UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

The Volcano Hazards Program: Objectives and Long-Range Plans

by

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THE VOLCANO HAZARDS PROGRAM: OBJECTIVES AND LONG-RANGE PLANS

I. INTRODUCTION

Volcanoes and the products of volcanoes have a much greater impact on people and society than is generally perceived. Although commonly destructive, volcanic eruptions can be spectacularly beautiful and, more importantly, they have produced the very air we breathe, the water we drink, and our most fertile soils. Volcanoes also have a profound effect on climate, and their roots form geothermal energy reservoirs and contain valuable mineral deposits including copper, molybdenum, tin, silver, gold, and diamonds. Of course, volcanoes will continue to erupt whether we understand them or not, but one of the functions of enlightened government and a mission of the U.S. Geological Survey (USGS) is to try to understand and to assess the dangers of volcanic eruptions to our land and people.

Volcanic hazards assessment and systematic volcano-monitoring activities have been carried out by the Geological Survey for many decades, mainly at the Hawaiian Volcano Observatory (HVO). Established in 1912, HVO was administered between 1919 and 1948 by various Federal agencies (National Weather Service, USGS, and National Park Service), and since 1948 it has been operated continuously by the USGS. Volcanological research and monitoring during the 1970's was funded at a relatively low level of about $1 million annually.

Prior to the reawakening of Mount St. Helens in 1980, only a few scientists, principally with the USGS, perceived that there was any serious potential for volcanic eruptions in the relatively densely populated conterminous region of the United States. With the increased information they gathered, came increased concern; and as early as May 1968, Dr. William P. Pecora, USGS Director at that time, stated in the Christian Science Monitor that he was "especially worried about snow-covered Mount St. Helens." In 1975, a team of USGS scientists published in the journal Science that Mount St. Helens was the one volcano in the conterminous United States most likely to erupt "...perhaps before the end of this century." This prophetic finding was followed by a more detailed USGS publication in 1978, complete with an assessment of the kinds, magnitudes, and areal extents of potential volcanic hazards that might be expected.

The catastrophic eruption of Mount St. Helens in May of 1980 heightened public awareness of the vulnerability of man and man's structures to many geologic hazards, and volcanic hazards in particular. Comparison of historic records of past eruptions from Mount St. Helens and other Cascade volcanoes, together with current evidence of increased seismic and other precursory activity in the western U.S., strongly suggests that the threat of volcanic eruptions in the near future has not diminished.

Therefore, in the summer of 1980, the USGS program for volcanic hazards assessment, volcano monitoring, and volcanological research was substantially expanded to provide assurance that endangered areas of the Nation be better prepared to deal with future threats of disaster. The expanded program has the goal of achieving a state of initial readiness in terms of volcanic and related hydrologic hazards assessments and monitoring of volcanoes, to be able to advise public safety agencies and officials regarding potential hazards associated with volcanic activity at each of 17 "high priority" Cascade volcanoes. These activities, which might be labeled "emergency preparedness," were to be accompanied by an accelerated fundamental research program to advance and improve the capabilities of the USGS to address both the immediate and longer-term concerns associated with volcanic activity.

The USGS has been attempting during the past 2 years to develop a comprehensive, balanced Volcano Hazards Program consisting of the following main elements: volcanic hazards assessment, volcano monitoring, fundamental research, and emergency-response planning and public education. Such an integrated program is needed not only to meet immediate potential emergencies, but also to gain a better understanding of the fundamental mechanisms of volcanism, which in turn provides the means for improving our ability to predict the time, place, and possibly magnitude of eruptions.

This document (1) summarizes the potential for volcanic eruptions and related activity in the United States for the foreseeable future, (2) describes the current program for mitigating the hazards from eruptions, and (3) outlines a broader, long-range program to improve mitigation measures by refining predictive capability and hazards assessments.

It should be noted that knowledge gained from the study of volcanoes and volcanic activity does not solely benefit the goal of mitigating volcanic hazards but also contributes substantially to other applied research that benefits society, including the development of geothermal energy resources, the exploration and exploitation of mineral resources, the forecasting of weather and climate, and contributions to soil and agricultural sciences.

Many individuals, in addition to the authors, have contributed to the formulation of this plan. Initial input and suggestions were received from D. R. Mullineaux, Chief, Volcanic Hazards Project; D. W. Peterson, Scientist-in-Charge, Cascades Volcano Observatory; R. W. Decker, Scientist-in-Charge, Hawaiian Volcano Observatory; T. P. Miller, Chief, Branch of Alaskan Geology; and R. A. Page, Branch of Seismology. B. A. Morgan III, J. C. Wynn, N. E. Gunderson, and C. J. Zablocki assisted in preparation of an early version of the manuscript, and constructive reviews were provided by R. L. Christiansen, C. D. Miller, L.J.P. Muffler, D. R. Mullineaux, R. I. Tilling, P. A. Antill, F. S. Baxter, and D. A. Rickert.

II. GENERAL ASSESSMENT OF THE POTENTIAL FOR FUTURE ERUPTIONS

This section presents an assessment of the potential for volcanic eruptions in the United States. Volcanoes that are currently active or have been active in recent geologic time are noted by geographic area and by age of the latest eruption in Figure 1. Those volcanoes in the U.S. presently considered potentially active and likely to erupt in the future may be conveniently grouped in general order of decreasing concern, subject to revision as studies progress, as follows (same notation as Figure 1):

Group 1. Volcanoes that have short-term eruption periodicities (100-200 years or less) and/or have erupted in the past 200-300 years:

Cascades

1. Mount St. Helens, WA
2. Mono-Inyo Craters, CA
3. Lassen Peak, CA
4. Mt. Shasta, CA
5. Mt. Rainier, WA
6. Mt. Baker, WA
7. Mt. Hood, OR

Hawaii

8. Kilauea
9. Mauna Loa
10. Hualalai
11. Haleakala

Alaska

12. Augustine Volcano
13. Redoubt Volcano
14. Mt. Spurr
15. Iliamna Volcano
16. Katmai Volcano
17. Aleutian volcanoes

Group 2. Volcanoes that appear to have eruption periodicities of 1,000 years or greater and last erupted 1,000 or more years ago:

Cascades

A. Three Sisters, OR
B. Newberry Volcano, OR
C. Medicine Lake Volcano, CA
D. Crater Lake (Mt. Mazama), OR
E. Glacier Peak, WA
F. Mt. Adams, WA
G. Mt. Jefferson, OR
H. Mt. McLoughlin, OR

Alaska

I. Mt. Wrangell
J. Mt. Edgecumbe

Group 3. Volcanoes that last erupted more than 10,000 years ago, but beneath which exist large, shallow bodies of magma (molten rock) that are capable of producing exceedingly destructive eruptions:

AA. Yellowstone caldera, WY
BB. Long Valley caldera, CA
CC. Clear Lake volcanoes, CA
DD. Coso volcanoes, CA
EE. San Francisco Peak, AZ
FF. Socorro, NM

