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U.S. Geological Survey

# The Cascade Volcanoes:
# Monitoring History and Current Land Management

by

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## Introduction

This report was written to allow rapid review of the monitoring history of fifteen major Cascade volcanoes and vent zones that have been active within Holocene time, and to provide a list of managers responsible for administration of the regions in which each volcano lies. It is intended as a communication tool between scientists and land managers, and as a guide for persons interested in beginning or following up on research within these fields at a particular volcano. The term "monitoring" in this report encompasses research in those branches of geology, hydrology, and geophysics that are commonly applied to evaluate the hazards posed by a volcano and the likelihood of future eruptions from it; they include geodesy, seismology, gas and surface water geochemistry, magnetic and gravity studies, electrical conductivity and self-potential studies, hydrology, igneous petrology, volcanic stratigraphy, glaciology, and hazards assessment. The region covered begins with Mount Baker in the north and ends at Lassen Peak in Northern California.

Each of the fifteen sections contains a summary of past and present monitoring activities and land management at a volcano or vent zone and its vicinity. Names, affiliation, and telephone numbers of key geoscientists and land managers are presented in tabular form for rapid overview and simplicity of maintenance. Maps showing the locations of earthquakes and seismograph stations are provided for the volcanoes from Mount Baker to Mount Hood in the north, and Mount Shasta, the Medicine Lake Caldera, and Lassen Peak in the south. A considerable effort has been made to make this review as comprehensive as possible, and the author hopes that readers will send references for any studies that should have been included. These should be sent to the address listed on the title page.

Although monitoring activities are almost exclusively limited to the major volcanoes covered here, they represent only a fraction of the vents that have been active in Holocene time in the Cascades. For this reason, there are sections for vents that have well-documented Holocene activity but are not currently monitored, such as the McKenzie-Santiam Pass Vent Zone, Mount McLoughlin, and other areas of the southern Oregon High Cascades.

**History of Volcano Monitoring in the Cascade Range**

Four periods in the development of monitoring of the Cascade volcanoes can be recognized from the literature. Prior to 1958, information on activity at the Cascade volcanoes was primarily obtained from visual reports and limited seismic monitoring. The eruptions of Mount Baker, Mount St. Helens, Mount Hood, Lassen Peak, and Mount Rainier in the 19th and early 20th centuries occurred during this period; these observations are well summarized by Stephen Harris (1989). The only seismograph station operating near a Cascade volcano prior to 1958 was at Mineral, California, 15 km south-southwest of Lassen Peak; it began continuous operation in 1939 and included high-gain components after 1949.

The period from 1958 through 1979 saw the development of seismic monitoring of the Cascade volcanoes in several stages, as summarized in Weaver et al (1990). The first seismograph station at Mount Rainier was installed at Longmire in 1958. Beginning in 1963, annual earthquake catalogs complete at the magnitude 4.0 level and above were available, largely due to the installation of seismic stations of the World-Wide Seismographic Station Network in Washington, Oregon, and California. In the late 1960's and early 1970's, short-term studies of local seismicity were conducted at Mount Rainier, Mount St. Helens, Mount Hood, and Lassen Peak using temporary networks of seismograph stations (Weaver and others, 1982). The development of regional networks of short-period, high-gain stations in the 1970's in Washington, Oregon, and California allowed locations of earthquakes below the magnitude 4.0 level in the Cascades. By 1972 a few stations in these networks were being installed at individual volcanos, and by 1979 at least one permanent station was operating near Mt. Baker, Mt. Rainier, and Mt. St. Helens, and networks of permanent stations were operating around Mt. Hood, Mount Shasta, and Lassen Peak. These volcano stations were monitored from visual recorders (helicorders and develocorders) at the USGS Western Region office in Menlo Park and the University of Washington in Seattle.

In addition to seismic monitoring, studies of thermal and hydrothermal features on Mount Rainier, Mount Baker, and other volcanoes were made in the 1960's and early 1970's using ground and air-based infrared scanners and photography (Moxham and others, 1965, 1970; Friedman, 1972; Friedman and others, 1973, 1980; Lange, 1975) and satellite telemetry (Moxham, 1972; Friedman and others, 1973).

