U.S. Department of the Interior/Geological Survey

The Eruption of Mount St. Helens:
Entering the Era of Real-Time Geology

Reprint from: U.S. Geological Survey Yearbook, Fiscal Year 1980

The March 27, 1980, eruption of Mount St. Helens formed these two craters; later eruptions fused them into one.

Cover photograph; Mount St. Helens, Washington, as it appeared in 1978.

The Eruption of Mount St. Helens:
Entering the Era of Real-Time Geology

by Robert L. Wesson

Time generally means something different to geologists than it does to others. The geologists' common view of time is like looking through the wrong end of a pair of binoculars. All the myriad events that mark the passing of our daily lives—the passage of the seasons, rains and thaws, floods and droughts, growth and death—are tightly compressed into a murky record of mountain building and erosion, of the deposition of sediments and the weathering of exposed rocks, of evolution and extinction. The geologic history which has been pieced together by the investigations of geologists extends back 4.5 billion years to the origin of the Earth. This history is characterized by spatial changes on a grand scale—the movement of continents, the opening and filling of ocean basins. Generally, however, these movements take place so slowly as to be virtually imperceptible to man without the aid of instruments developed only recently. The general uniformity and continuity of geologic processes through this 4.5 billion years are central to geologists' approach to understanding the Earth, its resources, and its hazards. However, not all geologic processes occur at continuous imperceptibly slow rates. Indeed major geologic changes can be accomplished in days or even minutes. No more powerful recent reminder of the Earth's capacity for sudden and catastrophic change can be cited than the explosive and disastrous eruption of Mount St. Helens on May 18, 1980.

U.S. Geological Survey scientists had their collective eye on Mount St. Helens over the years and, as a consequence, were able to advise local, State, and Federal officials about the threats from the volcano such that many hundreds, perhaps thousands, of lives were saved. This successful experience vividly demonstrates the geologist's increasing capability to switch his geologic vision from the long view of thousands or millions of years, to the short view of days and weeks; from a history of Mount St. Helens over the last 40,000 years and especially the last 4,500 years to an estimate of what the mountain will do today — and tomorrow.

In the past, geologists—and the Geological Survey—have used their understanding of geologic history, and the processes which shape it, principally to answer "where" and "what" questions—questions about the location and physical description of geologic deposits or features, such as, where are mineral deposits or petroleum resources located? Increasingly, geologists are being asked "when" questions:

The May 18, 1980, eruption of Mount St. Helens in the Cascade Range, Washington.

When will the next major earthquake strike California? When will we run out of ground water in the high plains of the West? When will the next Cascade Range volcano erupt explosively? The new tenor of these questions presents serious challenges to the earth sciences and to the Geological Survey in particular. The scientific challenges are severe, requiring answers to questions, many of which, so far, at least, are beyond our grasp; but no less difficult are the challenges to the Geological Survey, and to society, of how to use predictive information about geologic hazards.

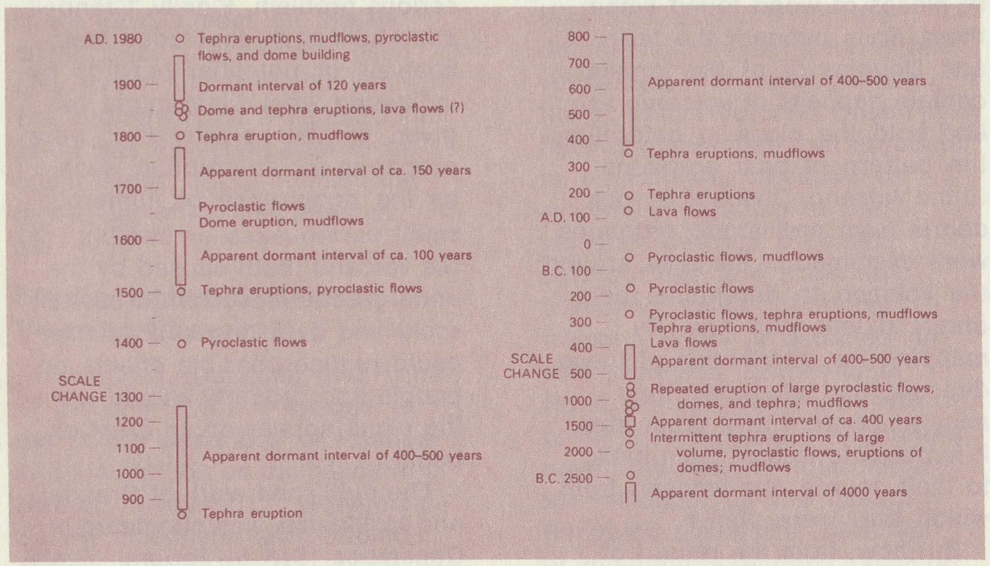
What are these challenges? And how is the Geological Survey meeting them? The scientific challenges are the challenges of understanding; the institutional and societal challenges are of communication, education, and the understanding of risk.

Research and the Long View: Basis for Prediction

There can be no scientifically credible warning without a thorough understanding of the geologic history and of the geologic processes at work. The path leading to this understanding is not a straight one nor one which can be cut short. It is, in all likelihood, a circuitous and torturous path which must be followed step by step, with flashes of insight followed by dead ends and backtracking. Each step, whether forward or backward, adds some small bit to the total understanding. The investment of research does not always pay off immediately, nor is the final payoff always evident while the work is being done. With the eruption of Mount St. Helens, three long-term research efforts paid off handsomely. Only one of these was aimed directly at the volcanic hazards posed by Mount St. Helens. Perhaps even that was a long shot. What were these areas of research? And how did they come to pay off?

Hazard studies of Mount St. Helens

Geologic studies of the volcanoes of the Cascade Range began in 1841 with Charles Wilkes' U.S. Exploring Expedition. However, the documentation of the hazards posed by them, and particularly by Mount St. Helens, was done by the career-long efforts of Geological Survey geologists Dwight R. Crandell, Donal R. Mullineaux, and their collaborators. The investigations of Crandell and Mullineaux included the construction of a detailed history of the activity of Mount St. Helens over the last 4,500 years. During this time, the volcano experienced several apparently dormant intervals of about 100 to 150 years and some dormant intervals as long as 400 to 500 years. Throughout this 4,500 year period, however, the dormant intervals were repeatedly interrupted with periods of activity which included numerous explosions, eruptions of ash, hot avalanches of rock debris, the building of domes, emission of lava and the flows of volcanic debris, and flows of mud and ice off the glacier-mantled slopes of the volcano. This history led Crandell and Mullineaux to conclude in their hazards report, published in 1978, that, "Mount St. Helens has been more active and more explosive during the last 4,500 years than any other volcano in the conterminous United States . . . Mount St. Helens has had a long history



Eruptions and dormant intervals at Mount St. Helens since 2500 B.C.:The circles represent specific eruptions that were observed or that have been dated or closely bracketed by radiocarbon age determinations; the vertical boxes represent dormant intervals.

of spasmodic explosive activity, and we believe it to be an especially dangerous volcano because of its past behavior and the relatively high frequency of its eruptions during the last 4,500 years. In the future, Mount St. Helens will probably erupt violently and intermittently just as it has in the recent geologic past, and these future eruptions will affect human life and health, property, agriculture, and general economic welfare over a broad area."