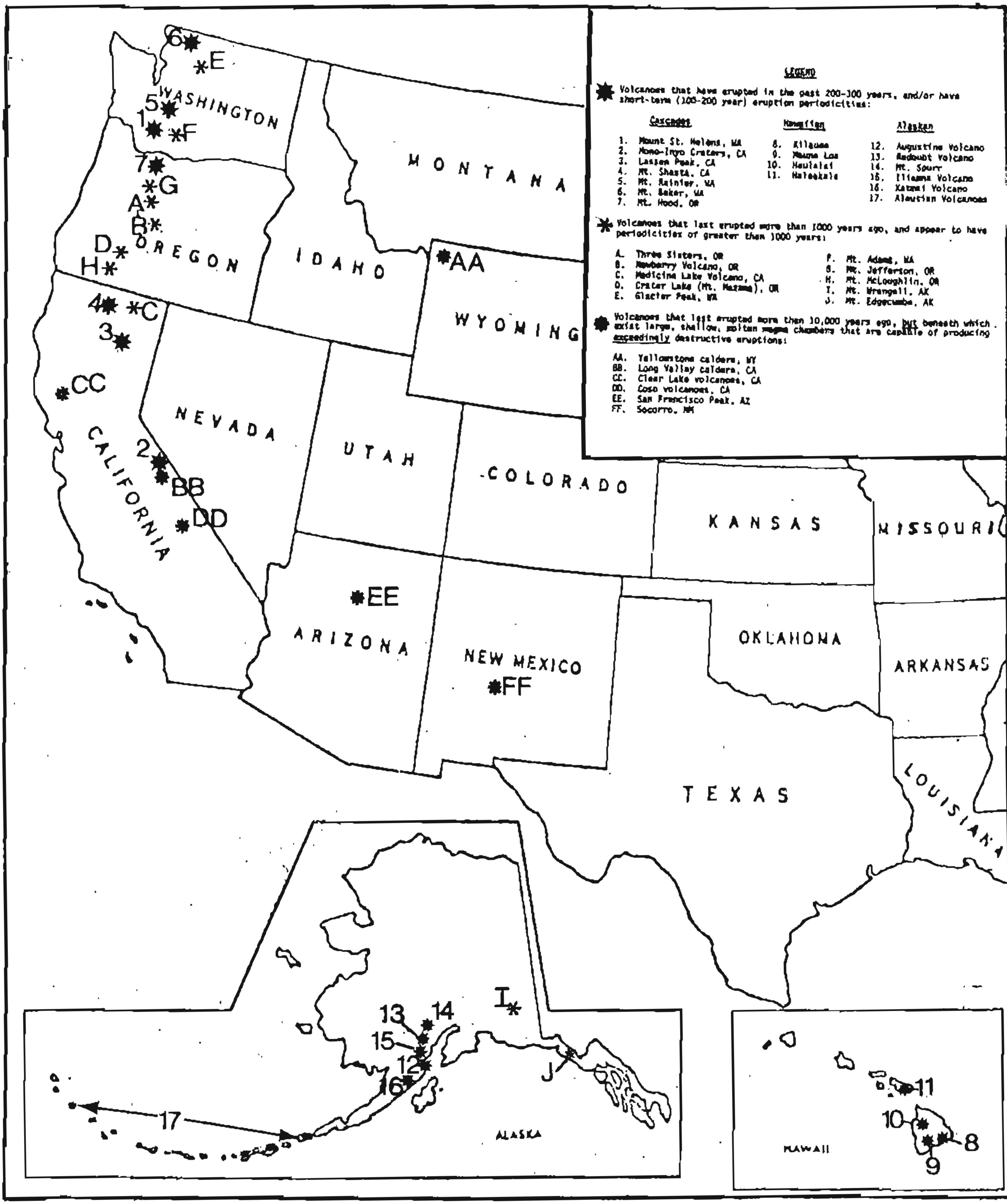

Figure 1. Location of Potentially Hazardous Volcanoes in the United States.

Certain of the volcanoes noted in the first two groups, in particular Mono-Inyo Craters, Lassen Peak, Mt. Shasta, Three Sisters, Newberry, and Medicine Lake, have reached or are approaching a stage of chemical evolution similar to that attained by Mt. Mazama just before the cataclysmic eruptions that formed Crater Lake about 6,600 years ago. A similar eruption today from any one of these volcanoes would be a disaster of previously unexperienced proportions. It would totally devastate life and property within 50-100 miles of the volcano, and would cover a large part of the western U.S. with many inches of volcanic ash. The economic and social impact would be felt throughout the country. An eruption from a magma chamber beneath any one of the volcanoes in the third group would be at least an order of magnitude larger and have even greater impact. At present we have insufficient data or experience that would enable us to recognize with certainty the precursory phenomena preceding such a calamity. However, an effort is being made to study the nature of events that immediately preceded the 6,600-year-old Crater Lake eruption to determine what precursors might provide some warning. This emphasizes by example the importance of fundamental research on volcanic phenomena and processes that is needed to provide the data to make our hazards assessments realistic and our monitoring meaningful.

Mount St. Helens, other Cascade volcanoes, other western conterminous U.S. volcanoes, Hawaiian volcanoes, and Alaskan volcanoes are described below.

A. Mount St. Helens, Washington

Prior to its recent reawakening, Mount St. Helens was last active in the mid-1800's, between 1832 and 1857. During this 25-year period the volcano reverted to more explosive activity several times before finally becoming dormant (see Figure 2). Comparisons with similar volcanoes elsewhere in the world indicate that such prolonged and fitful behavior is typical. For example, Santa Maria volcano, Guatemala, and Bezymianny volcano, Kamchatka, initially erupted explosively in 1922 and 1956, respectively, and have remained intermittently active to the present time (60 and 26 years duration, respectively). Like Mount St. Helens in the mid-1800's, they have gone through alternating periods of complete quiesence, non-violent dome-building, and explosive stages. On the basis of these comparisons, it is likely that Mount St. Helens will continue to be a serious threat for at least 20-30 years and will show considerable variability in activity that will require continued intensive monitoring.

Mount St. Helens, because it is currently active, poses the greatest immediate threat to life and property in the Pacific Northwest. Although the eruptions have declined in frequency and intensity over the past two years, they are likely to continue intermittently and with varying intensity for the next 2 or 3 decades, as they did in the mid-1800's and probably in earlier episodes. Periodically during this time, the volcano may even become completely quiescent for several years, and then become active again. It may not become as explosive as it was in May 1980 for perhaps at least another century, but similar, historically active volcanoes elsewhere in the world (e.g., Bezymianny, Kamchatka, and Santa Maria, Guatemala) have repeatedly reverted to dangerously explosive activity during their decades-long dome-building episodes.

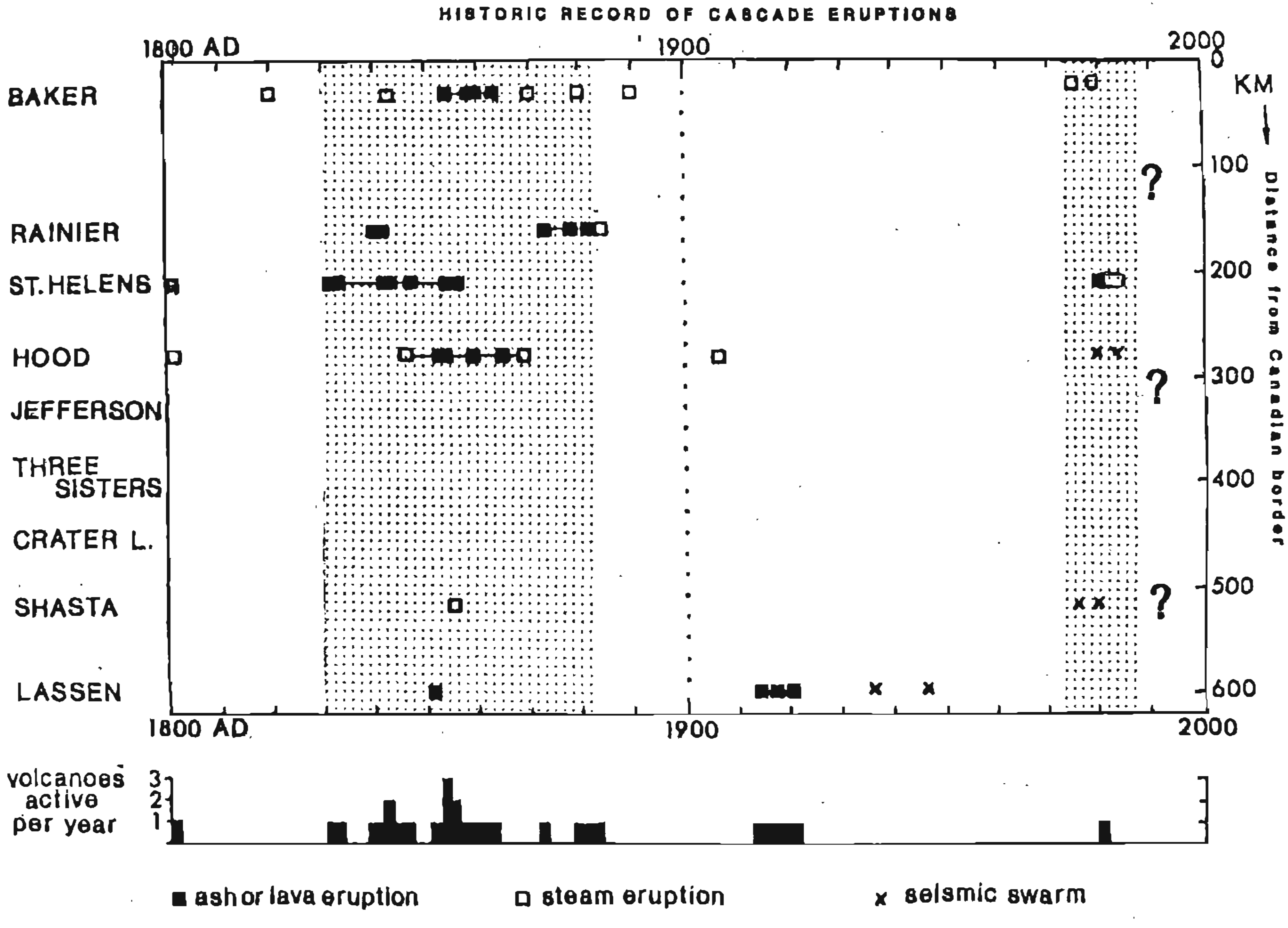

Figure 2. History of Cascades Volcanism, 1800-1980.

Minor ash eruptions and hot avalanches, and possible associated mudflows and floods, from the intermittently growing lava dome within the crater pose the main hazards for the present and immediate future. Past activity suggests that the current episode eventually may culminate in extrusion of more fluid and more extensive lava flows. Hot avalanches and lava flows, particularly if erupted onto thick snow cover, could generate damaging mudflows and floods in the Toutle and lower Cowlitz River valleys, possibly affecting the towns of Castle Rock and Longview. The greatest dangers will be to people working on or near the volcano: loggers reclaiming timber around the volcano, forestry and other land-management specialists, engineers and construction workers on dam construction and dredging operations, and scientists monitoring the volcano.

