated parts of the debris-avalanche deposit. This lahar peaked near the mouth of the Toutle River at midnight and left deposits 1 meter thick on parts of the flood plain and 5 meters thick in the channel. These deposits immediately reduced channel depths and increased the possibility of flooding along the Toutle and lower Cowlitz Rivers. Smaller lahars were formed by the melting of debris-laden ice and snow during the afternoon of May 18.

The debris avalanche that triggered the eruption slid north into Spirit Lake and west 25 kilometers down the North Fork Toutle River valley, covering the valley floor with unconsolidated debris to an average depth of 45 meters and as much as 180 meters in some places. Rapid erosion resulting from the breaching of numerous ponds and lakes on the deposit and surface runoff have produced a new drainage system on the avalanche. Streams following the initial drainage pattern quickly eroded narrow channels because of the generally steep slopes and the readily erodible character of the avalanche deposit. Channels more than 300 meters wide and 45 meters deep have been carved by the new North Fork Toutle River. Nearly 4 years after the devastating eruption, erosion rates remain high, and the channels display complex, alternating scour-and-fill sequences.

The avalanche debris filling the North Fork Toutle River Valley consists of unconsolidated, poorly sorted volcanic debris. Approximately 60 square kilometers of valley were buried to an average depth of 45 meters and as much as 180 meters near Spirit Lake.
▼

Debris-Dammed Lakes

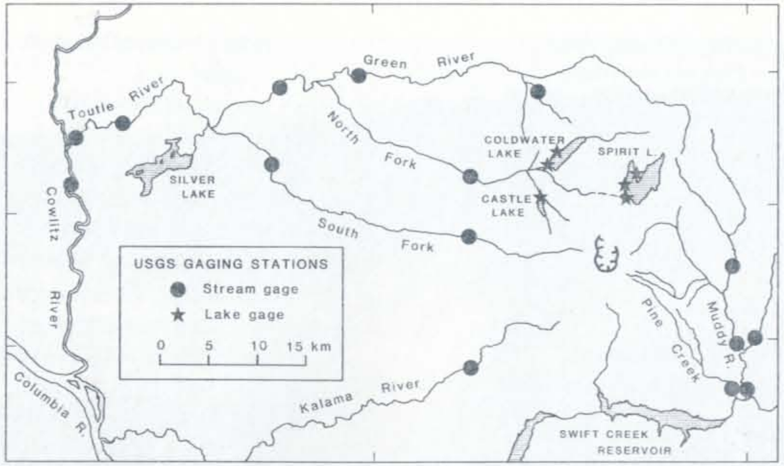
The debris avalanche raised the level of Spirit Lake 64 meters and dammed its natural outlet even higher. Many small ponds filled closed depressions on top of the avalanche deposit, and several lakes formed in tributaries dammed by the avalanche; the largest lakes formed in the tributaries of Coldwater and Castle Creeks. In late 1980, some of the ponds overtopped and swiftly eroded their new outlets. The rapid release of water generated highly erosive flows on the avalanche and transported large volumes of sediment down the lower reaches of the Toutle and Cowlitz Rivers.

Failure of the debris dams holding Spirit, Coldwater, and Castle Lakes would result in catastrophic mudflows comparable to or larger than those of May 18, 1980. Controlled outflow channels have been constructed to stabilize the water levels of Coldwater and Castle Lakes, and water from Spirit Lake is currently being pumped into the Toutle River by the Corps of Engineers as a temporary measure to control its level. Permanent solutions are being considered to alleviate the flood threat from Spirit Lake.

The Geological Survey gathers information on hydrologic hazards at Mount St. Helens in the following ways: (1) by measuring the annual rates of erosion, transportion, and deposition of sediment along streams draining the volcano, (2) by monitoring the water elevations and the stability of the debris dams impounding Spirit, Coldwater, and Castle Lakes, and (3) thorough research on the flow characteristics of lahars and streams with high sediment loads.

Spirit Lake with Mount Rainier in the background, September 1, 1982. On May 18, part of the debris avalanche slid into Spirit Lake, raising its level nearly 60 meters and damming its natural outlet to a higher level. Water displaced by the avalanche surged up the surrounding hillslopes, washing the blown-down timber from the lateral blast into the lake. Water currently is being pumped out of Spirit Lake to prevent it from overtopping its dam.