The record of Mount St. Helens' history was deciphered by a combination of classical geologic mapping and stratigraphic studies with modern techniques. These studies included geochemical analysis to trace deposits from prehistoric falls of ash by their "mineralogical fingerprints" and to determine the age of deposits by radiocarbon analyses of pieces of wood found within them. Soils beneath the ferns and Douglas fir of the forests contain deposits of volcanic ash and hold the clues to determine the pattern of past eruptions of the volcano. Deposits of rock debris from prehistoric eruptions were examined in the area around the volcano to determine their origin, extent, and age. By mapping the distribution of these deposits and analyzing their mineral content and grain size, it is possible to trail them back to their source: the volcano from which they were spewn.

But how, from the record of past eruptions, can future hazards be estimated? A critical assumption was made that eruptions in the future will be of the same general type and have the same general effects as those in the past. Using this kind of approach, Crandell and Mullineaux described a set of "hazard zones." The first zone was on the flanks of the volcano and along valleys leading from it, which would be endangered by lava flows, mudflows, pyroclastic flows (avalanches of hot rock debris ash), and floods. The second zone was in the nearby and downwind areas which would be endangered by the ash fall. These zones were further differentiated by the frequency with which parts of the zone were affected by past eruptions. The potential for flooding caused by flows of mud into the reservoirs behind power dams on the Lewis River, which drains the south and east sides of the mountain, was viewed as a particularly serious problem. Finally, Crandell and Mullineaux concluded their analysis of potential hazards by indicating what hints might be given by the volcano if it were preparing for an eruption, such as the occurrence of numerous small earthquakes or swelling of the volcano (both caused by the underground movement of molten rock) and by listing actions that could reduce possible effects on people and property should warning signs appear or an eruption begin.

The published work of Crandell and Mullineaux was circulated in December 1978 to Federal, State, and local officials and was supplemented by a meeting with

USGS scientist installs portable seismic recording equipment on flank of Mount St. Helens.

key officials and with personal discussions. But, understandably, concern about an event in a sparsely settled region was accorded relatively little attention; the event might have localized impact and be of passing interest only every 100 years or so and might have impact on places distant from the volcano itself only every 500 to 3,000 years. The probability of a catastrophic event was low compared to frequent floods, not to mention the day-to-day crises that affect us all.

Studies at the Hawaiian Volcano Observatory

Fountains, cascades, and rivers of glowing lava are images of the active volcanoes of Kilauea and Mauna Loa on the island of Hawaii. Since 1912, Geological Survey scientists have studied, and have been trained, in this unique natural laboratory of volcanic processes. The very fluid lava of Hawaii is revealed by the smooth, gently sloping forms of the Hawaiian volcanoes as compared to the thick viscous lava that produced the steep, sometimes rugged character of most Cascade Range volcanoes. The difference in the fluidity of lava also accounts for the difference in the behavior of the volcanoes. The investigations at the Hawaiian Volcano Observatory have demonstrated that eruptions in Hawaii are preceded by systematic swelling of the volcano, swarms of small earthquakes, and a periodic trembling called "harmonic tremor" which is detected on seismographs. Eruptions of Hawaiian-type volcanoes are rarely explosive but, nevertheless, have potentially serious impacts for residents on the island. Repeated successful warnings of impending eruptions based on swelling of the volcano and swarms of earthquakes gave a generation

The cooled, solidified surface of Kilauea Iki lava lake, Hawaii.

of Geological Survey scientists experience not only with the active science of volcanology—albeit in quite a different geologic setting from Mount St. Helens—but also experience in dealing with officials, the press, and the public before, during, and after an eruption.

Earthquake and geothermal studies in the Cascade Range

The active geologic process in the Cascades—of which Mount St. Helens is a part—has other manifestations: earthquakes and geothermal energy. Since 1973, the scientists at the University of Washington, supported by and in cooperation with the Geological Survey, have studied the occurrence of earthquakes in the Puget Sound-Cascade region of Washington State. The core of these studies has been the establishment of a tool for basic research: a seismographic network. Studies of the potential for geothermal power associated with the active volcanic regions of the Cascade Range led to an expansion of the network, with the motive of using the occurrence of earthquakes—and studies of the propagation of seismic waves from them—for locating "hot" regions of the Earth's crust and of developing an understanding of the origin of these hot regions. As it turned out, this seismic network and the joint University of Washington-Geological Survey project were to give the first clues that Mount St. Helens was about to awaken from her 123-year sleep.

Earth Scientists Refocus From the Long View To the Short View

On March 20, 1980, the vicinity of Mount St. Helens was shaken by a magnitude-4 earthquake. The location of the earthquake, as determined by the seismograph network which included one station near the volcano, was at shallow depth immediately northwest of the summit. However, this earthquake was only the first of an intense sequence or swarm of earthquakes. Both the magnitude and number of these earthquakes were unusual for the Pacific Northwest, and their location directly beneath the volcano was immediately recognized as the possible symptoms of an impending eruption. What was the probability of an eruption? And, if the mountain did become active, what precisely would happen? No one knew. The possible scenarios for an eruption, or noneruption, were many, but no one knew how to assess the relative probabilities of the possible scenarios. Geological Survey and University of Washington scientists, working together, began to install portable seismograph equipment and to expand the permanent seismograph network, an exercise which has become commonplace following almost every significant earthquake or earthquake sequence in the United States. One of the principal aims of this effort was to try to determine whether this earthquake sequence was indeed symptomatic of molten rock moving beneath the volcano. As the days passed, the number of earthquakes increased, and the comparison with preeruptive sequences at other volcanoes became more compelling. Snow avalanches, triggered by the earthquakes, led to the closing of the upper slopes of the volcano by the U.S. Forest Service. By March 25, the frequency of magnitude-4 earthquakes reached a level of as many as eight per hour. Sightseers flocked to the area hoping for a glimpse of some activity. On March 26, the immediate vicinity of the volcano was closed on the basis of the potential hazards from an eruption.

On March 27, the Geological Survey issued a cautiously worded but formal "Hazards Watch," indicating that Survey scientists did not "have adequate hard information to determine whether an immediate volcanic eruption will or will not occur. Furthermore, it is not possible at this time to indicate which of the possible geologic effects of the eruption might take place or whether these effects might be experienced only very locally on the volcano or over a wider area." However, the Hazards Watch summarized potential dangers as indicated in the work of Crandell and Mullineaux.

That day the volcano began to erupt steam and ash. Following the actions recommended in the USGS publication, U.S. Forest Service and State and local and

Scientist examines earthquake data as recorded on a seismograph located near Mount St. Helens.