A major, immediate concern arose in the summer of 1982 when it was discovered that the debris flows damming stream drainages and forming Spirit, Coldwater, and South Fork Castle Lakes were becoming severely eroded and would not be effective barriers at significantly higher water levels. Overtopping of the debris dams or failure by underground seepage and piping could result in catastrophic flooding. During the fall of 1982 the U.S. Army Corps of Engineers began maintaining the level of Spirit Lake by pumping, and the USGS began monitoring for potential catastrophic flood events. Critical studies of the mechanical properties and stability of the debris flows and for a seismic study of active faults beneath the Spirit Lake area are needed. Furthermore, the continuous presence of Corps of Engineers personnel and equipment at Spirit Lake, which is particularly vulnerable to even mildly explosive eruptions in the crater, will require considerably more monitoring than had previously been anticipated, to assure the safety of the operations of the Corps of Engineers.

B. Other Cascade Volcanoes

Incomplete but reasonably reliable accounts of the 19th century activity in the Cascades indicate that several other Cascade volcanoes, as well as Mount St. Helens, were active in the mid-1800's (see Figure 2). During the 48-year period between 1832 and 1880, Mt. Baker, Mt. Rainier, Mt. Hood, and possibly Mt. Shasta were unusually active, and on more than one occasion two or three volcanoes erupted during the same year. While none of these eruptions were as destructive as the Mount St. Helens eruption of May 1980, similar eruptions today would certainly have more serious social and economic impact than they did then, when the country was sparsely populated and less developed.

For the past 100 years the Cascade volcanoes (with the exception of Lassen Peak which erupted in 1915-17) have been unusually quiet, but since 1975, the occurrence of seismic and other types of apparent precursory volcanic activity has increased significantly. In 1975, Mt. Baker suddenly began steaming vigorously, and it has continued steaming to the present, although at a reduced level. In 1978, earthquake swarms accompanied by unusual ground rifting occurred in volcanic terrain east of Mt. Shasta. In 1980, 3 months after Mount St. Helens burst to life, earthquake swarms shook the slopes of Mt. Hood. In 1981 and 1982 earthquake swarms were again recorded east of Mt. Shasta. In 1982 additional signs of restlessness have been noted further south in California, at Lassen Volcanic National Park, Long Valley caldera (Mammoth Lakes), and the Coso Range volcanoes in southern Owens Valley.

This recent increased restlessness in the Cascades and along the east front of the Sierra Nevada, coupled with evidence that there is an increased potential for large-magnitude earthquakes on both the Sierran frontal fault and the San Andreas rift within the next few decades, suggests that we are in a time of unusually strong interaction between the Pacific and North American crustal plates, when a higher incidence of hazardous events is likely. This has prompted a number of scientists to believe that the Cascades, and possibly other western U.S. volcanoes, are on the threshold of another episode of increased eruptive activity similar to that of the mid-1800's.

The potential for volcanic activity at other particularly hazardous Cascades volcanoes is described below.

1. Mt. Baker, Washington. Reliable historic observations indicate intermittent activity between 1843 and 1859, occasionally spreading ash on its slopes and once sending a hot mudlfow with charred trees into a part of the Baker River valley now occupied by Baker Lake reservoir. In 1975 increased fumarolic emissions from the summit crater caused rapid melting of glacial ice and some concern that an eruption might be imminent. Melting of the summit ice has continued at a high rate since then, but with no further signs of increased activity. The cause for the increased thermal activity is not definitely known, but intrusion of magma into the cone is the most likely cause. It therefore may still be capable of erupting. In the event of an eruption, the greatest danger would be from debris flows and mudflows entering Baker and Shannon reservoirs, possibly sending secondary floods through the small city of Concrete which is just below the dam of Lake Shannon.

2. Mt. Rainier, Washington. Mt. Rainier, the highest in elevation of the Cascade cones, was intermittently active between 1825 and 1882, when at least 14 different eruptions were reportedly observed. Although some of these reports seem questionable, at least one eruption was large enough to spread pumice and ash over the entire east side of the mountain. The greatest hazard from Mt. Rainier, however, is not from ash eruptions themselves, but from immense debris and mudflows which commonly have accompanied them. During the past several thousand years, such mudflows have repeatedly coursed down the major valleys, particularly on the north, west, and south sides for distances of 30 miles or more. The largest such flow occurred 5800 years ago, and traveled as far as the present site of Auburn, Washington. It inundated the present sites of Enumclaw and Buckley -- now highly

developed and heavily populated areas. Floods accompanying this mudflow probably reached Tacoma and Seattle. A similar mudflow today would endanger the lives of hundreds of thousands of people and have the potential of causing physical damage in the order of billions of dollars, exclusive of the extended economic impact it would have on a large part of the Northwest.

3. Mt. Hood, Oregon. Mt. Hood has had three major episodes of activity in the past 15,000 years - 15,000-12,000 years ago; 1,800-1,500 years ago; and 300-200 years ago. Reliable historic accounts indicate that minor pumice and ash eruptions also occurred in 1859, 1865, and 1906. During the three major episodes, pyroclastic flows, accompanying the extrusion of near-summit lava domes, completely devastated the slopes of the volcano, particularly on the south and west sides, and mudflows and floods coursed further down the major valleys, particularly on the north and west, occasionally reaching as far as Troutdale and Hood River on the Columbia River. Although future eruptions are not likely to significantly affect metropolitan Portland, which is 50 miles west, eruptions could seriously affect its water supply which comes in part from reservoirs in the vicinity of Mt. Hood.

4. Mt. Shasta, California. Mt. Shasta, exceeded in height by Mt. Rainier but considerably more voluminous, has been intermittently active for more than 120,000 years and has had at least 13 major eruptions during the last 10,000 years. Its most recent eruption was probably in 1786. In the past, eruptions of pyroclastic flows and extrusion of lava flows and domes have constituted the main activity, and these have commonly generated large mudflows extending more than 30 miles from the volcano and probably floods of greater extent. Pyroclastic falls have been few and of limited extent.

   The towns of Weed, Mount Shasta, and McCloud are built on the lower flanks of the volcano in extremely vulnerable positions that have been swept by pyroclastic flows in the past. Major eruptions from the summit of Mt. Shasta probably would require the evacuation of all of these towns and cut off traffic along Interstate 5, the main north-south route in northern California. Mudflows and floods accompanying an eruption could reach Shasta Reservoir 35 miles to the south, and might send secondary floods down the entire Sacramento River, although lowering of the reservoir would reduce this possibility. Nevertheless the influx of sediment and debris into the reservoir plus its precautionary lowering would seriously affect water supplies in the entire Sacramento Valley.

5. Lassen Peak, California. Lassen Peak is one of several large lava domes that have erupted in the past 10,000 years in western Lassen Volcanic National Park. The age of Lassen Peak dome itself is not

well known, but spectacular eruptions occurred at its summit between 1914 and 1917, resulting in a lateral blast (similar to but smaller than Mount St. Helens), pyroclastic flows, a mudflow, and small lava flows. There were no casualties because the affected area contained only two or three small farms and was not as frequently visited as today. Just north of Lassen Peak, Chaos Crags, a group of four steep-sided lava domes, erupted 1,100 years ago, following an episode of pyroclastic falls and flows. About 300 years ago the steep margin of one of these domes collapsed, sending a 2-mile long avalanche (Chaos Jumbles) into the area of Manzanita Lake, which was the site of the main Park visitor's center until moved in 1974 as a precaution against a possible similar event in the future. Preliminary geophysical data suggest that Lassen Peak may be underlain by a large, shallow, molten magma chamber from which future large eruptions can be expected. The area needs further intensive study and careful monitoring.

In 1851, an eruption, similar to that which formed Parícutin Volcano in Mexico in 1943-52, occurred in the eastern part of Lassen Peak, covering about four square miles of forest. Reconnaissance studies indicate that similar isolated eruptions have occurred at uncertain intervals over a vast area in northeastern California and southwestern Oregon, and can be expected to recur in the future. Predicting the site and time of such eruptions is impossible on a long-range basis, but could be possible in a shorter time range with adequate regional monitoring.

C. Other Western Conterminous U.S. Volcanoes

1. Long Valley caldera, California. Long Valley caldera, in central eastern California, recently has become an area of immediate special concern. The 1980-1982 seismic activity and ground uplift has prompted concern about possible renewal of volcanic activity there. During the past 2 years, the caldera floor, known to be underlain by a large chamber of magma, has bulged upward at least 13 inches; the town of Mammoth Lakes on the flank of this bulge has risen as much as 5 inches. Earthquakes, occasionally accompanied by spasmodic tremor, associated with this ground deformation suggest that magma is being injected into the caldera ring-fracture system to depths possibly as shallow as two miles. This intrusive activity may eventually terminate without serious consequence, but as long as uplift and seismicity continue, the potential for eruption is high. Possible kinds of eruptive activity range from minor steam-blast explosions to catastrophic caldera-forming eruptions like those that formed the caldera 700,000 years ago. While the minor steam-blast explosive activity is more likely than the caldera-forming eruption, any form of eruptive activity could be devastating to the nearby town of Mammoth Lakes, a popular resort and recreation center that accommodates 20,000 or more people during winter and summer weekends. Public notice of

potential hazards at Mammoth Lakes has committed the Survey to a program of continued monitoring at Long Valley caldera involving seismic, deformation, geochemical, thermal, and hydrological studies. Such a monitoring program is similar to that carried out at the two volcano observatories, although on a smaller scale.