Coldwater Lake behind the avalanche deposit. Tributaries of the North Fork Toutle River were dammed by the massive debris avalanche deposit and subsequently formed lakes behind the blockages. The largest of these are Coldwater and Castle Lakes. Outlet channels were constructed in 1981 and 1982 to prevent the lakes from overtopping their dams.



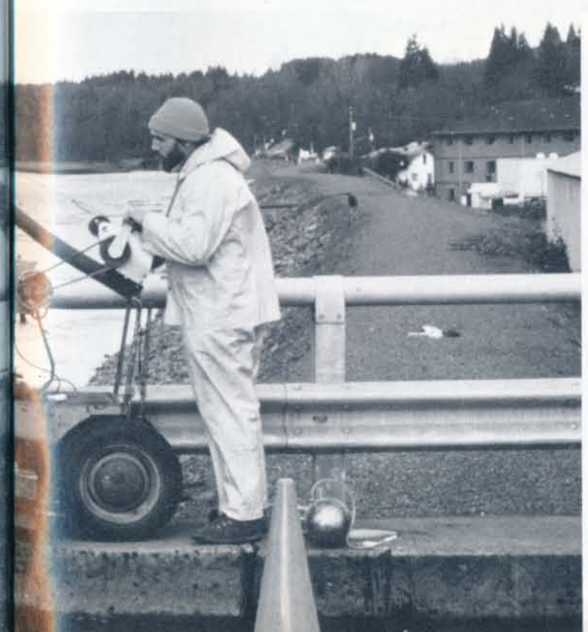
Locations of stream and lake gages maintained by the U.S. Geological Survey. The gages are operated in cooperation with the National Weather Service and the Federal Emergency Management Agency as part of an early warning system in case the debris dams fail.

Erosion, Transportation, and Deposition of Sediment

Water and Sediment Discharge Measurements

Thirteen gaging stations were constructed after the May 18 eruption to measure water and sediment discharge of the rivers draining Mount St. Helens; these stations supplement those already in place on reservoirs and rivers around the volcano. Gaging stations continuously record the water-surface elevation or stage of a river. Stream discharge is calculated from the relationship between this recorded stage and periodic manual discharge measurements. Hydrologists also collect water samples at the gage sites and analyze them to determine total suspended sediment transported by the streams.

The network of river gages provide information for flood forecasting and for long-term sediment-transport trends. These data are used by the National Weather Service to warn of severe flooding conditions and by the Corps of Engineers to develop sediment-control solutions.

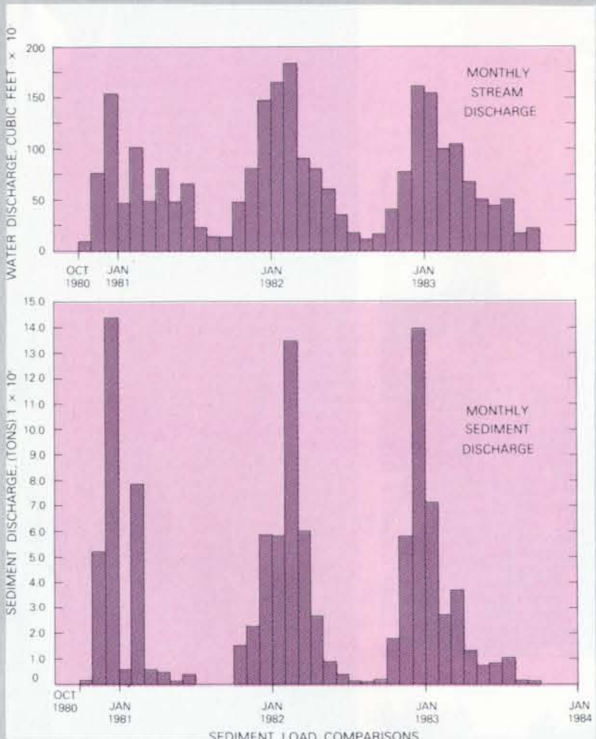


Taking sediment samples in the Cowlitz River at Castle Rock, Washington, on February 20, 1982. (Photograph by Terry Leighley, Sandia Labs.) ▶

Stream gaging in the Toutle River, near Tower, Washington, on December 5, 1981. ▶