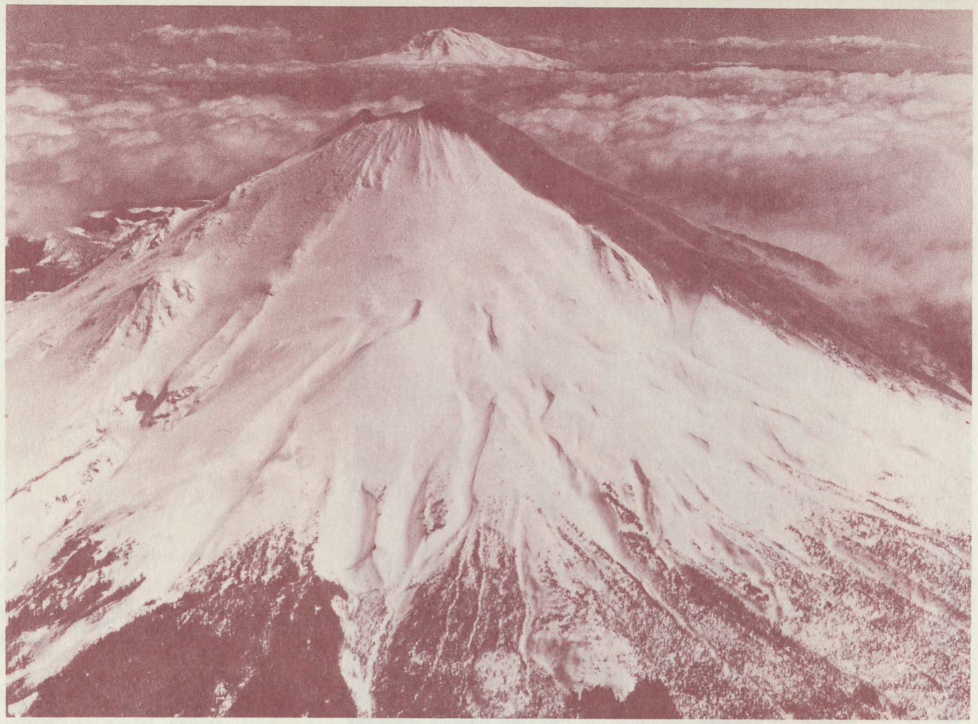
other emergency officials evacuated people from the immediate area.

It was a chaotic time. The event captured the imagination of the Pacific Northwest and the Nation. No volcano had been active in the conterminous United States since 1921. The pressure from the news media was intense. Demands for interviews were so great that scientists could not comply with all and still perform their work. Sightseers jammed the roads leading from the volcano and blocked possible evacuation routes. In addition, many sightseers evaded road blocks hoping to get a closer look.

Analyses of ash indicated that so far only rock fragments were involved; no new molten rock had been ejected. But on April 1 and again on April 2, University of Washington and Geological Survey scientists recognized the first sign of harmonic tremor, which normally is associated with the movement of molten rock. On April 3, the Geological Survey updated its Hazards Watch, indicating that "the harmonic tremors . . . are the best indications so far that magma (molten rock) is involved and moving underground. We still cannot predict, however, whether this apparent subsurface movement of magma will break through the surface to produce an eruption of molten material." Governor Ray of Washington called out the National Guard to help maintain the closure of an area around the volcano to all but property owners and scientists. These moves were unpopular and contested, particularly by loggers excluded from the forest.

USGS volcanologist David Johnston uses a correlation spectrometer to measure the sulfur dioxide content of gases ejected during an eurption of Mount St. Helens.

Following the first phase of the steam and ash eruption of March 27, a major system of cracks across the summit crater was observed, suggesting the spreading of the north flank of the mountain. Throughout the first 3 weeks of April, evidence of the bulging of the northern slope of the mountain accumulated; visual observations of the cracking and slumping of the glaciers and bedrock were substantiated by photogrammetric surveys and geodetic measurements. By April 25, instruments were in place to monitor the expansion of the bulge on a daily basis. The measurements carried on through early morning on May 18 indicated steady northward expansion of the bulge at rates of 0.5 to 2 meters per day. As the bulge grew, so did concern about the potential hazards it posed. On April 30, the Geological Survey again updated its Hazards Watch, indicating that the apparently unstable mass, if triggered by an eruption or earthquake, could lead to a massive avalanche, which in turn could lead to mudflows and floods in the valleys draining the north side of the mountain. "USGS scientists cannot pinpoint the exact cause of the bulge with the available data," the press release said, "but suspect that the bulging may reflect a combination of swelling from the upward movement of viscous (sticky)



The first eruption of Mount St. Helens on March 27, 1980, sent an ash plume approximately 17,000 feet high. Ash from the eruption covers the snow on the right-hand side of this March 31 photograph. Mount Rainier is in the background.

magma and gravitationally induced downward creep. . . ."

Did the U.S. Geological Survey tell—or indeed recognize—the whole story? In hindsight, it seems possible to say that the appearance and expansion of the bulge added substantial weight to the hypothesis that significant molten material was accumulating in the volcano and, consequently, that the odds of a significant eruption were substantially increased. However, the scientists could not reach a consensus. Although many individual geologists and geophysicists made this judgment, even aloud at the volcano, the Survey, through its institutional procedures of hazard warning, was not moved to reach this judgment. Why? Scientific uncertainty, institutional fear of being wrong, substitution of more visible threat of a massive avalanche for the less visible threat of an eruption? Herein quantifiable uncertainty? Where does an established scientific interpretation stop and hunch begin?

Reacting to the advice from the Geological Survey, Governor Ray established two "hazard zones" around the volcano. A "red zone" included the area within a radius of approximately 5 miles from the mountain. Admission to this zone, which included the vacation community of Spirit Lake, was prohibited to all except law enforcement officials and scientists. A "blue zone," which extended 5 miles beyond the red zone in some places, was under the same prohibitions as the red zone, except that logging operations and visits by property owners were permitted, but no overnight stays were permitted. The zones were unpopular. They were violated by journalists and scientists in helicopters and by curiosity seekers. Loggers and property owners, excluded from their homes, were particularly critical. The bulge, ominous as it was to geologists, did not seem to bother oldtimers of the region, or even some of the scientists working in its shadow, who seemed unable to grasp the danger from a potentially explosive volcano.

As scientists monitored the bulge and considered its implications, and as picnickers gathered at road blocks waiting for a view of a plume of steam or ash, owners of private property began to demand access to their cabins and houses to gather their possessions. Finally on May 17, property owners were allowed into the red zone by signing releases and agreements that they would be out before nightfall.

View of the fractured surface of the bulge on the north side of Mount St. Helens taken just a few days before the violent eruption of May 18, 1980. Before the eruption, this bulge had been expanding outward at the rate of 5 feet per day.