2. Mono-Inyo Craters, California. The Mono and Inyo Craters form a 15-mile-long chain of 30 or more lava domes and pumice craters in California between the towns of Mammoth Lakes and Lee Vining on the east front of the Sierra Nevada. They have erupted intermittently over the past 40,000 years and, after Mount St. Helens, are the most frequently active volcanoes in the western U.S. Recently acquired data indicate that eruptions have increased in frequency with time; during the past 1,500 years, eruptions have occurred every 200-300 years, the last being 250 ± 50 years ago. Based on these data, an eruption from some part of the chain is likely within the next 50 years. Past eruptions have typically included pyroclastic falls, pyroclastic flows, and extrusion of lava domes. Pyroclastic falls and flows pose the greatest hazard to life and property. The resort town of Mammoth Lakes is only four miles south of the most recent vents and lies within the fall-out area of several of the most recent pyroclastic falls, which were hot enough to incinerate entire forests. Similar eruptions today could destroy the entire town and also seriously affect the water source of the city of Los Angeles, which derives a large portion of its supply from the area.

3. Yellowstone caldera, Wyoming. Yellowstone National Park is another area of special concern. It has been the site of the largest volcanic eruptions known worldwide -- more than 100 times greater than the eruption that produced Crater Lake and 6,000 times greater than the 1980 eruption of Mount St. Helens. Eruptions of this size have occurred at Yellowstone about 2,000,000 years ago, 1,300,000 years ago, and 630,000 years ago (about every 700,000 years). This periodicity of about 700,000 years might suggest the imminence of another major eruption, but the inherent uncertainties of such age determinations make assessment of that likelihood difficult. However, Yellowstone caldera, like Long Valley caldera, is known to be underlain by a large, shallow magma chamber. Moreover, the caldera floor also has recently been discovered to be rising at the surprising average rate of at least 0.7 inches/year, perhaps for the past 50 years or more. In addition, the area is seismically very active. Consequently, it is an area that deserves constant long-term monitoring.

4. Rio Grande rift, New Mexico. For the past 20 years, unusual seismic activity has been detected beneath the Rio Grande rift in the vicinity of Socorro, New Mexico. How long this has been going on is not known. Recent seismic-reflection profiling of the area has detected an anomalous sheet-like body at a depth of 15 miles beneath the

surface which has been interpreted as an actively intruding magma sill. The Rio Grande rift has been the site of repeated volcanic activity for the past 10 million years, and since magma sills seem to be the most likely sources of past eruptions, the Socorro sill may well produce future eruptions. To forewarn of such a possibility, the Socorro area should be under continuous geophysical and seismic surveillance.

D. Hawaiian Volcanoes

Mauna Loa and Kilauea, located on the "Big Island" of Hawaii, are two of the world's most active volcanoes. During the 200 years prior to 1950, Mauna Loa erupted on the average of every 4.5 years. After a 25-year repose, it erupted at its summit in July 1975. Although seismic and ground deformation studies do not indicate that another eruption of Mauna Loa is imminent, past activity suggests that the next eruption will take place along one of its two principal rift zones. Such rift eruptions in the past have characteristically issued much larger volumes of lava than those discharged from the summit region. Rift eruptions in the past have occasionally inundated the present site of Hilo, a town of 30,000 -- the largest on the island.

Kilauea has had a higher frequency of eruptions than Mauna Loa during the past 25 years. Its most recent eruptions were at its summit region in April and September of 1982 and in the east rift zone beginning in January 1983. These eruptions were preceded by a 7-year period during which lava broke to the surface only twice, but significant subsurface magma movements within the southwest rift zone, indicative of shallow magma intrusion, were detected on 15 occasions, including three in 1981. The eruption that began in January 1983 was still underway as of April 1983.

Hualalai volcano, also located on the "Big Island", has not shown signs of returning to an active state since it last erupted in 1801. Similarly, Haleakala, the volcano that makes up the eastern part of the island of Maui, has erupted only once in historic time (about 1790) and shows no indications of becoming active again in the near future. Mauna Kea, on the "Big Island", has not erupted for 2,000 years but probably is capable of erupting again. Thus, Mauna Loa and Kilauea volcanoes pose a continuing threat to the city of Hilo, residential developments on the south coast, and some multimillion-dollar resort developments on the Kona Coast.

E. Alaskan Volcanoes

Alaskan volcanoes are in remote or sparsely populated areas and do not present the same potential for catastrophic damage to property and loss of life as other U.S. volcanoes. However, Alaskan volcanoes erupt frequently, and eruptions from the several active volcanoes bordering the Cook Inlet (e.g., Augustine, Iliamna, Mt. Spurr, and Redoubt volcanoes), the Cold Bay area (Shishaldin and Pavlof), and in the Katmai area could threaten shipping, fishing, air traffic, and oil exploration and development in the area, and a major eruption from Mt. Wrangell could threaten the Alaskan pipeline.

An important consideration regarding the study of Alaskan volcanoes, particularly those in the Aleutians, is that they lie along one of the world's largest and most active volcanic arcs; eruptions in the past 12 years have averaged two per year. This frequency provides an unusual opportunity for research and the study of a wide variety of active volcanic processes. Although remoteness, frequently inclement weather, and logistics are obstacles to prolonged activities, remote seismic and geophysical monitoring, aided by satellite telemetry and observational visits to as many eruptions as feasible, would contribute substantially to the understanding of fundamental mechanisms of volcanism.

III. PROGRAM GOALS, OBJECTIVES, AND COMPONENTS

The Disaster Relief Act of 1974 (PL 93-288) assigns to the Geological Survey the responsibility of providing timely warnings of volcanic eruptions and related activity. The ultimate goal of the USGS Volcano Hazards Program is, therefore, to reduce the loss of life, property, and natural resources that can result from volcanic eruptions and related consequences. Progress toward this goal is being achieved by a broad range of work with the objectives of (1) preparing assessments of the potential geologic and hydrologic hazards associated with eruptions of volcanoes in the United States, (2) monitoring precursory activity at active and potentially hazardous volcanoes, (3) conducting fundamental volcanological and related hydrological research, and (4) providing hazards information to other Federal, state, and local agencies and officials for land-use and emergency-response planning. The hazards assessments and the monitoring projects are carried out on the basis of a priority list of volcanoes, with primary emphasis on those volcanoes that appear to be most likely to erupt in the near future and that are major threats to life and economic well-being of those areas.

The current Volcano Hazards Program is an interdivisional activity involving the cooperative efforts of the Geologic, Water Resources, and National Mapping Divisions. The Geologic Division is primarily responsible for seismic, physical, and observational monitoring of volcanoes and for volcanic hazards assessments and related research; the Water Resources Division conducts related hydrologic monitoring and hazards assessments and research; and the National Mapping Division prepares a wide range of cartographic and geographic data and products essential for the above activities, as well as for emergency-response planning of other Federal, state, and local agencies.

Accurate and timely hazards assessments are the basis for appropriate land-use and emergency-response planning and are also used to guide the design of effective monitoring networks. The accuracy of the assessments depends principally on the type and quality of information available. Initial or preliminary assessments are prepared with information that is available at the time, but these assessments must be updated as new information becomes available from monitoring networks, research studies, and other sources. The assessment process is therefore a continuing process, with each subsequent assessment of an individual volcano becoming increasingly accurate and more useful for land-use and emergency-response planning.

Reliable data from monitoring networks to detect precusory activity provide the information needed for warnings of impending eruptions. These data are also used to update hazards assessments and as critical input to basic research studies. The reliability of information from monitoring networks depends primarily upon selection of the appropriate natural phenomena to monitor (e.g., seismic activity, ground deformation, chemical composition of fluids and gases of hot springs and fumaroles). These phenomena must be associated with volcanic activity that precedes an eruption, such as the subsurface movement of magma. Identification of the appropriate precursory phenomena to monitor is a principal objective of basic research studies on volcanic processes. Comprehensive monitoring networks should be maintained at the volcanoes of greater concern (such as Mount St. Helens and Long Valley), and minimal networks should be maintained in areas of other currently active and potentially hazardous volcanoes (such as Mt. Baker and Mt. Hood). The minimal networks are intended only to detect any increase in precursory activity and would have to be expanded considerably in order to provide the more detailed information needed for specific location and nature of the increased activity and for issuance of warnings to the public.

The accuracy of hazards assessments and the reliability of monitoring networks depend directly upon results of research studies. These results are vital to our understanding of the basic mechanisms of volcanism, and provide the only sound basis for assessing volcanic hazards, thereby reducing risks from volcanic eruptions.

Therefore, in order to effectively carry out its mandated responsibilities, the Survey has organized its Volcano Hazards Program to focus on four major types of activities: volcanic hazards assessment, volcano monitoring, fundamental research, and emergency-response planning and public education. Each of the components encompasses both geologic and hydrologic aspects. These components are described below, along with significant accomplishments for each.