Two volcanoes showed unusual activity during this period, which drew public and scientific attention to the hazards to population centers posed by the Cascade volcanoes (Cullen, 1978) and underscored the need for long-term volcano monitoring programs. In 1969, a large section of the Emmons Glacier on the northeast side of Mount Rainier became extensively crevassed, accompanied by a threefold increase in the rate of local seismic events on the Longmire station (LON in Figure 2). A temporary volcano-monitoring seismic network was installed around Mount Rainier during this time, the first of its kind in the Cascades (Unger and Decker, 1970). The increase in fumarolic activity at Mount Baker in March, 1975 initiated the first gravity and tilt studies on a Cascade volcano. Although not related to volcanic activity, an earthquake swarm that occurred east of Mount Shasta in 1978 provided an impetus for adding a local seismic network in the area surrounding Mount Shasta and Medicine Lake.

The onset of volcanic activity at Mount St. Helens in March 1980 initiated a wide spectrum of geological, geophysical, geochemical, and remote sensing monitoring programs there, as documented in Lipman and Mullineaux (1981), and spurred greatly increased monitoring of other Cascade stratovolcanoes over the next six years. During this period, baseline and follow-up studies of tilt and trilateration were performed at Mounts Baker, Rainier, St. Helens, Hood, and Shasta; also Newberry Caldera, Crater Lake, and the South Sister. A network of 32 seismograph stations was installed in the Oregon Cascades in 1980 by the USGS, and operated for two years. Fumarole geochemistry was studied at Baker, Rainier, St. Helens, Hood, Shasta, and Lassen Peak; gravity surveys were conducted at Mount St. Helens, Mount Shasta and Lassen Peak. The volumes of glacier ice at Mount Rainier, Mount Hood, the Three Sisters peaks, and Mount Shasta were measured to identify the potential volumes of meltwater available for eruption-induced floods or lahars (Driedger and Kennard, 1986).

The years since 1986 have seen a somewhat slower pace in monitoring activites. The current lull in eruptive activity at Mount St. Helens has reduced the need for the high level of monitoring that characterized the 1980-1986 period. The lack of significant deformation or seismicity at other volcanoes during the 1980's, coupled with fiscal limitations, has limited follow-up studies of phenomena such as fumarole geochemistry, gravity, and local magnetic fields at the other volcanoes.

The significant developments in monitoring since 1986 have included the reestablishment of a limited seismic network in the northern and central Oregon Cascades in 1987, the beginning of seismic and deformation monitoring of Medicine Lake Caldera in 1988, and follow-up deformation studies at Mount Rainier in 1988 and 1989. Also, experience gained in interpreting seismograms from non-earthquake sources has enabled seismologists to recognize seismograms from debris avalanches and flows at Mount St. Helens and Mount Rainier, raising the possibility of issuing real-time warning of such events in the future both at those volcanoes and others.

Readers should keep in mind that seismic monitoring in the Cascades developed in stages, and caution is advised when making interpretations from the seismicity maps of the volcanoes in this report. Although all earthquake hypocenters shown have an RMS of the traveltime residuals of 0.35 seconds or less and a location error of less than 5 km, low station density in the Cascades prior to the late 1970's means that some events meeting these criteria may still be mislocated. Earthquakes as small as magnitude 1.5 are shown to illustrate the general features of seismicity near each volcano, but the seismic data catalogs from which the figures were made are not complete at that level.

**Agencies Involved with Monitoring Activites**

The U.S. Geological Survey has the primary responsibility of monitoring volcanoes in the western U.S. The volcano monitoring programs are performed by scientists within the Geologic and Water Resources Divisions, most of whom are located at three principal monitoring centers.