The Picnic Becomes a Nightmare

On the morning of May 18, the picnic became a nightmare. Mount St. Helens erupted catastrophically. The north side of the mountain collapsed in an avalanche, almost certainly triggered by a magnitude-5 earthquake, releasing the pent-up power of the magma with its gas under high pressure. The suddenly unconfined molten rock and gas

The erupting Mount St. Helens, 11 a.m. on May 18, 1980.

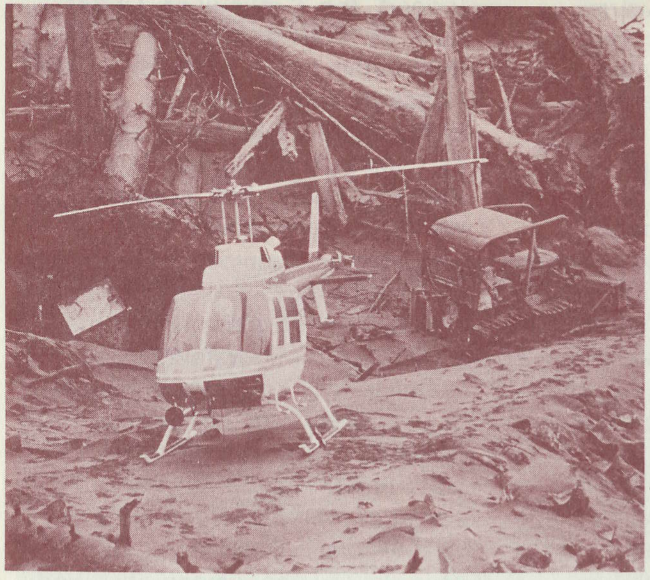
exploded like a bottle of warm champagne suddenly uncorked. The resulting blast devastated everything in a sector extending as far as 16 miles north of the volcano and nearly 20 miles wide.

A massive debris avalanche filled the valley of the North Fork Toutle River for a distance of about 17 miles downstream. Mudflows continued on down the Toutle carrying extremely large loads of sediment, logs, and debris on to the Cowlitz and Columbia Rivers. The deposited sediments blocked the shipping channel in the Columbia and dangerously reduced the ability of the Cowlitz River to carry water within its banks without flooding.

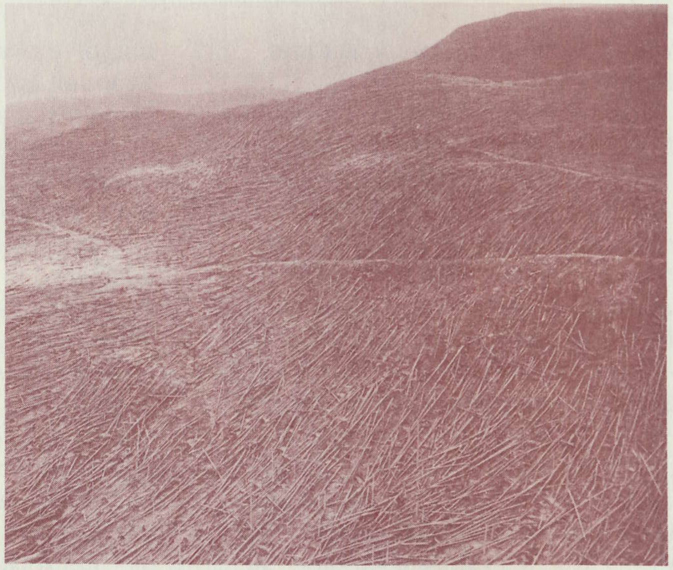
Volcanic ash streamed higher than 12 miles into the atmosphere by the force of the explosion and was carried eastward by the wind to deposit ash in a plume across eastern Washington and into Idaho and beyond. What had formerly been a symmetrical cone —the "Mount Fuji of the United States"—was now a truncated cone, marred by a gaping north-facing amphitheater. The questions of "when" and "how big" had finally been answered. Prior to the eruption, Geological Survey scientists, in describing the range of possibilities, had sometimes in passing mentioned the explosion of Mount Mazama, which formed the famous Crater Lake in Oregon, as an example of an eruption well beyond that which could reasonably be expected at Mount St. Helens. Indeed, the 6-mile-wide Crater Lake is a vivid example of raw destructive power of the explosive Cascade volcanoes. The eruption of Mount St. Helens was small by comparison, but was larger than the public had seemed willing to believe was likely.

What was the most "expectable" size of the eruption and how did the May 18 eruption compare? So far, our understanding of the history of Cascade volcanoes is insufficient to answer the question of the *most* expectable size, either on the basis of statistics of past eruptions or on the basis of the kinds of premonitory phenomena observed —that is, the earthquake, the bulge, the steam eruptions. But Crandell and Mullineaux did make some estimates about the range of possible eruptions and their relative probabilities based on their study of the 4,500 year history of Mount St. Helens. They estimated that eruptions depositing an inch or less of ash within 50 miles or so of the volcano would have a frequency of 1 per 100 years. They estimated that eruptions depositing a few inches of ash at distances of 100 miles and more, as did the May 18 eruption, would have a frequency of 1 per 2,000 to 3,000 years or less. So the May 18 eruption was not a "common" event, but closer to the "worst case." Previous eruptions, however, have erupted much larger volumes of ash.

The course of potentially catastrophic geologic processes such as eruptions and earthquakes may



Part of the destruction after the May 18, 1980, eruption of Mount St. Helens: Scientists used a helicopter to reach the site and to investigate the effects of the eruption.



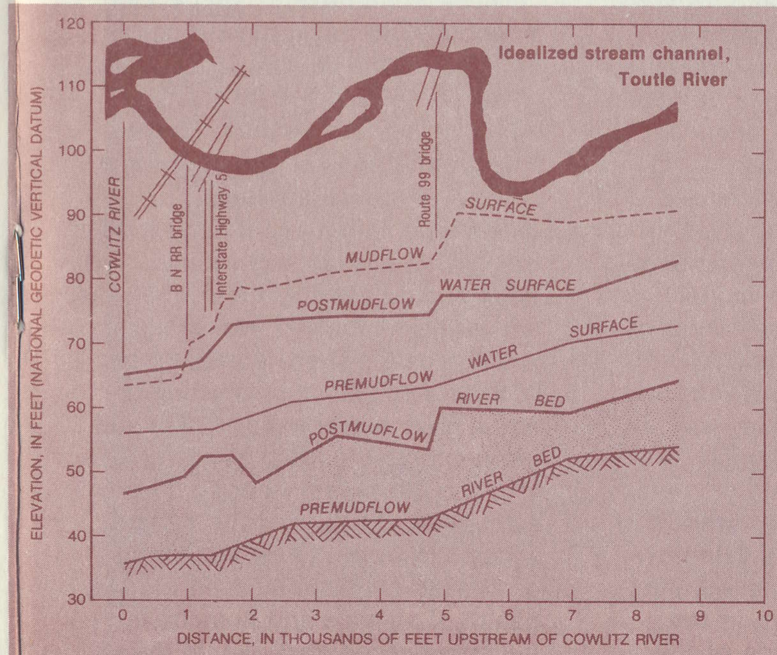
Thousands of trees over a 185-square-mile area were knocked down by the blast of the May 18, 1980, eruption.