A. Volcanic Hazards Assessment

The goals of this component are to identify those volcanoes and volcanic areas most likely to produce eruptions in the foreseeable future, to determine the kinds, magnitudes, and frequencies of such possible eruptions, and to delineate the areas most likely to be affected by the wide range of phenomena that may occur during or following an eruption. These phenomena include pyroclastic explosions, blast effects, volcanic-ash fallout, avalanches, landslides, mudflows, floods, and large-scale hillside erosion and stream-channel modification. Such knowledge for any particular volcano is gained from study of the records of its historic activity, from detailed stratigraphic, geochronologic, and chemical studies, and from geologic mapping of its prehistoric and historic deposits. The recognition of certain patterns and frequencies of past activity provide the best available basis for predicting long-term future activity and for the assessment of volcanic risk. Such assessments enable the USGS to provide other Federal, state, and local agencies, public utilities, private industry, and the general public with information necessary to prevent or minimize the loss of life and property through preparation of contingency emergency-response plans for hazards reduction, including evacuation, survival, and recovery in areas affected by an eruption. Such assessments also provide information for wise long-term land-use planning, which forms the basis for safe and controlled development of areas frequently affected by eruptions, mudflows, and floods, thereby reducing the economic impact of volcanic disasters. Risk assessment also guides the planning for monitoring activities and research studies. To be most effective, risk assessments and contingency plans must be completed before an eruption occurs. Because the geologic studies upon which risk assessments are based require 3-5 years for completion, adequate lead time must be included in program planning and funding.

A component of hazards assessment is the determination of risk to existing and proposed engineering structures in volcanic areas and the provision of information and advice to approporiate agencies and organizations so that damage to such structures may be minimized or eliminated and their use or function not be impaired in the event of an eruption. Such structures include bridges, roads, power plants, dams, reservoirs, and water and sewer systems. Such assessments provide criteria for short- and long-range planning for response to eruptions and are necessary for the safe evacuation, survival, and recovery of populace in areas affected by eruptions.

Significant accomplishments in volcanic hazards assessment include:

- Hazards assessment studies of Mount St. Helens by Crandell and Mullineaux provided the basis for restricting public access to Mount St. Helens prior to the May 1980 eruption, which saved thousands of lives according to U.S. Forest Service estimates.

- Publication of volcanic hazards maps and risk assessment reports for Mt. Baker, Mt. Rainier, and Mount St. Helens, Washington; Mt. Hood, Oregon; and Mt. Shasta, California (1967-1978).

- Publication of preliminary hazards assessment report for Glacier Peak, Washington (USGS Open File Report 82-830).

- Glacier mapping was completed and ice volumes were determined for Mt. Rainier and Mt. Hood, in order to assess their possible contributions to hydrologic hazards during future eruptions.

- Studies on the predicted filling of Spirit Lake near Mount St. Helens, Washington were completed and a report describing the potential downstream hazards resulting from uncontrolled breaching of the debris dam was released. The conclusions of this report prompted a declaration of emergency by the President.

- Geomorphological studies within the Mount St. Helens blast area have been accelerated to determine the effect of rapid erosion and stream-channel changes in future flooding downstream.

- A mudflow-routing model for the Toutle and lower Cowlitz Rivers (Mount St. Helens) has been developed and used to predict the maximum area likely to be affected by possible breaching of Spirit Lake and other debris-dammed lakes in the Toutle River drainage.

- A "Notice of Potential Volcanic Hazard" has been issued for the Mammoth Lakes, California area in the Long Valley volcanic caldera, based on recently detected ground deformation and changes in seismic and thermal activity.

- Publication of "Potential Hazards from Future Eruptions in the Long Valley-Mono Lake Area, East-Central California and Southwest Nevada - a Preliminary Assessment," Geological Survey Circular 877.

- Baseline cartographic data have been made available for most volcanic areas, with preliminary maps being updated and smaller scale maps being replaced with larger scale maps.

8. Volcano Monitoring

The goal of volcano monitoring is to establish on all active and potentially active volcanoes seismic, geophysical, geochemical, geodetic, and hydrologic monitoring networks or systems capable of detecting real-time changes indicative of an impending eruption. Such monitoring networks or systems provide information that enables the USGS to provide (1) short-term warnings (in terms of days or hours) of probable eruptions, (2) estimates of the possible nature, magnitude, extent, and duration of an eruption and its effects, and (3) information and advice to Federal, state, and local officials for the release of specific volcanic-hazards warnings and the implementation of emergency-response plans. Monitoring must be carried out on an uninterrupted basis in order to maintain data continuity which is essential to provide adequate warnings.

In order to achieve these monitoring objectives and to maintain a competent and experienced staff of volcanologists available for emergencies, the Geological Survey operates two volcano observatories: the Hawaiian Volcano Observatory (HVO) at Kilauea volcano, Hawaii, and the Cascades Volcano Observatory (CVO) at Vancouver, Washington, near Mount St. Helens. These two facilities serve not only as bases for monitoring the active and dormant volcanoes of Hawaii and the Cacades, but also are centers for the training of volcanologists and for research and development of new monitoring techniques and instruments.

The Hawaiian Volcano Observatory has been in operation since 1912, and has pioneered the development of most of the monitoring methods and instruments now used worldwide. It has a staff of about 20 volcanological scientists and technicians.

The Cascades Volcano Observatory was established in 1980 to monitor the current activity of Mount St. Helens, which is expected to continue for as long as several decades, and to serve as a base for periodic monitoring of the other, currently less active but potentially dangerous, Cascade volcanoes. It presently has a staff of about 60, including volcanologists, geophysicists, geochemists, hydrologists, technicans, and other support personnel.

Volcano monitoring, in addition to providing warnings to communities endangered by eruptions, also provides information necessary to keep our national transportation systems (roads, railways, and particularly airlines) functioning safely during heavy ash fallout. Furthermore, there are certain kinds of catastrophic eruptions, admittedly infrequent, which, without warning and without adequate preparation, would not only be national disasters in themselves but could also seriously impair our national defense for a considerable time. Heavy ash-fall could immobilize entire military installations, including air bases, missile bases, and computer and communications facilities, and cause hazardous conditions for aircraft. Two areas capable of producing such catastrophic eruptions are Long Valley caldera, California, and Yellowstone caldera, Wyoming, both of which are currently showing disturbing signs of renewed activity. Such eruptions probably would have far more serious and prolonged effects than a magnitude 8+ earthquake in California. The recovery from the extremely heavy and widespread ash fall from such eruptions could affect both the agricultural and industrial productivity of the Nation for decades.

Significant accomplishments in volcano monitoring include:

- All 16 eruptions of Mount St. Helens since May 25, 1980 have been predicted, with no false alarms -- a success rate unprecedented in the relatively young science of volcanology. These predictions have been based principally on seismic and deformation monitoring, wherein deformation studies usually provide 2-3 weeks advance notice of increasing eruptive potential and seismic monitoring enables issuance of warnings within several hours of eruptions.

- A flood-hazard and mudflow-warning system, using satellite telemetry, has been installed on the Toutle, Cowlitz, and Lewis River drainages (Mount St. Helens), and flood-warning gauges are being operated to monitor potential breaching of the debris blockage at Spirit, Coldwater, and South Fork Castle Lakes.

- A flash-flood warning, based on data obtained from the joint USGS/National Weather Service satellite flood-warning system, was issued on March 19, 1982, for the Toutle River, allowing timely temporary evacuation of residents.

- Increased use of automation and radiotelemetry in monitoring Mount St. Helens has significantly reduced risk to scientists working in the crater and has provided a more continuous and complete record of monitoring data vital for predictive purposes.

- Baseline deformation and gravimeter stations have been established on Lassen Peak and Mount Shasta, California; Mount Hood, Oregon; and Mount Baker and Mt. Rainier, Washington.

- Baseline geochemical data have been obtained from fumaroles and hot springs at Lassen Peak and Mount Shasta, California; Mount Hood, Oregon; and Mount Baker and Glacier Peak, Washington.

- In cooperation with the Department of Energy (DOE), two aerial infrared surveys of most of the potentially active Cascade volcanoes and Long Valley caldera, California have been completed to provide a basis for comparing future thermal changes.

- Monthly summaries of volcano-related seismic activity for California and Oregon, as well as for individual volcanoes, have been distributed regularly.

- Early detection of possible magma intrusion, based on seismic and ground-deformation studies, led to recognition of a potential volcanic hazard at Long Valley caldera (Mammoth Lakes, California).

- A ground-water monitoring system was established at Long Valley caldera to detect changes in the hydrologic system as possible precursors to volcanic activity.

- The April 30 and September 25, 1982 and January 3, 1983 eruptions of Kilauea, the first eruptions since November 1979, were successfully predicted, based on interpretations of microearthquake and ground-tilt activity.

- Installation of continuously telemetered electromagnetic monitoring equipment at Kilauea, Hawaii has further improved this technique as a possible real-time predictive method.

C. Fundamental Research

The goals of fundamental research on volcanic processes are to establish (1) a statistically valid basis for explaining the distribution of volcanoes and volcanic eruptions in space and time and (2) a sound theoretical and empirical basis for understanding volcanic processes and for predicting volcanic eruptions and related hydrologic consequences. Research studies span a wide variety of scientific topics and include (1) the correlation of volcanic activity with other possibly causative or related geophysical phenomena, (2) possible relations between volcanism and seismicity in the context of plate tectonics, (3) the physical properties and chemical evolution of magma and lava, and (4) the mechanisms of magma generation at depth, transport through the crust, and eruption at the surface. Results from such studies are vital to our understanding of the basic mechanisms of volcanism, and thereby provide the only sound basis for predicting volcanic eruptions, assessing volcanic and related hydrologic hazards, and reducing risk.