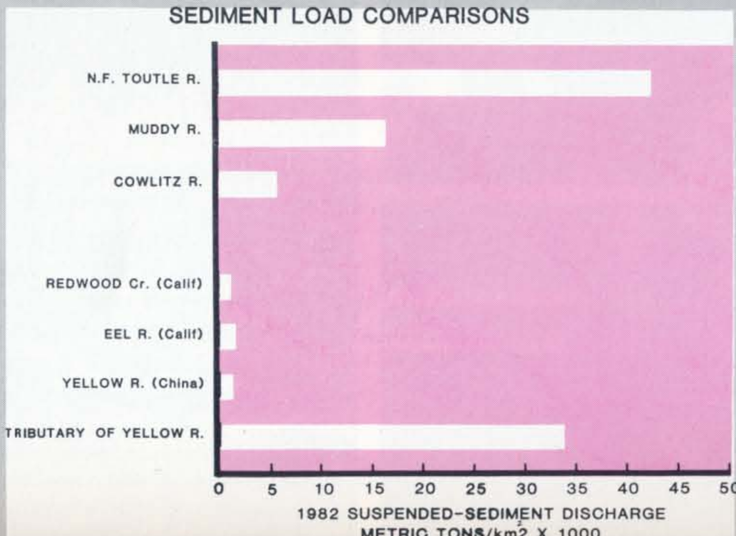
U.S. Geological Survey scientist Al Onions taking suspended sediment samples along Highway 99 near Castle Rock, Washington, on December 5, 1982. ▼

Since May 18, 1980, sediment transport rates for the rivers flanking Mount St. Helens, especially the Toutle River, have been among the highest in the world. More than 20 million tons of suspended sediment was transported from the Toutle River basin in the first 7 months after the May 18, eruption, or 15 million tons in only 13 days. About 39 million tons of suspended sediment was transported from October 1981 to September 1982, enough to cover an average city block to a depth of 8 kilometers. Since 1980, storms have been of only low to moderate intensity; consequently, less than 5 percent of the total volume of the avalanche deposit has been removed by erosion, so it will persist as a sediment-management problem for many years.



Relationship between stream discharge and suspended sediment load for the Toutle River near its confluence with the Cowlitz River.

Comparison of 1982 sediment load for rivers around Mount St. Helens and other rivers in the United States and China.



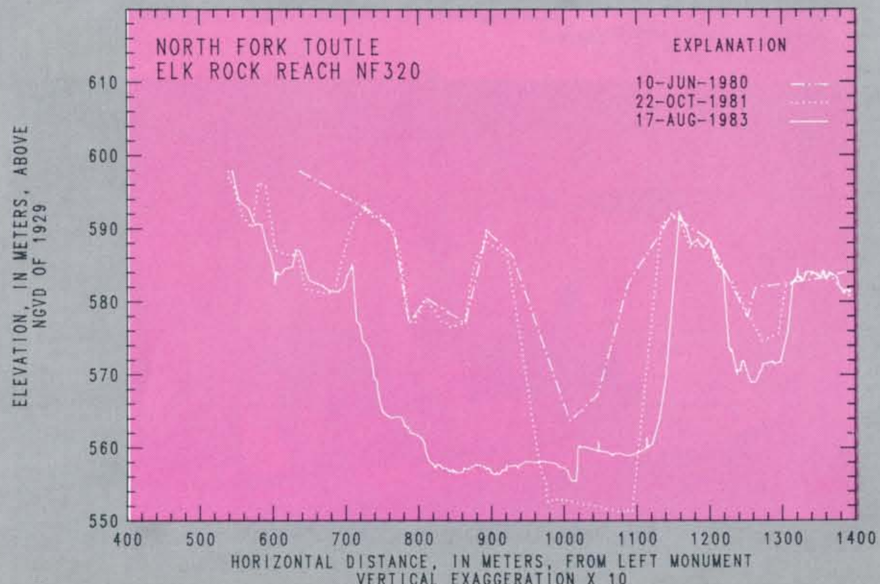
Surveying an erosion channel in a mudflow along the upper Muddy River on June 26, 1981. (Note people at top and bottom for scale.)

Airboat used for cross-sectional measurements on the Toutle River, October 1982. (Photograph by Pat Pringle.)