depend on many random factors. Indeed, the most surprising aspect of the eruption was the magnitude of the disastrous lateral blast, which devastated the landscape north of the mountain. Although some evidence for much smaller prehistoric lateral blasts was available, geologists had expected the main force of an eruption to be directed vertically upward. Consequently, it may be very difficult, if not impossible, to know in advance from the symptoms of an impending event whether the event will be a "common one" or a "worst case." We would like to think we can solve this problem, perhaps by

determining the volume of molten material available in a volcano or the size of the area over which anomalous phenomena are observed before an earthquake, but there is certainly no guarantee that these ideas will be right. Indeed, prior to May 18, some geologists began to feel that the molten rock, indicated inside the volcano by the bulge and the earthquakes, might solidify inside the volcano in a system of what geologists call "dikes" and, aside from the threat of avalanches and mudflows, be of no particular threat at all. Will the observed symptoms of a geologic process lead to a "worst case," a "common" event or a "nonevent?" This is another key dilemma facing the real-time geologist.

On May 18 and the days after, impacts of the eruption that had not been anticipated by the public were keenly felt by residents of the Pacific Northwest. Although Governor Ray, at the end of April, had declared the entire State an emergency area because of the possibility of widespread ash fall, the volume of the ash which settled like an ominous dark snow over eastern Washington and Idaho created problems of unexpected proportion and nature.

Who had prepared for the problems of operating motor vehicles and machinery in an atmosphere of constant dust stirred up by wind or the movement of vehicles, an atmosphere in which the particles of ash are far more abrasive than common dust? And who in Portland, Oreg., where the spectacular plume of ash on May 18 had provided a thrilling display, expected that the mud and rocky debris carried down the Toutle and Cowlitz Rivers would block the shipping channel in the Columbia



Channel bottom and surface elevation of the lower Toutle River prior to, and after, the mudflows of May 18, 1980: Pre- and post-eruption water surfaces are based on a flow of 38,000 cubic feet per second.

River, temporarily closing the important port facilities in Portland? Or who anticipated the added impact of the thousands of logs stacked at loading yards along the Toutle Valley which were picked up by the mudflows and swept away the bridges along the river as if they were made of paper? Because many of the phenomena dealt with by the real-time geologist occur so infrequently—from the perspective of man—the impacts are commonly unexpected. Preparations require preparing for the unexpected.

As an example, the Cowlitz River channel was found to be clogged with sediment deposits following the floods of May 18; average flows would cause flooding. Meanwhile, snowmelt runoff from the higher elevations of the Cascades was rapidly filling upstream reservoirs. Any significant runoff either from accelerated snowmelt or rainfall would exceed reservoir capacity and result in flooding along the clogged reach of the lower river. Geological Survey hydrologists created a computer model of the river system using new channel surveys, parts of which were provided by the Corps of Engineers and private engineering firms. Output of the model allowed immediate assessment of inundation limits for any Cowlitz River flow rates and provided a realistic basis for warning and evacuating flood-threatened residents.

Hundreds, perhaps thousands, of lives were saved by the establishment of the hazard zones. Some of those who died were in the closed areas in defiance of the closure. People are skeptical, however, about hazard-warning statements contrary to their common experience, particularly when their livelihood is at stake. Fortunately, the eruption occurred on Sunday when logging operations permitted in the "blue zone," much of which was devastated, were shut down. Real-time geologists must learn that they, like Dr. Stockmann of Henrik Ibsen's *An Enemy of the People,* will not always be either popular or even believed by segments of society.

Questions in the Aftermath

What would the volcano do next? Was the debris flow stable? Would the waters dammed behind it be released in further floods? Would the now clogged Cowlitz River be able to contain, without flooding, more water should the reservoir upstream become full?

These were the questions asked immediately after May 18. The prospect of the volcano continuing to be active for 10 to 20 years, as it had in the 19th century, forms a background against which a whole new set of questions began to take shape. When could people go back in to salvage and rebuild? What should be rebuilt and what should be relocated? Would the volcano give a short-term warning of further eruptions as it seemed not to have done on May 18? Could the geologists predict subsequent eruptions in time for people to be evacuated safely from the hazard zones? What would be the effects of the ash on crops and on the health of animals and humans in the affected regions? Would the easily erodible mass of ash and debris in the tributaries of the Cowlitz be mobilized and eroded by winter rains, carrying yet more debris into the Cowlitz and Columbia?

As the months passed, some questions were answered, others deferred. Measurements were made in the clogged channels of the Cowlitz River, and computer models were calculated to determine the amount of water which could be released safely from upstream reservoirs and to determine the inundation limits for potential floods. How long will the activity last? Will the volcano rebuild itself? The volcano, as expected from experience elsewhere, continued its activity, with eruptions on May 25, June 12, July 22 and 28, August 7 and 15, October 16-17, December 27-January 3, 1981, February 5-7, 1981, and April 10, 1981. Volcanic domes were erupted into the crater, then exploded during eruptions of ash. Varying patterns of seismic activity have emerged which seem, so far, diagnostic of these continuing eruptions, enabling warning and evacuation of workers in endangered zones. Other possible precursors, such as gas emissions, seem promising.

The debate about the efficacy of attempts to contain sediment in

The lower portion of the massive debris flow in the upper North Fork Toutle River— the largest known volcanic debris flow of its kind in the world.

the Toutle Valley and to preserve the gains made by dredging in the Cowlitz and Columbia Rivers continues. Flash floods from new mudflows or the breach of dammed lakes were recognized as a threat. An elaborate system of stream and lake gages equipped with real-time data transmission systems has been installed to monitor the movement of water and sediment downstream. It is hoped that sufficient warning of floods can be given to communities along the Cowlitz.

Prior to the eruption, Geological Survey scientists worked closely with the U.S. Forest Service and, as the situation developed, with State and local officials. After the eruption, the number of individuals and entities needing contact with the Geological Survey scientists, elected officials, and their staffs grew rapidly—the Federal Emergency Management Agency, the Corps of Engineers, the Environmental Protection Agency, and many more. The real-time geologist works in a fishbowl. Important decisions based upon individual interpretation must be made by a multitude of persons. Commonly, the decisions must be made immediately, and, even more commonly, questioners must be given help to rephrase their questions so that meaningful answers are possible. The real-time geologist requires a capability for translation and public relations so that the results of his scientific investigations and interpretations can be used by people needing the answers.

Sharpening the Near Vision: Lessons and Challenges for the Real-Time Geologist

The eruption of Mount St. Helens bears many lessons for the Geological Survey and for practitioners of real-time geology. Certainly some lessons are yet to be made clear. Implicit in each of these lessons is a challenge for the future. The lessons and challenges are not limited to the prediction of volcanic eruptions but have wide applicability to anyone who would try to forecast the future behavior of the Earth and the processes which shape it, the prediction of earthquakes, glacier surges or retreats, ground water exhaustion or contamination, or future climatic changes.