**The David A. Johnston Cascades Volcano Observatory**

Most geologic, hydrologic, and geophysical studies of the Cascade volcanoes are based at the David A. Johnston Cascades Volcano Observatory (CVO) in Vancouver, Washington. Volcano monitoring programs within the Geologic Division include ground deformation, magnetic and gravity studies, geology and petrology, photography, remote sensing, and local seismic monitoring of Mount St. Helens. Water Resources programs include studies of the evolving geomorphology of the 1980 avalanche and directed blast deposits at Mount St. Helens; lahar magnitude and frequency, studies of mass movements, and slope stability (Brantley and Topinka, 1984; WOVO, 1989). Although much of the scientific focus of both divisions is on Mount St. Helens, it includes other volcanoes as well.

The Cascade Volcano Observatory is the primary agency responsible for issuing advisories and warnings of potentially hazardous volcanic and hydrological events. When it becomes necessary to issue a hazard notice to the public, the Observatory staff prepares a statement for release by the U.S. Forest Service. The USFS notifies about 50 organizations by telephone, including local, state, and Federal agencies, and private corporations having operations and personnel near the hazardous area. The news media also receive the statement, and relay it to the public (WOVO, 1989).

**The University of Washington and Seattle USGS office**

Seismic monitoring of the Cascade volcanoes from Mount Baker to the Newberry Caldera is the responsibility of the University of Washington Geophysics Program and the USGS in Seattle, which jointly operate a 118-station regional seismic network in Washington and northern Oregon. Seismic signals from all stations are continuously digitized and monitored for earthquakes by the HAWK seismic data acquisition system, which operates on a Masscomp MC-5600 minicomputer (University of Washington Geophysics Program, 1989). Earthquakes are located by analysts using interactive seismic trace-picking software, and archived in monthly on-line earthquake catalogs.

Earthquake activity is also monitored from a selected group of stations which are displayed on helicorders (visually recording seismographs). Catalogs of local seismic events at Mounts Baker, Rainier, St. Helens, Adams, Hood, and the Newberry Caldera are maintained from daily analysis of these helicorder records. The Geophysics Program notifies local, state, and Federal agencies when a significant earthquake occurs, and answers inquiries on seismic activity in Washington and northern Oregon from these agencies, the news media, and the general public.

**USGS- Menlo Park office**

The Cascades in northern California lie within the regional seismic network operated by the USGS office in Menlo Park. Mount Shasta, Medicine Lake, and Lassen Peak each have local networks of 6 to 9 stations in their vicinity. In addition to seismic monitoring, geologists in Menlo Park have done extensive studies of the volcanic stratigraphy, regional structural relations, field mapping, and petrologic studies of the products of recent eruptions at the Cascade volcanoes from Central Oregon south to Northern California.

In addition to these three principal monitoring centers, scientists with the Water Resources Division are based in other USGS offices in Tacoma, Washington, Portland, Oregon, and Sacramento, California. These scientists perform studies in hydrology, glaciology, and water geochemistry at the volcanoes.

**Geologic Investigations Outside of the USGS**

Many investigations of Holocene eruptive activity at the Cascade stratovolcanoes have been performed by scientists outside of the USGS. As their studies are directly relevant to our current understanding of volcanic hazards at these volcanoes, these scientists have been included in this report with their areas of study.

**Land Management**

With the exception of some private land holdings around the perimeter of Mount Shasta and in the Newberry Caldera and tribal lands on Mount Adams and Mount Jefferson, all of the Cascade volcanoes in this report lie within public lands administered either by the U.S. Forest Service or the National Park Service. Most of the higher elevations of the stratovolcanoes are managed as wilderness areas. Motorized vehicles are prohibited, and there are strict limits on the use of machinery and low-altitude air travel; such activities require permission from National Forest Supervisors or National Park Superintendents. At the more intensely monitored volcanoes such as Mount St. Helens and Lassen

Peak, the use of helicopters for routine monitoring work is allowed in protected areas under existing agreements with the U.S. Forest Service and the National Park Service.

Each National Forest is administered from its headquarters, which are usually located in the largest city within or closest to the Forest. Each Forest is divided into districts, each under the supervision of a District Ranger. Persons desiring to undertake scientific studies on National Forest lands should first contact the appropriate District Ranger for their area of study.