Hydrologic research is directed toward understanding the impacts of volcanic eruptions on streams and lakes to aid in the planning of effective mitigation. The overall effort includes (1) the study of the geomorphology of the sediments of volcanic origin including channel-geometry changes of major and minor streams, changes in channel slope because of scouring or filling, and the resulting impact on floods, (2) the study of the process of transport of extremely high sediment loads, (3) the study of bank erosion in the basins as it relates to roads, bridges, houses, and other developments on the flood plains, (4) the study of the processes of mud-flow movement and the physical properties of the flowing material, (5) the modeling of rainfall-runoff events in order to document the effects of ash-fall and the return of the drainage to stable conditions, and (6) the evaluation of the short- and long-term impacts on the chemical and biological quality of water in the streams and lakes including the determination of recovery rates of the benthonic community.

Recent research projects include:

- Studies of the 1980 Mount St. Helens pyroclastic flows to understand their emplacement mechanisms and related processes.
- Studies of the distribution, grain-size characteristics, and chemical constitution of the Mount St. Helens ash-fall deposits, and the effects of erosion, post-depositional compaction, and consolidation on them.
- Photogrammetric studies of the Mount St. Helens dome-building eruptions of 1981-82 to accurately determine their volumes and modes of eruptions.
- Water-quality and biological studies to characterize the reestablishment of stream benthos in selected streams near Mount St. Helens.
- Documentation of the occurrence, distribution, and fate of organic vegetation decay products in the vicinity of Mount St. Helens.
- Studies of the effects of Mount St. Helens ash on soil chemistry and wheat crops.
- Studies of three-phase fluid systems as applied to the origin of the Mount St. Helens lateral blast.
- Determination of ice volumes on Cascade volcanoes to estimate their contributions to hydrologic hazards associated with future eruptions.

Significant accomplishments in fundamental research include:

- Publication of Geological Survey Professional Paper 1250, "The 1980 Eruptions of Mount St. Helens, Washington," an 844-page document containing 64 reports on the early results of studies of the volcanic activity and eruptive products of Mount St. Helens in 1980.
- Completion of a gravity survey of Lassen Volcanic National Park, California, as part of the effort to detect the possible existence of a magma chamber at depth.

- Completion of a seismic-refraction survey in the Mount Shasta-Medicine Lake transect of the Cascade Range, in an effort to determine the crustal structure of the Range.

- Establishment of a joint program with DOE for detailed research studies of the Mono Lake-Long Valley area in California aimed at volcanic hazards (as well as geothermal resources and continental scientific drilling objectives.)

- Identification of the evolution of certain volcanic gases as a precursory phenomena of value in the prediction of eruptions, and the association of harmonic tremor with the evolution of these gases.

- Experimentation in Hawaii with a new electrical self-potential technique to detect flow of magma at depth, with encouraging results indicating that the method may provide longer lead-time for warnings of impending eruptions than seismic methods.

- Documentation of downstream changes in the rheology of major mudflows generated during the initial phases of the March 19, 1982 eruption of Mount St. Helens by detailed measurements of velocity, discharge, and sediment concentrations along the Toutle and Cowlitz Rivers.

- Investigation of the sedimentology and stratigraphy of the modern and pre-historic mudflows at Mount St. Helens that has improved the understanding of their rheological behavior and has provided new insights about their magnitude and frequency of occurrence.

D. Emergency-Response Planning and Public Education

In addition to carrying out projects with scientific and technical objectives, other equally important activities of the Volcano Hazards Program involve general public education and the dissemination of information necessary for the preparation of emergency-response plans for volcanic eruptions and secondary geologic and hydrologic hazards. It is essential that the general public and Federal, state, and local officials responsible for public safety be fully informed of the possible volcanic hazards within their areas of concern, so that, in the event of an eruption, actions to minimize hazards and the loss of life and property can be taken quickly and with the minimum of confusion. To achieve this, the public and responsible governmental officials must be made aware of the seriousness of the hazards so that emergency-response plans can be prepared well in advance of an eruption. Careful planning and communication with local and regional governments and with the news media are essential to achieve the right balance for avoiding both panic and complacency.

USGS activities and legislatively mandated responsibilities for this component include:

- Issuance of notices, watches, and warnings of volcano eruptions (see Federal Register, vol. 42, no. 70, p. 19292-19296).
- Dissemination of volcanic hazards reports, maps, and news releases to the public and to other Federal, state, and local officials.
- Organization of and participation in emergency-response planning meetings and workshops in cooperation with other Federal, state, and local agencies.

Significant recent accomplishments include:

- Establishment of an operational USGS emergency-response plan for future volcanic eruptions.
- Initiation of memos of understanding with the U.S. Park Service, U.S. Forest Service (USFS), Federal Emergency Management Agency (FEMA), Federal Aviation Administration, and National Weather Service.
- Organization of a volcanic hazards workshop at Mount Shasta, California, in cooperation with FEMA, USFS, and state and local organizations, in November 1981.
- Participation in a California volcanic hazards workshop organized by the California Department of Conservation and Department of Emergency Services in December 1981.
- Organization of a public workshop at Mammoth Lakes, California, concerning potential volcanic hazards in the Long Valley-Mono Lakes area, in cooperation with the California Division of Mines and Geology and the California Office of Emergency Services, in August 1982.
- Continued participation in the Mount Baker, Washington volcanic hazards coordination plan formulated in 1975.
- Establishment of an emergency-response plan with FEMA, Washington State Department of Emergency Services, Cowlitz County Sheriff, and other Federal and local agencies for dealing with a potential Spirit Lake breakout.
- Participation at a series of three public-information meetings in the Mount St. Helens area relative to the hazard at Spirit Lake.
- Participation in the FEMA-sponsored Toutle-Cowlitz Watershed Management Plan.

IV. A LONG-RANGE VOLCANO HAZARDS PROGRAM

A. Funding History

The funding history of the USGS Volcano Hazards Program in terms of final budget authority for fiscal years 1978 through 1984 (projected) is shown below, in thousands of dollars:

1978	1979	1980	1981	1982	1983	1984
$1,055K	$1,078K	$4,387K	$12,656K	$9,664K	$10,834K	$7,392K

Funding in 1978 and 1979 reflects the older, modest program which covered only monitoring studies at the Hawaiian Volcano Observatory and very limited volcanic hazards assessments in the Cascades. No hydrologic studies were funded during this period. Funding in 1980 and 1981 reflects the increases resulting from the Mount St. Helens eruption and the establishment of a Cascades Volcano Observatory in Vancouver, Washington, late in 1980.

The responsibilities associated with volcanic hazards continue. Since May 18, 1980, Mount St. Helens has erupted 16 times. While none of these eruptions were as explosive as that of May 18, 1980 (most were mild dome-building events), their frequency and potential threat of explosive behavior demands that they be closely monitored. The March 1982 eruption was mildly explosive and resulted in flash flooding of meltwater, laden with volcanic ash, which caused downstream damages of over $2 million. Monitoring of such eruptions occurring at 1 to 4 month intervals results in costs of $20,000 to $30,000 per eruption in excess of the normal operating budget at the Cascades Volcano Observatory. In addition, increased seismic activity and deformation have been detected at Long Valley, California.

A program of volcanic hazards activities, particularly volcano monitoring, must be carried out on a continuous basis over an extended period of time to be effective. It is the long-term trends of seismic, geodetic, chemical, thermal, and hydrologic changes that are most useful in anticipating volcanic eruptions and related activity, as well as for accurate hazards assessments and high-quality scientific results. This is nowhere more clearly demonstrated than at Mount St. Helens where intensive continuous monitoring has allowed consistently accurate prediction of the last 16 eruptions. Records that are fragmentary or have large data gaps are of little use. This section describes such a long-term program.

B. General Objectives

In order to provide an adequate response to the national need for information about potential hazards from volcanic eruptions, the Volcano Hazards Program should have a balanced set of activities that are sufficiently comprehensive and carried out at a relatively stable and consistent level of effort for an extended period of time. Only in this manner can data of an appropriate type and quality necessary for accurate assessment of volcanic hazards and prediction of eruptions be accumulated, analyzed, and interpreted. A 15-year period seems a reasonable period of time for a long-term plan to be projected and implemented.

The long-term program has the following general objectives:

- maintenance of the Hawaiian and Cascades volcano observatories at adequate operational levels,
- seismic, geodetic, geophysical, geochemical, thermal, and hydrologic monitoring of active and potentially active volcanoes throughout the U.S.,
- systematic geologic mapping and volcanic and hydrologic hazards assessment studies, including updating of basic cartographic and geographic data,
- appropriate research on volcanic and related hydrologic processes,
- maintenance of a quick-response team to evaluate and monitor volcanoes showing premonitory activity,
- appropriate international collaborative studies at active foreign volcanoes, and
- fulfillment of our obligations to promote public understanding of volcanoes and their potential hazards.