The capability for looking into the future, even in an uncertain probabilistic way, will come from basic research into the nature of the geologic processes which may present future hazards; research to determine the history of past events, their nature, their frequency, and their effects; and research into the mechanics, the fundamental physics, and chemistry of the processes. Only through improved understanding can we improve our ability to take the Earth's pulse and estimate its future activity, benign or deadly.

It will not be easy to know exactly what research to do, and the value of the research may not be obvious as it is being done. But the experience of Mount St. Helens emphasizes the value of combining the classical methods of investigation with the modern, of combining historical investigations with the process oriented, and of combining the geological, geophysical, and geochemical approaches. The real-time geologist must utilize the best of the classical methods along with the best of the most modern.

For a long time to come, problems of real-time geology will be at the leading edge of understanding in earth science. From a scientific point of view, this will make them fascinating. From the point of view of society, this will make these problems very difficult because uncertain scientific judgments will require flexible public policies, policies which may not always be as cost effective as they might be if their scientific basis were certain. The possibility must be faced squarely that a predicted event may fail to occur. The science of real-time geology is new. Little, if any, public policy is in place to utilize its results. Policy is exceedingly difficult to develop in advance, in the abstract. The challenge to the real-time geologist is that the public policy will be developed as we go along. Further, the real-time geologist will be asked to help make the policy, an area where geologists have little experience or expertise.

Many problems in real-time geology involve phenomena which pose substantial hazards to life and property. Consequently, the public pays much closer attention to studies in real-time geology than to classical investigations. This poses many problems for the earth scientist unaccustomed to doing his research under the bright lights of the television

A scientist aims a laser beam geodimeter at the rampart surrounding the dome within Mount St. Helens' crater in September 1980 to detect movement. Repeated measurements of movement on the rampart reflect the rise and fall of magma pressure below the crater floor.

cameras. The pressures of the media can easily distort the perspectives of the scientists. In other cultures where less value is placed on openness, public attention need not be a problem, particularly if the impending phenomena has few if any symptoms visible to the naked eye. But in the United States, the public is perceived as having "a right to know," even to know many things which at that moment may be unknowable or, at least, very uncertain.

Emergency preparedness requires leadership. Preparations against an unseen hazard, such as earthquakes, rarely spring from enlightened self interest. So public attention to the scientific findings, uncertain as they may be, is required to motivate public action. At the same time, the public attention and discussion can magnify sometimes subtle differences in judgment among scientists, reducing credibility in the public eye. Intense public attention makes the job of the real-time geologist no easier.

The natural instinct of a scientist is to follow his intuition, wherever the scent of discovery may lead him. Commonly, this instinct creates a tension with the need to plan. Contingency plans, however, must be in place to respond quickly and effectively to the threat or occurrence of a potentially hazardous geologic event.

The list of scientific problems ahead for real-time geologists in the Geological Survey is immensely challenging. What does the future hold for the other potentially explosive volcanoes of the Cascade

New growth begins among the rocks covered by ash from the eruptions of Mount St. Helens.

Range and Alaska? When and where will the next major earthquake strike California? When will the Ogallala aquifer supplying water to the High Plains be exhausted? How can systems be designed and monitored to assure that hazardous wastes do not reach ground water supplies? What is the future of our climate?

The eruption of Mount St. Helens is only the beginning. We have entered the era of real-time geology. The challenges before the U.S. Geological Survey will require the highest quality of geologic research. These challenges will also require, however, substantial growth in our ability to communicate our results and to assist in their interpretation and implementation.

The following sections were supplied by the Office of Earth Sciences Applications, and the Geologic, Water Resources, and National Mapping Divisions of the U.S. Geological Survey.

* * *

Hazard Warning and Preparedness

The hazards warning, preparedness, and technical assistance program is a relatively new responsibility of the U.S. Geological Survey stemming from the Federal Disaster Relief Act of 1974. The hazards warning activity is designed to develop public awareness of geologic-related hazards and encourage long-range mitigation measures. In addition, a hazards warning dissemination service has been developed to insure timely and effective warnings of geologic hazards to affected Federal, State, and local governments. Where possible, technical assistance and advice are made available also. The system for evaluating and transmitting notifications of hazards includes Notices of Potential Hazards, Hazard Watches, and Hazards Warnings (Predictions). The responsibility for the hazards warning, preparedness, and technical assistance program lies in the Office of Earth Sciences Applications, the Survey's unit involved in multidisciplinary projects concerned with the application of earth sciences information to natural resource planning and management.

When Mount St. Helens began showing signs of renewed activity in mid-March 1980, the Geologic and Water Resources Divisions began collecting and assessing data and, with the Office of Earth Sciences Applications, determined that the possibility of an eruption was great enough to issue a hazard announcement to State and local officials. The Office issued a Hazard Watch on March 27, 1980, the day of the initial eruption. Subsequently, the Office became the focal point for dissemination of information on the geologic and hydrologic activity at Mount St. Helens to Federal, State, and local authorities outside the immediate area of the volcano.

The later May 18, 1980, eruption was, for most people, unexpectedly violent and damaging. The Geological Survey was overwhelmed by the need to assess the event and to meet the public and government needs for information and advice. This was particularly so for the Survey's field office in Vancouver, Wash. A representative of the Office of Earth Sciences Applications arrived in Vancouver on May 19, 1980, to assist as field liaison to Federal, State, and local governments and to help handle the extremely large demand for information. When the Federal Emergency Management Agency assumed leadership of the Federal Government's response to the eruption, the Office helped to establish and run the Mount St. Helens' technical information network. They also provided daily briefings to disaster-response officials and backed up the Survey press spokesperson.

Representatives of the Office remained in the field through June

1980 when the Federal Government's response became sufficiently advanced to allow a return to more "normal" operations. Since June 1980, the Office has been given the responsibility for coordinating the development of a Survey Emergency Response Plan for future volcanic eruptions of other Cascade Range and Alaskan volcanoes. This plan has been completed and is in effect.

Drawing upon its experience in issuing hazard warnings and assisting in coordinating emergency response activities, the Office has found that the public and the States could better be served by a more positive information program. Although the Office first issued a notice of the potential hazards from an eruption of Mount St. Helens in December 1978, the area was not as well prepared for the 1980 eruptions as it might have been. Therefore, the Office is developing plans for a series of workshops for Federal, State, and local emergency response officials which will help them to better understand and prepare for potential eruptions at the other Cascade Range volcanoes. In addition, the Office is working with public and private emergency management organizations to exchange, evaluate, and make use of information about how people and organizations respond to the threat of natural hazards and to document the many lessons to be learned from the 1980 eruptions of Mount St. Helens. (from Staff, Office of Earth Sciences Applications)

* * *

Volcanic Hazards

Immediately following the first major earthquake on March 20, U.S. Geological Survey specialists in volcanic hazards assessment began intensive consultations and meeting with officials of the Gifford Pinchot National Forest, the land managers for Mount St. Helens, as well as many other Federal, State, and local officials involved in emergency preparedness and contingency planning.