The Forest Service, the Park Service, and other agencies that have personnel out in the field have themselves been important monitoring resources. To name only two examples, rangers provided the first visual reports of the deposits from large rockfalls at Mount Rainier in 1963 and 1989 (Crandell and Fahnestock, 1965; Norris, 1989). Such observations are particularly valuable in sparsely monitored regions, such as the southern Oregon High Cascades. Land managers and field workers in all disciplines are encouraged to report observations of anomalous activity at volcanoes to the appropriate scientists listed in this report.

**Acknowledgements**

I am thankful for the help provided by the USGS scientists who explained the details of their published work, and contributed unpublished data for this report. At the Cascades Volcano Observatory, Steve Brantley supplied updates of staff and monitoring activities; Ken McGee provided details of current and past monitoring of gas geochemistry at several volcanoes, and Dan Dzurisin and Gene Iwatsubo explained deformation monitoring programs carried out at CVO. At the Menlo Park USGS office, Steve Walter contributed summaries of seismic activity at the California volcanoes, and provided a detailed, thoughtful review of the text and figures in this report. Chris Jonientz-Trisler at the University of Washington and Carolyn Driedger at the Tacoma USGS office shared their data on seismic signals from debris flows at Mount Rainier and Mount St. Helens. Finally, I would like to thank the people with the U.S. Forest Service and National Park Service who helped me compile the lists of names and addresses of administrators within their agencies; they were courteous and patient during this sometimes tedious task.

# Mt. Baker

Data current as of October 1990

1. **Pertinent Data:**

**Elevation:** 10541', 3285m

**Coordinates:** (summit) 48° 47.00' N 121° 48.00' W

**Last Eruption and its products:** Sporadic tephra eruptions during the 1800's through 1880 (Harris, 1989).

**USGS Topographic Maps:**

| Scale | Map | Date |
|---|---|---|
| 1:250,000 | Concrete | 1962 |
| 1:62,500 | Mt. Baker | 1952 |

2. **Administrative setting**

Mount Baker lies mostly in the Mount Baker Wilderness, in the Mount Baker National Forest, Whatcom County. The southeastern section of the volcano is in the Mount Baker Recreation Area. Permission must be gained from the Forest Supervisor before any instruments are installed in wilderness areas on USFS land. The usual procedure is to make the request through the District Ranger, who will then refer it to the Supervisor for approval.

3. **Monitoring Status**

**Gas Geochemistry**

The increase in fumarolic activity and elevated ground temperatures in the Sherman Crater in March 1975 prompted a rapid increase in monitoring activities there. Prior to March 1975, the highest measured temperature in fumaroles in the Sherman Crater was 90° C; by May, some had exceeded 120 ° and the highest was 131° (Malone, 1979). Gases from fumaroles in the Sherman Crater were manually sampled and temperatures were measured during the summer of 1975, and again during 1980-81.

A continuously operating hydrogen sensor was installed during the summer of 1981, which telemetered data to CVO via a GOES satellite. It was destroyed by severe weather during the following winter and was not replaced, as continuing its operation under similar conditions in upcoming winters seemed impractical (Ken McGee, personal communication, 1990). There is no current gas monitoring at Mount Baker.

**Geodetic Monitoring**

Following the increase in fumarolic activity in March, three tilt-levelling stations were installed near the 2,000m level on the mountain. No tilt was discernable when these stations were resurveyed later in 1975 and in 1976, which along with the very low seismicity and limited deformation implied by the gravity survey described below ruled out the possibility of significant intrusion of magma into the cone during this period. Later occupations in 1981 and 1983 also did not indicate any significant changes in tilt.

Similar results were reported from surveys of the trilateration network, which was installed in July, 1981. The 16 lines were remeasured in 1983, the last year any deformation data were collected at Mount Baker, and showed no changes (Chadwick and others, 1985).

**Gravity Study**

In May, 1975, a gravity network of three stations was installed to monitor possible deformation of the cone. Two sites were located on the rim of Sherman Crater, and a third near the town of Concrete was used as a reference station. A small but consistent decrease in gravity at the crater stations (0.33 mgal) was observed between measurements in May and September 1975, corrected for seasonal and geothermally induced reductions in snow and ice cover on the peak (Malone, 1979). Of several models proposed for the cause of this decrease, a loss of mass due to the increased fumarolic discharge seemed most appropriate, given the lack of significant seismicity or tilt during this period. However, without geodetic data from the crater itself, this interpretation remains somewhat speculative. No further gravity studies have been made to date.