C. <u>Specific Objectives</u>

Specific objectives for the three technical elements of the long-term program are:

1. <u>Volcanic Hazards Assessment</u>

    a. Collect, review, and evaluate all available information on active and potentially active volcanoes in the U.S. in order to establish a comprehensive list of volcanoes and volcanic areas, prioritized on the basis of their overall potential risk to society, and to provide a basis for the orderly study and more detailed risk assessment of individual volcanoes.

    b. Conduct, in order of priority, detailed geologic, stratigraphic, geochronological, and paleomagnetic studies of the major potentially hazardous volcanoes to determine the character, distribution, thickness, and age of their eruptive deposits, both lavas and tephras, in order to determine the kinds, magnitudes, frequencies, and extent of eruptions.

c. Inventory ground water and other water sources within volcanic edifices in order to evaluate their potential influence on phreatic eruptions, slope stability, mass movement, and the generation of mudflows during eruptions.

d. Conduct seismic and other geophysical surveys in an effort to identify those volcanoes that presently may be underlain by shallow magma chambers and, hence, be of particular concern.

e. Publish in an orderly and timely manner hazards assessment reports and maps for individual volcanoes, states, and areas of relatively high volcanic risk.

f. Inventory and assess the risk to existing and proposed transportation systems (roads, bridges, airports, railways) and municipal utilities (power, water, sewage, natural gas) and make recommendations concerning their siting and construction relative to specific volcanic hazards.

g. Provide information and advice for research in the design and construction of engineering structures resistant to specific volcanic hazards.

h. Devise and conduct experiments testing the effectiveness of various lava deflection techniques such as topography modification, hydraulic cooling of lava, and lava dams.

2. Volcano Monitoring

a. Establish seismic monitoring networks on each active and potentially active major volcano in order to detect and accurately locate on a real-time basis earthquakes of magnitude 1 or greater, which may be premonitory to a volcanic eruption.

b. Assemble at least two telemetered state-of-the-art portable seismic arrays that can be rapidly deployed around a volcano showing renewed activity, so that premonitory seismic events can be more accurately located, characterized, and tracked on a real-time basis.

c. Establish and continously or periodically monitor ground-deformation networks on active and potentially active volcanoes, utilizing distance-, angle-, and tilt-measuring instruments such as geodimeters, theodolites, and tiltmeters, as well as gravimeters and magnetometers, in order to detect changes accompanying intrusion of magma.

d. Install telemetered gas-monitoring instruments on all volcanoes emitting fumarolic gases and periodically collect and analyze gases and measure temperatures at these sites; during eruptions, monitor H_2, CO_2, and SO_2 emissions using ground-based and airborne sensors.

e. Periodically monitor thermal anomalies at potentially active volcanoes using both ground-based and aerial infrared detectors.

f. Establish a flood- and mudflow-warning system, including satellite telemetry, on each active major volcano to detect and provide early warning of hazardous flows following eruption events.

g. Operate and maintain the Hawaiian Volcano Observatory at Kilauea, Hawaii, and the Cascades Volcano Observatory at Vancouver, Washington, to serve as sites for data collection and analysis and as research and training facilities for volcano monitoring activities in the United States.

3. Fundamental Research

a. In cooperation with the Smithsonian Institution, develop a global data bank of volcanological information that may be analyzed for patterns in time and space and then compared and correlated with other cyclical or periodic geophysical phenomena such as tides, seismicity, and magnetism.

b. Conduct systematic and comprehensive geologic, petrologic, volcanological, and geophysical studies of selected important magmatic systems in order to improve the ability to model the processes active in such systems.

c. Conduct detailed topical studies of volcanic rocks and deposits, particularly those that have been observed in eruption, so that the processes and conditions of their emplacement may be more accurately correlated and compared with the characteristics of the resulting deposits, thereby allowing an accurate assessment of risk from the study of older deposits of potentially active volcanoes.

d. Conduct petrologic and geochemical studies of volcanic rock sequences of active and potentially active volcanoes in order to detect patterns of chemical and physical change that may relate to eruptive frequency and periodicity and to processes of magma generation, transport, and eruption.

e. Conduct laboratory experiments and measurements on volcanic rocks and materials in order to determine their physical properties at temperatures and pressures analogous to those in the crust and mantle, for improved location of volcanic earthquakes and interpretation of data obtained from other seismic, magnetic, electrical, and other geophysical exploration and monitoring methods.

f. Investigate the nature and properties of multi-phase fluids (gas-liquid-solids) in order to determine their effects on eruptive processes, especially explosive eruptions.

g. Determine crustal structure and its interralation to volcanism, particularly in the Cascade Range, by interpreation of geophysical data from such studies as deep seismic-reflection and refraction surveys.

h. Investigate, evaluate, and promote where appropriate the development of new geophysical and geochemical monitoring techniques (e.g., rock magnetism, magnetotellurics, and electrical studies) and methods of data processing and transmission (e.g., computer analysis and satellite telemetry) in order to improve our ability to provide real-time monitoring of precursory volcanic activity.

i. Develop, by means of field studies and analytical modelling, a better understanding of the various mechanisms of generation of volcanic debris flows, so that equations may be formulated to predict their travel times, impact forces, and areal extents.

j. Determine the effects of ultra-high sediment suspension (characteristic of streams in volcanic terrains) upon hydraulics, bedload, transport, and channel configuration, in order to better predict the short- and long-term impacts of downstream sedimentation and flooding.

D. Plans for Studies

Plans to address these objectives are described below.

1. Volcanic Hazards Assessment

Volcanic hazards assessments, some of them preliminary, have already been prepared for Mt. Baker, Glacier Peak, Mount St. Helens, Mt. Hood, and Mt. Shasta. Studies are currently in progress at Mono-Inyo Craters and Lassen Volcanic National Park, California, and at Three Sisters and Crater Lake, Oregon. Previous assessments of Mt. Rainier and Mount St. Helens are being updated as a result of new insights gained from the 1980 Mount St. Helens eruption. As these assessments are completed during the next several years, assessments of Medicine Lake Highlands in California and Newberry Volcano, Mt. Jefferson, and Mt. McLoughlin in Oregon would begin. Assessments of all potentially hazardous volcanoes in the conterminous United States would be prepared. In Hawaii, upgraded volcanic hazards assessments are in progress for Kilauea and Mauna Loa. Geologic mapping and hazards assessments of Alaskan volcanoes would be carried out on a staggered schedule. Studies would be undertaken in succession on volcanoes in the Cook Inlet area (Mt. Spurr, Crater Peak, Redoubt, Iliamna, and Augustine volcanoes), the Cold Bay-Sand Point-Dutch Harbor area (Pavlof, Shishaldin, Westdahl, and Makushin volcanoes), the Katmai area, and Mt. Wrangell. Volcanic hazards assessments should be continually updated as new knowledge and understanding of volcanic processes accrues.

2. Volcano Monitoring

Comprehensive monitoring of the active volcanoes of Hawaii should be continued indefinitely -- not only to ensure adquate warning of hazards, but also to continue building and improving our understanding of active volcanic processes.

Monitoring at Mount St. Helens probably will be required for the next decade or two and, for the immediate future, should be carried out at a level commensurate with the hazards to which the activities of the Corps of Engineers at Spirit Lake will be exposed. Intensive monitoring at Long Valley caldera should continue as long as active precursory processes can be detected. The seismic monitoring network of Yellowstone National Park should be established, and ground-deformation studies and other monitoring networks should be expanoed and improved to include satellite telemetry and real-time monitoring at Mt. Baker, Mt. Rainier, Mt. Hood, Crater Lake, Mt. Shasta, and Lassen Peak. In addition, an expanded seismic monitoring network should be established on the more frequently active Alaskan volcanoes bordering the Cook Inlet and at Mt. Wrangell which are most likely to seriously affect human activities and installations. This improved monitoring capability would provide the data continuity that is so important to the recognition, interpretation, and evaluation of precursory changes.

3. Fundamental Research

In the long term, those research activities that ultimately contribute most to improved warning capability are paramount. Significant improvement in warning capability can be achieved only through a better understanding of fundamental magmatic, volcanic, and related hydrologic processes. Optimum progress in these related areas is most likely to be made through comprehensive, carefully coordinated studies of selected magmatic/volcanic complexes, in which geological, volcanological, geophysical, geochemical, petrologic, and hydrologic investigations are conducted simultaneously and are well integrated. To be complete, such studies should include geophysical investigation of the deep crustal structure in the region, so that the influence of crustal dynamics on local magmatic and volcanic processes is fully understood.

Certain laboratory and theoretical studies also have the potential of significantly improving monitoring capability. Laboratory experiments to determine the properties of rock, magma, and gas at high pressures and temperatures not only provide insight into conditions at depth where magma is generated, but also provide data necessary to improve the location of earthquakes related to volcanism. Theoretical and experimental studies of the nature and causes of harmonic and spasmodic tremor are critically needed to improve warning capability.

After the onset of an eruption, and for many years after the cessation of eruptive activity, the most serious continuing hazards are commonly hydrologic in nature. Fundamental studies of erosion, deposition, and transport in volcanically impacted terrains are needed to provide improved warnings of debris-flows, mudflows, and floods concurrent with and consequent to eruptions.

E. Resources

Resources for the conduct of this continuing program should be relatively stable over the long-term and are based on present-day volcanic activity. Any major new eruptive activity at Mount St. Helens, or elsewhere, would require a reallotment of resources of the program to provide an increased effort at that location, particularly for more intense monitoring immediately prior to, and for a certain period of time after, an eruption.

Hazards-assessment activities are most intensive in the early part of any long-term program because initial assessments of volcanic hazards must be prepared as soon as possible for all active and potentially active volcanoes. As new information becomes available, primarily from research studies, assessments must be updated; therefore, reassessment of earlier-studied areas is periodically necessary. In addition, during impending or active eruptions, hazards assessment analyses are required on a short-term (commonly daily) basis. Continuing resources for these long-term and short-term aspects of hazards assessment must therefore be a part of any viable program.