Throughout the week before the eruption, scientists from the USGS Geologic Division and the University of Washington arrived on the scene to increase surveillance and to assess volcanic hazards. Indeed, by the time the eruption entered its second week of activity, 25 to 30 scientists were on hand carrying out a wide variety of monitoring and volcanic hazards assessment investigations. By March 31, the onsite volcanic hazards assessment was presented at a major meeting of agencies responsible for public safety, and on April 1, a large-scale volcanic hazards map was prepared for use by these agencies and the general public. Survey scientists participated in daily meetings and briefings with U.S. Forest Service and other officials and advised them on the locations of roadblocks to control access to hazardous areas around the volcano. Survey scientists contributed essential geotechnical and volcanic hazards information used in the preparation of the "Mount St. Helens Contingency Plan" issued by the U.S. Forest Service, Department of Agriculture, on April 9.

Since the devastating May 18 eruption, Mount St. Helens has continued to erupt intermittently. Significant eruptions occurred on May 25, June 2, July 22, August 7, August 15, and October 16-17. These eruptions produced steam and ash columns, pyroclastic and pumice flows, and small mudflows and were commonly followed by extrusions of bulbous volcanics composed of viscous pasty lava into the bottom of the crater. The first of these domes followed the June 12 eruption and was largely destroyed by the July 22 eruption. A second dome formed after the August 15 activity and was later obliterated by the October 16-17 eruptions. The third volcanic dome grew immediately after cessation of the October eruptions and persisted through late November as a muffin-shaped mound; incandescent rock could be observed at night through cracks in its crusted surface.

(Editor's note: The size of this dome was greatly increased by new viscous lava extruded during two additional eruptions, from about December 27-January 3, 1981, and February 5-7, 1981. No significant explosive activity was associated with these eruptions, and at the end of the February eruption the dome stood more than 600 feet high and had a diameter of about 2000 feet—about as high as the Washington Monument and as long as seven football fields laid end to

The volcanic dome stood several hundred feet above the crater floor in late January 1981 and dwarfed the helicopter used by Survey scientists to study the still-hazardous Mount St. Helens.

end. Another dome eruption began on April 10 and added a new lobe to the dome.)

During the course of the 1980 eruptive activity of Mount St. Helens, significant advances in both the development and application of monitoring techniques, as well as in the understanding of Cascade Range volcanism, were made by both Survey and non-Federal scientists. Since the inception of activity in late March, nearly continuous gas-composition monitoring by Survey and Dartmouth College scientists indicates that the monitoring of sulphur dioxide, carbon dioxide, and hydrogen shows real potential as predictive tools, particularly for the lesser eruptions of June through August. Detailed analysis of the accompanying earthquake activity indicates that characteristic seismic patterns herald the close of each eruptive episode. Gradual changes in the ash and lava chemistry during the course of the 1980 activity provide a basis for anticipating the possible general character of future eruptions. Studies of the pumice-flow eruptions and deposits are providing new insights into the mechanisms of their emplacement and cooling history. Indeed, the 1980 Mount St. Helens activity has provided a veritable scientific workshop and laboratory that will undoubtedly yield important new advances in the field of volcanology and will provide new insights necessary for the prediction of future volcanic hazards in the Cascade Range. (from Staff, Geologic Division)

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Hydrologic Hazards

The devastation caused by rock, mud, ash, and other debris from the violent eruption of Mount St. Helens was highly publicized by the news media. Less attention was devoted to the potential flood hazards. This can be explained by the fact that many of the water problems which result from a volcanic eruption are not so dramatically or immediately obvious. Frequently, the effects on water resources require scientific investigation and the passage of time before their full implications are understood. When the Geological Survey combines its many years of accumulated hydrologic data and experience with its on-the-spot investigations at Mount St. Helens, it is anticipated there will be better understanding of the longer term effects of sediment transport and mudflows, chemical and biological changes in water quality, and changes in channel morphology.

When the major eruption occurred on May 18, the Water Resources Division was geared to provide immediate water information. Following the initial eruption of March 27, 1980, the Division installed 25 water-quality monitoring sites designed to detect changes in water quality that might result from volcanic activity. These sites provided data to supplement that already being obtained in the area from the U.S. Geological Survey's National Stream Quality Accounting Network and the cooperative programs with the Washington State Department of Ecology and the Tacoma City Light Department.

At some of the sites, continuous water-quality monitors were installed which were equipped with GOES satellite telemetry to transmit temperature, specific conductance, and pH data eight times a day. Also, on March 27, after the first small ash eruption, the Division selected tentative sites on streams draining Mount St. Helens for indirect measurements of floods and mudflows.

When the major eruption occurred, a variety of potential water-related hazards required immediate attention. The on-the-scene investigations of Division crews served many purposes, among them allaying fears of present danger and monitoring eruption-related phenomena which could present problems after a period of days, weeks, months, or perhaps even years.

In the area of the mountain, the field crews were able, in many instances, to provide immediate assistance in assessing the water-related hazards. They began discharge measurements at vital points on the afternoon of May 18 and furnished valuable data for the flood forecasting of the National Weather Service. A significant

View of the debris flow in south Coldwater Creek caused by the May 18, 1980, eruption of Mount St. Helens. The trees on the once-forested Coldwater Ridge on the right side were completely blown away by the blast. Mount St. Helens' crater is just to the right of Coldwater Ridge.

Division installation was GOES satellite telemetry at the North Fork of the Toutle River. It was able to transmit every 5 minutes if the gage reading exceeded a preset level. The data were automatically received by the National Weather Service River Forecast Center in Portland, Oreg., and the National Weather Service office in Seattle, Wash.

Immediately after the eruption, it was also important to be able to conduct on-the-spot evaluations of the potential for disastrous floods caused by the destruction of glaciers, sediment accumulation, mudflows, and debris. Water Resources Division crews investigated the tremendous quantity of sediment deposited in rivers in the area. In the Cowlitz River, they estimated that about 25,000 acre-feet of sediment clogged the channel between the mouth of the Toutle River and the Columbia River. (This volume of sediment would cover 1 square mile to a depth of nearly 40 feet.)

Because the eruption destroyed the glaciers on the north slope of the volcano, the USGS Glaciology Project office estimated that approximately 140,000 acre-feet of glacier and snowpack water was removed from the mountain. The snowpack and much of the glacier ice, probably mixed with rock and debris, produced massive mudflows in the Toutle River system and lower Cowlitz. Debris raised the level of Spirit Lake on the North Fork of the Toutle River by 200 feet.

Huge deposits of mud and debris in parts of the Cowlitz River made the available flood-plain delineation maps and river profiles obsolete. By May 26, the Division had completed the first up-to-date river profiles and flood delineation maps. Cooperation from the U.S. Army Corps of Engineers and private firms facilitated and expedited the field survey and mapping effort. New stream gaging stations were installed to provide flood-warning data.