**Seismicity**

Seismic activity at Mt. Baker has been monitored by the University of Washington Geophysics Program since 1972, when station MBW began operating on its western flank. Seismic events are interpreted daily from helicorder records from the MBW station, and since 1987 they have been logged into an on-line data base. Typical activity includes numerous small, low-frequency events which have been interpreted to originate in the glaciers (Weaver and Malone, 1976, 1979). Since 1969, when the seismic network was installed in the Cascades, only a few locatable earthquakes have occurred in the vicinity of Mt. Baker each year. The largest was only of magnitude 2.5. Even during the 1975-76 crisis period the mountain was nearly aseismic; a temporary network of 5 stations that was installed around the mountain following the increase in fumarolic activity detected very few earthquakes during its operation (Malone, 1979). Smaller, unlocatable earthquakes are seen a few times each month on the MBW helicorder records.

Seismicity in the Mount Baker region from 1969-1990 is plotted in Figure 1, which displays currently operating seismic stations and located earthquakes of magnitude 1.5 and above in the northern Washington Cascades. Earthquake activity in this region is dominated by both shallow crustal earthquakes beneath the western edge of the Cascades (Weaver and others, 1990) and deeper earthquakes within the subducting Juan de Fuca plate. The cluster of epicenters west of Mount Baker represents the magnitude 5.0 Deming earthquake on April 13, 1990 with its foreshocks and aftershocks (Qamar and Zollweg, 1990). Niether Mt. Baker or Glacier Peak (also shown in Figure 1) are significant seismic sources in this region.

**4. Information Contacts: Geological and Geophysical Data**

| Type of Data | Scientist | Agency | Division | Location | Telephone |
|---|---|---|---|---|---|
| Geology | Don Swanson | UW | GL | - | (206) 543-1190 |
| | David Frank | EPA | - | - | (206) 442-4019 |
| Holocene debris flows | Ken Cameron | USGS | WRD | CVO | (206) 696-7920 |
| Gas Geochemistry | Ken McGee | USGS | GD | CVO | (206) 696-7695 |

| | | | | | |
|---|---|---|---|---|---|
| **Geodesy** | Gene Iwatsubo | USGS | GD | CVO | (206) 696-7883 |
| | Dan Dzurisin | USGS | GD | CVO | (206) 696-7826 |
| **Seismicity** | C. Jonientz-Trisler | UW | GP | - | (206) 543-7010 |
| **Gravity** | Steve Malone | UW | GP | - | (206) 685-3811 |

GD = Geologic Division, USGS
WRD = Water Resources Division, USGS
UW = University of Washington
GL = Dept. of Geological Sciences (UW)
GP = Geophysics Program (UW)
CVO = Cascades Volcano Observatory
EPA = Environmental Protection Agency, Seattle

**Addresses:**

| | |
|---|---|
| CVO: | David A. Johnston Cascades Volcano Observatory, 5400 McArthur Blvd.,Vancouver, WA 98661 |
| UW: | AK-50, Geophysics Program, University of Washington, Seattle, WA 98195 |
| EPA: | 1200 6th Ave., Seattle, WA 98101 |