River-Channel Surveys

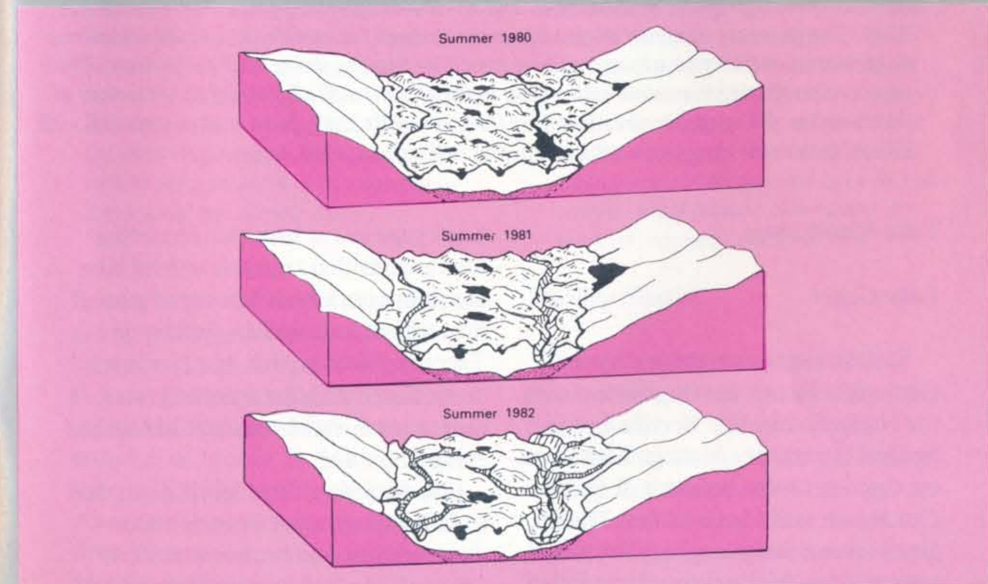
More than 150 cross sections of river channels are surveyed regularly to determine areas of erosion and deposition along rivers draining Mount St. Helens. These repetitive surveys measure bank and channel erosion and channel deposition at specific locations. Repeated aerial photographs also are used to identify sediment sources and sinks.

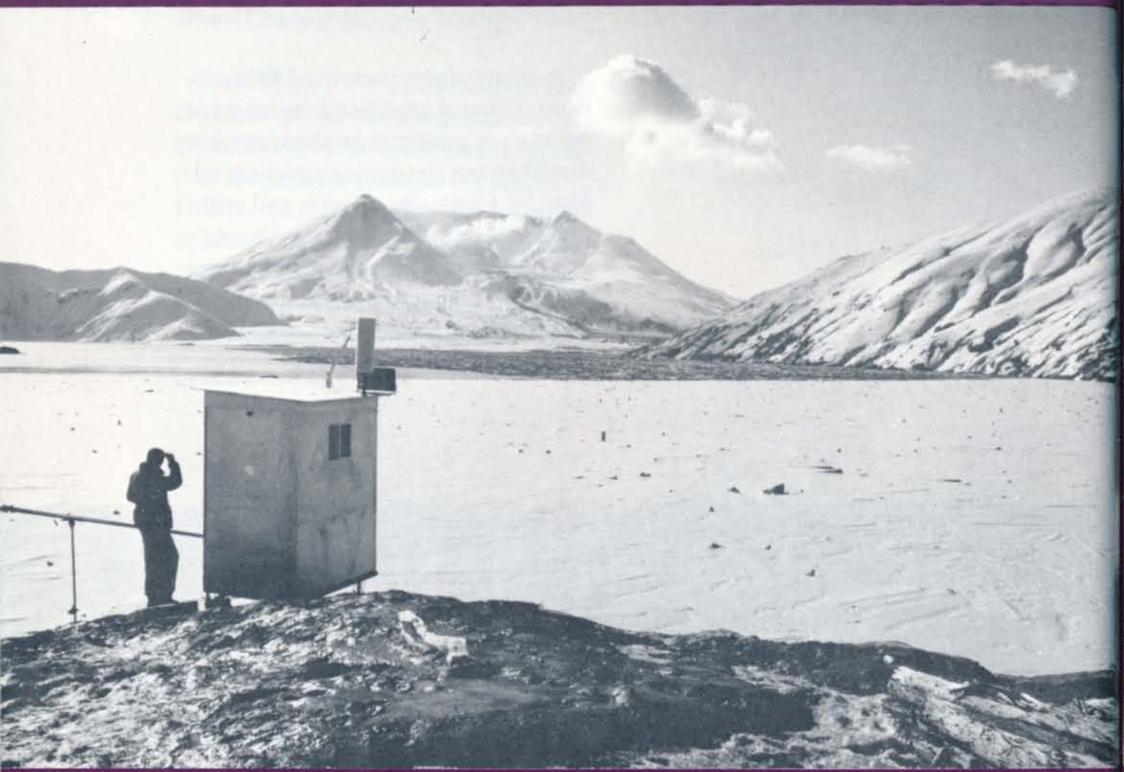
Cross section of the debris-avalanche deposit on the North Fork of the Toutle River at Elk Rock Reach. Depth profiles clearly show how the river quickly cut new channels after the May 18, 1980, eruption.