Volcano-monitoring activities require the largest share of resources and must be carried out on an uninterrupted basis in order to maintain data continuity that is essential for adequate warnings. The resources necessary to support monitoring at any particular volcano are likely to vary considerably at any given time depending on the intensity of the local activity. At the Hawaiian volcanoes, which have been persistently active at a relatively high level through historic time and show little signs of changing pattern, resources for monitoring are likely to be required indefinitely. For Cascade volcanoes, which, on the basis of currently available evidence, tend to be active for a few decades and then quiescent for a century or more, the resource requirements are likely to fluctuate and be of generally shorter-term. At any newly active volcano, new instrumentation and telemetry systems for monitoring and data transmission would require large unanticipated resources on short notice, which could temporily affect resources for other program elements. Where incomplete or no monitoring systems currently exist, resources for such additions would be necessary.

Resources devoted to fundamental research should expand during the first few years as new information is acquired. A substantial part of the total program should be applied to fundamental research studies each year, over the entire period of a long-term program, because the accuracy and completeness of hazards assessments, the selection of appropriate data and volcanic phenomena to monitor, and the development of reliable techniques to predict eruptions depend on results from a broad, robust, and continuous program of fundamental research.

Activities for emergency-response planning and public education require relatively modest resources each year, with requirements generally decreasing as the public awareness of the possibilities of volcanic eruptions and the potential hazards associated with them increases.

F. International Cooperation

Opportunities to study and observe volcanic eruptions, particularly explosive eruptions similar to those that are likely to occur in the Cascades, are relatively limited in the United States. Consequently, U.S. volcanologists and geophysicists, in order to gain experience and knowledge, must rely largely on opportunities to participate in monitoring eruptions elsewhere in the world. Such opportunities arise occasionally as requests for assistance from foreign countries are received through AID/State Department. A valuable adjunct to the Volcano Hazards Program would be a more formal program of international cooperation in volcanic hazards assessment, volcano monitoring, and fundamental research. Several countries (e.g., Japan, Italy, Iceland, Indonesia, and the Philippines) have already made overtures to the USGS for such cooperation, and we currently have a limited cooperative program with Indonesia.

An appropriate part of such a program would be maintenance of a quick-response team of scientists (geologist, volcanologist, seismologist, geophysicist, geochemist, hydrologist, and technicians) and an equipment inventory (seismometers, surveying equipment, tiltmeters, and gravimeters) drawn from USGS resources at the Cascades Volcano Observatory, the Hawaiian Volcano Observatory, and other centers.

Another valuable cooperative international activity would be development of a long-term Pacific-wide volcano monitoring system utilizing remote, automated monitoring equipment and satellite telemetry so that an accurate and complete record of circum-Pacific volcanism could be obtained.

The combination of a satellite-telemetered monitoring network and a quick-response team to respond to eruptions anywhere in the Pacific would greatly accelerate scientific progress in understanding the fundamental causes of volcanism and considerably improve our ability to predict eruptions and respond to emergencies in the U.S.

V. THE FEDERAL ROLE

Previous sections of this document have described the Geological Survey's Volcano Hazards Program -- its mandated responsibilities, goals, objectives, components, activities, and plans. This section describes the need for Federal involvement in such a program, in relation to participation and responsibilities of various Federal, state, and local organizations.

When considering the four components of the USGS Volcano Hazards Program as elements of a national effort on volcanic hazards, the lead agencies and collaborative organizations for a national program are as follows:

Component	Lead Agency	Collaboration
Volcanic hazards assessment	USGS	Federal and state land and mineral agencies, FEMA, state offices of emergency services.
Volcano monitoring	USGS	Federal agencies (USFS, BLM, NPS), state land and mineral agencies, state and private universities.
Fundamental research	USGS	Scientific community including state geological surveys and universities.
Emergency-response planning and public education	Local, state, and Federal (FEMA) emergency-response organizations	USGS for issuance of hazards notices, watches, and warnings; FAA, Army COE, USFS, NPS, BLM, and other Federal agencies.

USGS responsibilities in the above activities are mandated by the Disaster Relief Act of 1974. The degree of collaboration of state and local agencies and governments varies greatly among the states, a situation that does not lend itself to simple or general arrangements. In any case, however, the intent of the Survey is to promote state and local agency participation and to encourage their funding support of appropriate activities insofar as possible.

There are six principal reasons for Federal involvement in a program dealing with volcanic hazards:

A. Public Need for Information about Impending Volcanic Hazards

The public must be informed in a timely and accurate manner about threats from an impending volcanic eruption. The responsibility to do so by issuance of a volcanic hazards notice, watch, or warning has been legislated to the USGS. To be effective, this information must be issued with appropriate speed and accuracy and must be fully supported by scientific evidence.

This responsibility can be fulfilled only by the Survey carrying out a comprehensive and viable program for assessing potential hazards from volcanic eruptions, monitoring volcanoes of concern, and conducting related geologic and hydrologic research. Being involved in such a program provides the Survey not only with up-to-date geologic and hydrologic information about volcanic processes in general and about specific volcanoes in particular, but also with immediate availability of personnel with the broad range of geological, hydrological, geophysical, and geochemical expertise that is needed to respond to the quickly changing events prior to and associated with a volcanic eruption.

B. Interstate Implications of Volcanic Disasters

Although individual volcanoes may be totally within the boundaries of any one state, the products and consequences of an eruption of any such volcano, particularly ash falls which can be deposited hundreds of miles downwind, can affect a region encompassing many states. Consequently, hazards assessments, although usually focused on individual volcanoes, must span the borders of neighboring states, extending even into states that do not contain volcanoes. These assessments must, therefore, be undertaken with a regional approach.

Although individual states might satisfactorily carry out the relatively low-level monitoring of ostensibly dormant or quiescent volcanoes to acquire baseline data and to recognize precursory changes at an early stage, experience indicates that it is unlikely that any one state would have the additional personnel or equipment for the comprehensive monitoring that is required once precursory activity is recognized or when an eruption actually begins. The costs of purchasing new equipment and hiring additional people to carry out the higher level of monitoring are extensive and might well be beyond the financial, as well as technical, means of an individual state. Furthermore, experience has shown that continuity and organizational coherence are essential in the rapidly changing, stressful environment of an active eruption. The USGS can provide, and has provided, this critical coordination. It seems that the most effective role of state agencies in monitoring volcanoes is to provide some redundancy in routine and transitional monitoring so that corroboration of results and conclusions can be quickly provided to the public. This arrangement, by agreement, has worked very successfully in California.

C. Disruption of Regional and National Economies

A volcanic eruption can have a very severe impact on the Nation's economy because of the disruption of interstate commerce. The eruption of Mount St. Helens, for example, greatly disrupted much of the economy of the Pacific Northwest. The major regional industries of timber, fishing, and shipping were the hardest hit. This eruption caused not only a regional hardship but also was felt nationwide by industries relying on products produced mainly in the northwest region. Therefore, it is in the Federal interest to prepare and periodically update hazards assessments for all volcanoes which can affect regional economies, as a basis for defining and possibly mitigating these adverse impacts.

D. Implication for Federal Lands

Most volcanoes are situated on Federal lands administered by the Forest Service, National Park Service, or Bureau of Land Management. Therefore, the primary responsibility for the monitoring of precursory phenomena falls upon the Federal government in order to assure protection of the general public and private enterprises on Federal lands. The states may or may not be willing to assume a cooperative role in the operation of monitoring sites at which they have little or no vested interest or over which they do not exercise jurisdiction.

E. Mitigation of Subsequent Federal Disaster Assistance Costs

The USGS Volcano Hazards Program provides opportunities, through the use of earth-science information, to reduce post-eruption needs for Federal disaster assistance under FEMA and SBA programs. Assessments of the likely occurrence, extent, and severity of volcanic activity and associated hazards (similar to those available for Mount St. Helens and, more recently, for Long Valley, California) are an essential ingredient in the development of emergency preparedness and evacuation plans that can reduce the loss of life and property as an immediate consequence of an eruption. Over the longer term, assessments of volcanic hazards could be made an integral part of local, state, and regional land-use decisions, which would provide additional opportunities to further reduce or avoid the risk to lives and property during the formulation of development (or reconstruction) plans.

F. Need for an Integrated Research Program

Because much of the fundamental research that is required in a program dealing with volcanic hazards is generic and long-term in nature, a large proportion of this work should be supported through a single funding source in order to assure a comprehensive scientific effort, integration of research results, continuity of highest-priority projects, and requests for sufficient funds for an appropriate level of effort. Universities, the Smithsonian Institution, and other research institutions will remain in the forefront in conducting fundamental volcanological research, but a coordinated effort, particularly for research applied to monitoring and hazards assessment, can best be maintained through strong Federal (USGS) leadership. The research projects of the USGS Volcano Hazards Program should continue to receive direct funding, with an appropriate portion allocated by research contracts and grants to universities and other scientific institutions to supplement research funded through the National Science Foundation. This approach offers the advantage of maintaining a core volcanological research staff in a single organization (USGS), while providing a mechanism to more fully utilize the diverse expertise of the broader scientific community.