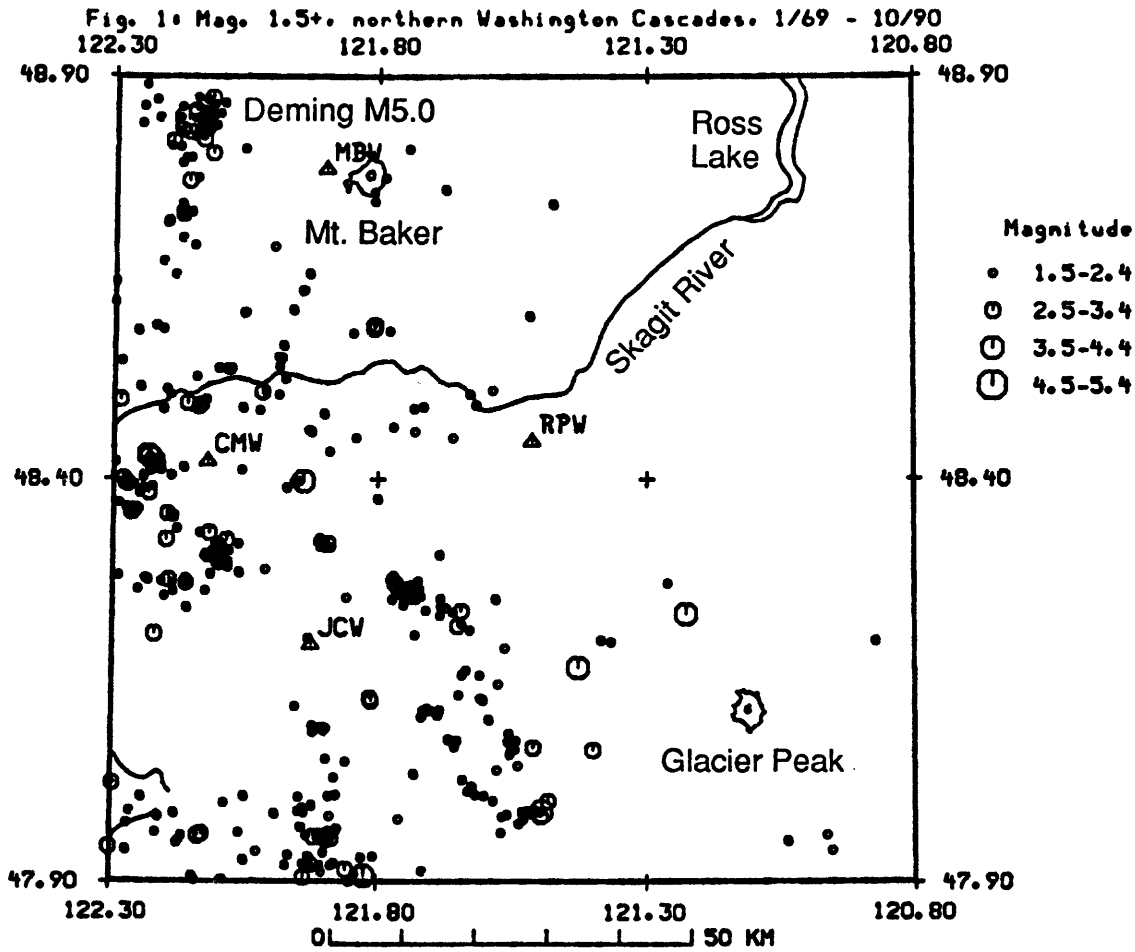
## 5. Information Contacts: Administrative

**U.S. Forest Service**

| National Forest | Person | Title | District | Telephone |
|---|---|---|---|---|
| **Mt. Baker** | J.D. McWilliams | Forest Supervisor | - | (206) 775-9702 |
| | Larry Hudson | District Ranger | Mt. Baker | (206) 856-5700 |

**USFS Addresses**

| | |
|---|---|
| Supervisor's Office: | 21905 64th Ave. W., Mountlake Terrace, WA 98043 |
| Mt. Baker Ranger District: | 2105 Highway 20, Sedro Woolley, WA 98284 |




Earthquakes of magnitude 1.5 and greater, from the UW earthquake catalog. The irregular lines around Mount Baker and Glacier Peak represent the 7,500-foot contour line.