In many places since the 1980 eruptions, channel modifications have been equal to or greater than those resulting directly from the damaging lahars on May 18. Generally, erosion and sediment transport by channel widening and downcutting dominate the upper reaches of the drainage basins, and aggradation and sediment transport dominate the lower reaches.

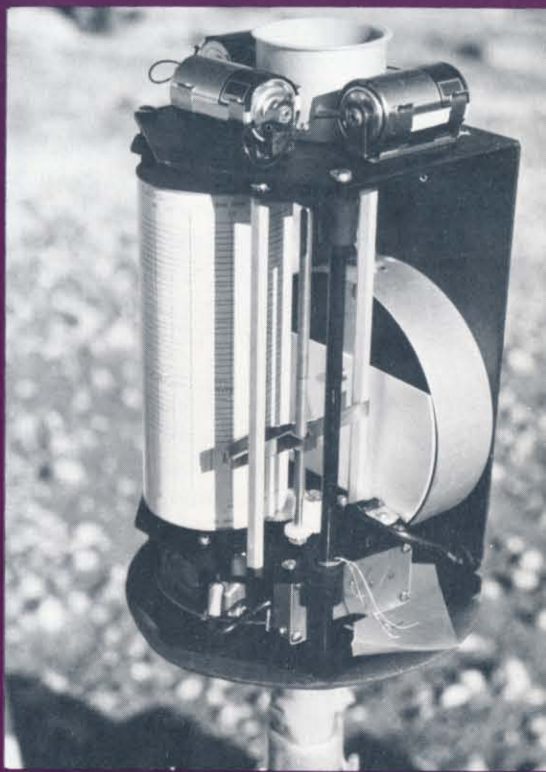
The development of drainage in the Toutle River Valley from 1980 to 1982 in the debris-avalanche deposits. The gully is about 305 meters wide and 46 meters deep. Stippled area represents pre-1980 deposits. The drainage development involved (1) an initial drainage pattern into the avalanche deposits, (2) the breaching of small ponds and lakes, rapid incision, and widening of channels, and (3) continued downcutting, widening, and complex scour-and-fill sequences. (Drawing by Bobbie Myers.)





A lake gage on the north side of Spirit Lake on February 5, 1983. A network of lake gages at Spirit, Coldwater, and Castle Lakes are designed to give warning to downstream residents if one of the debris dams fails, and another is downstream 18 kilometers at Elk Rock. The gages are designed to give advance warning if any of the impounded lakes rise or break out or if there is a massive flood-mudflow heading down the Toutle River. The gages are set to trigger an alert with a drop in the elevation of a lake level or with a rise in the elevation. The gage pictured is one of three on Spirit Lake. Spirit Lake is covered with ice and snow near the gage, with floating logs still visible on the surface.

Telemetry system used for the stream and lake gages. Data from the gages are transmitted by satellite to Geological Survey offices in Vancouver and Tacoma, Washington. Technician Jonathan Brown is programming the GOES satellite transmitter which is coupled to the stream stage recorder. (Photograph by Terry Leighley, Sandia Labs.)



Rain gage set up near Mount St. Helens. A network of weighing bucket and tipping bucket rain gages was set up in 1980 around Castle, Coldwater, and Spirit Lakes to assess rainfall patterns around Mount St. Helens. The information is used to help assess lake levels and fill. Some data are telemetered back to Vancouver, Washington; other gages are serviced manually once a month.

Lake Monitoring

Lake Gages

Six lake gages, maintained by the Geological Survey in cooperation with the National Weather Service and the Federal Emergency Management Agency, monitor the water levels of Spirit, Coldwater, and Castle Lakes. The gages serve as an emergency warning system if one of the debris dams fails. Each gage has at least two recording instruments that transmit several lake elevations each hour by way of a satellite to a ground receiving station in Tacoma, Washington. If a lake level drops faster than the specified rate, alert transmissions send lake elevations every 5 minutes.