The future USGS Water Resources Division program has a dual purpose: to better understand the hydrologic and geomorphic processes involved in the devastation and recovery of the affected area and to provide sound information for hazard warning and resource planning. The program aims to define pre- and post-eruption conditions and to monitor hydrologic changes. This will involve new surveillance networks, additional gaging stations, glacier study by periodic aerial photography, calculations related to flood profiles and inundation maps, production of mathematical models to reflect improved knowledge related to mudflows, improvement of sediment transport models, investigation of the effects of ash fall on soil, water, and runoff, and the susceptibility of ground water to contamination. Advancement of knowledge from these studies, together with development of improved scientific techniques, will bring additional expertise to managing water problems caused by future volcanic eruptions. (from Staff, Water Resources Division)

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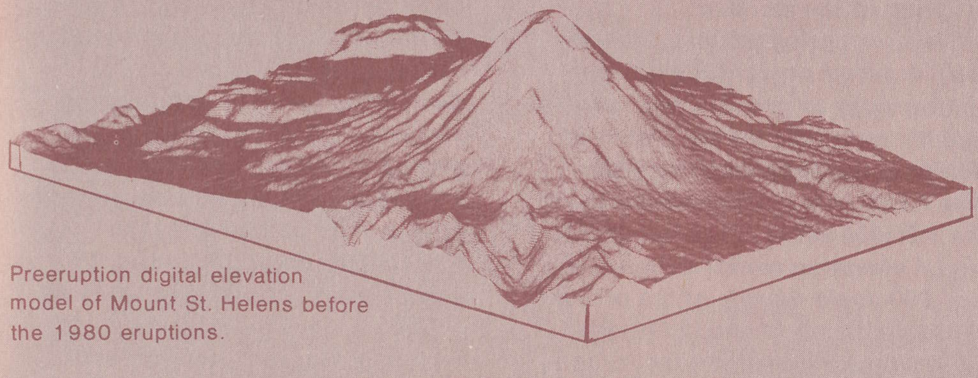
Maps: First Step in Hazard Assessment

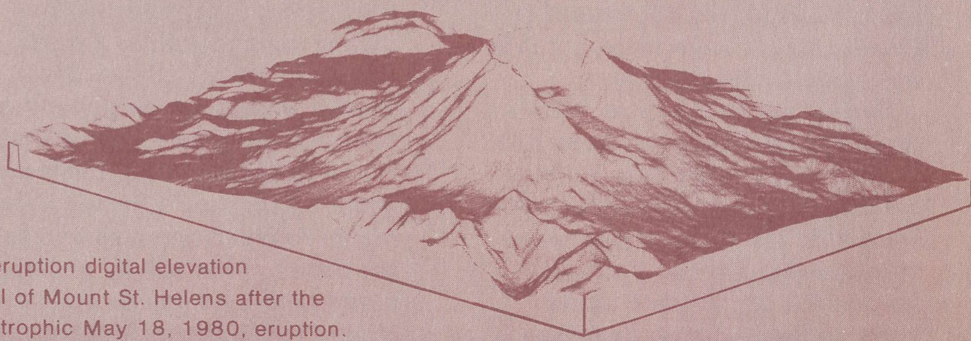
When something happens to the land, one of the first things people reach for is a good topographic map. When seismic tremors began to alert people of the potential for a volcanic eruption, maps of the area were "on the shelf" and ready for use. The area had been initially mapped by the National Mapping Division of the U.S. Geological Survey in the late 1950's when 15-minute maps at a scale of 1:62,500 were first published. Aerial photographs obtained in 1975 and 1979 had been processed into 7.5-minute orthophotoquads, which are scale-accurate photographic "maps" with minimal cartographic annotations showing the immediate mountain area at a scale of 1:24,000. These photographs were used to generate preeruptive digital elevation model data.

Surveying and mapping activities were directed from the Division's Western Mapping Center, which worked closely with the Washington State Department of Natural Resources and the U.S. Forest Service.

Prior to the May 18 eruption, initial special mapping efforts involved compiling five "bulge" maps at the 1:24,000 scale to record the developing preeruption topographic changes. These maps showed the growth of the northernmost



Preeruption digital elevation model of Mount St. Helens before the 1980 eruptions.



Posteruption digital elevation model of Mount St. Helens after the catastrophic May 18, 1980, eruption.

portion of the volcano and were used by geologists to monitor the rate of expansion leading to the eruption.

Immediately after the eruption, existing maps were used to prepare a special topographic vicinity map at a scale of 1:100,000 (1 inch equals about 1.6 miles) that provided coverage for about 3,000 square miles, showing parts of Clark, Cowlitz, Lewis, and Skamania Counties in Washington and Columbia County in Oregon. This map aided general planning in the devastated areas by scientists, land managers, law enforcement officers, and emergency support personnel. The map, published in four colors, was compiled and published within 3 weeks after the eruption of the volcano.

Division cartographers immediately ordered posteruption aerial photography to prepare new cartographic materials for the Mount St. Helens area. They included nine new 7.5-minute orthophotoquads at the 1:24,000 scale posteruption digital elevation model data and a 1:50,000-scale mosaic of the orthophotoquads to provide a base for compiling scientific and resource data. Additional 7.5-minute orthophotoquads for the Toutle and Cowlitz Rivers were prepared later for evaluations of drainage.

During July and August, two special crater maps were compiled at the 1:24,000 scale with 20-foot contour intervals to show the configuration. These maps portrayed development of a new volcanic cone within the erupted crater basin before and after its subsequent eruption.

Cartographers also used the new aerial photography to revise the special vicinity map published in early April to reflect surface changes that have occurred as a result of the eruption. The post-eruption map will include extensive text, photographs, and diagrams on the reverse side and is expected to be published early in 1981.

Plans call for new 7.5-minute topographic quadrangle maps at the 1:24,000 scale to cover nearby or adjacent areas not yet mapped at that scale. Previously published maps of the series are being inspected and revised as needed to show changes brought about by the eruption.

Assistance is being provided to the Water Resources Division in preparation of large-scale, 4-foot contour-interval topographic channel maps at the 1:4,800 scale. Assistance involves establishing precise vertical control at nine gaging stations. The maps, which will meet stringent accuracy standards, will be compiled by the National Mapping Division with assistance from commercial firms.

Such a large aerial survey and mapping program involved substantial coordination by the National Mapping Division with other Survey units as well as a wide variety of other Federal, State, and local agencies which depend on the maps for planning and analysis work. To aid the effort, the National Mapping Division's Resident Cartographer in Washington served as the onsite aerial survey or mapping coordinator and liaison official. (from Staff, National Mapping Division)

Mount St. Helens viewed from the north following the catastrophic eruption of May 18, 1980. The eruption removed about 1,300 feet of the mountain top; the highest point is now 8,364 feet above sea level, compared to the former summit elevation of 9,677 feet. Spirit Lake is in foreground.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1982 - 361-618 - 155/142

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.