# Glacier Peak

Data current as of October 1990

## 1. Pertinent Data:

**Elevation:** 10541', 3213m

**Coordinates:** (summit) 48° 06.00' N 121° 07.00' W

**Last Eruption and its products:** Lahar, tephra, and flood deposits at appx. 300 yrs. B.P. (Beget, 1982a)

**USGS Topographic Maps:**

| Scale | Map | Date |
|---|---|---|
| 1:250,000 | Concrete | 1962 |
| 1:100,000 | Sauk River | 1975 |
| 1:62,500 | Glacier Peak | 1950 |

## 2. Administrative setting

The peak lies in the Glacier Peak Wilderness, in the Mount Baker National Forest, Snohomish County. Permission must be gained from the Forest Supervisor before any instruments are installed in wilderness areas on USFS land. The usual procedure is to make the request through the appropriate district ranger, who will then refer it to the Supervisor for approval.

## 3. Monitoring Status

### Geodetic Monitoring

No geodetic studies have been made at Glacier Peak to date.

### Hydrothermal Water Geochemistry

Geochemical investigations have been limited to sampling of water from Gamma Hot Springs low on the northeast flank of Glacier Peak in August 1962, October 1979, and June 1982. No significant chemical changes have been seen over the years (CVO, unpub. data, 1982.)

**Seismicity**

Glacier Peak lies within the seismic network jointly operated by the University of Washington and the USGS from the University of Washington campus in Seattle. The two closest stations are each 61 km distant to the southwest and east; there are none on the mountain itself. As a result, the detection threshold for earthquakes in the Glacier Peak area is higher than at more extensively instrumented volcanoes such as Mount Baker or Mount Rainier. Smaller earthquakes and low-frequency glacial events such as those seen at Mt. Baker and Mt. Rainier may occur at Glacier Peak, but are not detectable with the current seismic network. Seismicity in the Glacier Peak region can be viewed in figure 1, which displays all located earthquakes of magnitude 1.5 and greater in the northern Washington Cascades from 1969 through 1990. Readers should be aware that the low station density in the Glacier Peak region has limited the resolution of hypocenters in the area, particularly prior to 1977, and some of the events plotted in Figure 1 may be mislocated. However, it is evident that Glacier Peak is not a significant seismic source in the region.

## 4. Information Contacts: Geological and Geophysical Data

| Type of Data | Scientist | Agency | Division | Location | Telephone |
|---|---|---|---|---|---|
| Geology | Kevin Scott | USGS | GD | CVO | (206) 696-7765 |
| | Jim Beget | UA | Geophysical Institute | - | (907) 474-5301 |
| Seismicity | C. Jonientz-Trisler | UW | GP | - | (206) 543-7010 |

GD = Geologic Division, USGS
UW = University of Washington
GP = Geophysics Program (UW)
UA = University of Alaska, Fairbanks

**Addresses:**

CVO: David A. Johnston Cascades Volcano Observatory, 5400 McArthur Blvd., Vancouver, WA 98661

UW: AK-50, Geophysics Program, University of Washington, Seattle, WA 98195

| | |
|---|---|
| UA: | Geophysical Institute, University of Alaska, Fairbanks, AK 99775-0800 |

**5. Information Contacts: Administrative**

| National Forest | Person | Title | Ranger District | Telephone |
|---|---|---|---|---|
| Mt. Baker | J.D. McWilliams | Forest Supervisor | - | (206) 775-9702 |
| | Fred Harnish | District Ranger | Darrington | (206) 436-1155 |

**Addresses**

**Mount Baker National Forest**

| | |
|---|---|
| Supervisor's Office: | 21905 64th Ave. W., Mountlake Terrace, WA 98043 |
| Darrington Ranger District: | Darrington Ranger District, Mount Baker National Forest, Darrington, WA 98241 |

# Mt. Rainier

Data current as of October 1990

## 1. Pertinent Data:

**Elevation:** 14410', 4392m

**Coordinates:** (summit) 46° 51.00' N 121° 46.00' W

**Last Eruption and its products:** Minor tephra eruptions from summit craters, witnessed in 1894 (Majors and McCollum, 1981)

**USGS Topographic Maps:**

| Scale | Map | Date |
|---|---|---|
| 1:250,000 | Yakima | 1971 |
| 1:125,000 | Mount Rainier Nat'l Pk. | 1924 |
| 1:100,000 | Mount Rainier | 1978 |
| 1:62,500 | Mount Rainier | 1971 |
| 1:24,000 | Mowich Lake | 1971 |
| | Sunrise | 1971 |
| | Mt. Rainier East | 1971 |
| | Mt. Rainier West | 1971 |