Overtopping of the debris dams due to filling from normal precipitation was considered to be the most likely cause of lake breakouts and resulting floods; controlled outlet channels and the Spirit Lake pumping operation have eliminated this possibility. However, a sudden influx of a large volume of volcanic debris from an eruption of Mount St. Helens could raise rapidly the level of Spirit Lake. An eruption producing pyroclastic flows more voluminous than those of May 18, 1980, would be necessary to cause overtopping.

Stability Studies

Several geologic and geophysical studies evaluate and monitor the potential instability of unconsolidated material that blocks the lakes. Failure of these debris dams could result from slumping of the dams, liquefaction from shaking during earthquakes, or headward erosion of gullies and channels. The studies suggest, however, that these possibilities are unlikely in the near future.

A seismic zone about 1,000 kilometers long trends north-northwest through Mount St. Helens and beneath the debris-avalanche deposit. During recent decades, several significant earthquakes have occurred along this zone, the largest of which was magnitude 5.5 and occurred in February 1981. Ground-water wells and seismometers on the surface of the avalanche deposit and in holes 6 to 30 meters deep are used to monitor the response of the unconsolidated debris to earthquake activity.

The relatively narrow debris blockage at Castle Lake is most subject to slumping or gravitational failure. Instruments in drill holes as deep as 30 meters monitor slope movements of the Castle and Spirit Lake dams, and ground-water tables are recorded at all three lake blockages. Erosion is monitored by repeated photographs and channel geometry surveys.

Research

The Hydrologic Monitoring Program provides hazard information and improves understanding of the hydrologic processes involved in the devastation and recovery of areas affected by the May 18, 1980, eruption and lahars. Information collected by the monitoring techniques are used to investigate factors affecting the stability of stream channels and the fluid dynamics of flows that transport high sediment loads.

The May 18 lahar deposits and small debris flows that continue to occur on the volcano also help hydrologists to interpret deposits in the historic record at Mount St. Helens and other Cascade volcanoes. Newly recognized pre-1980 lahar deposits in the Toutle River valley are interpreted to have been emplaced from previous breakouts of Spirit Lake. Lahar-hazards studies on Mount Hood Volcano in northern Oregon also have been aided greatly by the study of recent deposits at Mount St. Helens.

Mount St. Helens offers an unusual opportunity to study the flow characteristics of lahars and debris flows and to develop models for predicting their behavior and effects downstream. Information from these studies and the development of better scientific techniques will continue to improve understanding and the expertise needed to manage water resource problems caused by future volcanic eruptions.

This issue is very much larger than usual. We felt that the importance Mount St. Helens has had as a scientific phenomenon, as well as the special efforts of the U.S. Geological Survey staff at the Cascades Volcano Observatory in compiling these articles and illustrations, warranted a single issue rather than two separate issues. We hope you agree.

Henry Spall

About the Authors

Steve Brantley received his undergraduate degree in Geography from Oregon State University, Corvallis, Oregon, in 1980. Since then, he has been with the Cascades Volcano Observatory participating in hydrologic and volcanic studies at Mount St. Helens and other volcanoes, including Kilauea volcano in Hawaii, and at Yellowstone and Long Valley calderas. Currently, as the Observatory's public information scientist, he assists the scientist-in-charge in providing information to the public about the continuing activity at Mount St. Helens via the news media, presentations, and general interest publications. He enjoys backpacking, climbing, skiing, travel, and woodworking.

Lyn Topinka has been with the U. S. Geological Survey for 10 years. An interest in photography led her away from a computer career to her current position as staff photographer with the Cascades Volcano Observatory. She began photographing Mount St. Helens in April 1980, and since then, has photographed many aspects of Mount St. Helens and other Cascades volcanoes. She also has been working on a photographic data base and retrieval programs to better access the photographic archives of Mount St. Helens.

Conversion Table

To convert from metric units to U.S. Customary units, multiply Column A by Column B to get Column C:

A	B	C
Millimeter	0.0394	Inch
Centimeter	0.3937	Inch
Meter	3.281	Foot
Kilometer	0.6214	Mile
Square kilometer	0.386	Square mile
Cubic meter	35.31	Cubic foot
Cubic kilometer	0.2399	Cubic mile
Microradian	0.02	Second of arc

PUBLIC DOCUMENTS DEPARTMENT
WASHINGTON, D C 20402

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

POSTAGE AND FEES PAID
U.S. DEPARTMENT OF THE INTERIOR
INT 413

U.S.MAIL

Third-class
rate

U.S. Geological Survey scientist surveying the dome inside the crater of Mount St. Helens volcano, Washington, on August 22, 1981.