## 2. Administrative setting

Mount Rainier National Park includes all but the extreme western slopes of the volcano. The Park is nearly enclosed by the Mt. Baker-Snoqualmie National Forest, and a small portion of the Gifford Pinchot National Forest abuts its southern border. Each of the four borders of the Park is partly adjoined by wilderness areas within the two National Forests. Permission to install instruments on these wilderness lands is granted by the Forest Supervisors of each National Forest. The request should be made through the appropriate District Ranger, who refers the request to the Supervisor for approval. The procedure for installing instruments within the National Park is presented in the Administrative Contacts section below.

## 3. Monitoring Status:

### Geodetic Monitoring

Geodetic surveillance of Mount Rainier began in September 1982, when trilateration and tilt-levelling networks were installed around the mountain by staff from the Cascade Volcano Observatory. The tilt-levelling network consists of three triangular and four linear survey stations. The trilateration network contains 30 measured lines for detecting changes in slope distance and vertical angle around the volcano. Both networks were reoccupied in 1983, and no significant geodetic change was found (Dzurisin and others, 1983; Chadwick and others, 1985). Some inconsistencies were observed between 1982 and 1983 measurements of lines in the trilateration network. As field conditions were often poor during the 1983 survey, however, actual geodetic change was considered unlikely.

Both networks were partially surveyed in 1988, and a complete survey of the trilateration network was made in 1989. As in 1983, no significant geodetic change was detected at either network.

### Thermal Features and Hydrothermal Water Geochemistry

Visual reports of Mount Rainier's active hydrothermal system date from the first documented climb in August 1870, and its thermal features were mapped in the 1960's and early 1970's using ground and air-based infrared scanners and photography. Activity at Mount Rainier is greater than most Cascade volcanoes and appears to occur in four elevation zones, as summarized in Frank (1985):

- An extensive area (>12,000 $m^2$) of warm ground and fumaroles of 76-82° C in the east and west summit craters;

- Small areas of warm ground and fumaroles at sub-boiling temperature on Disappointment Cleaver and other, probably similar areas on the high headwalls (Willis Wall, Sunset Amphitheater, South Tahoma and Kautz Glacier headwalls);

- Sulfate and carbon dioxide-enriched thermal springs in valley walls on the lower flanks of the volcano, such as those beside the Paradise and Winthrop Glaciers;

- Chloride and carbon dioxide-enriched thermal springs issuing from non-volcanic rock at or somewhat beyond the base of the volcano, in the valleys of the Nisqually and Ohanapecosh Rivers.

In addition, short-lived steam vents have appeared at various locations on the upper flanks of the cone (Frank, 1985), and the breakup of the upper Emmons Glacier in 1969 may have been caused by subglacial hydrothermal activity. Although no regular gas monitoring program is currently in effect, the many climbers who visit the summit provide an informal monitoring resource during the summer months.

**Seismicity**

After Mount St. Helens, Mount Rainier is the most seismically active volcano in the Cascade Range in Washington and Oregon. The first seismograph station in the area was installed at Longmire, near the southwest entrance to Mount Rainier National Park, in 1958. The Longmire station (LON) was upgraded to a Worldwide Standard Seismograph Station in 1962, and arrival times from all seismic events were read daily from 1962 to 1975. Temporary networks of seismograph stations were installed around the mountain in 1969 to study local seismicity at the volcano (Unger and Decker, 1970) and again in 1972 as part of an experiment to investigate low-frequency seismic events seen at both Mount Rainier and Mount St. Helens. These low frequency events were subsequently determined to be glacial in origin and are are described in more detail below.

Since 1972, Mount Rainier has been monitored from the seismic network jointly operated by the Geophysics Program at the University of Washington in Seattle and the U.S. Geological Survey. The first short-period telemetered station near the volcano, FMW, was installed that year near the Mt. Fremont lookout on its northwest side. Four other stations have been added since 1983, including a short-period telemetered component at LON. This has improved the hypocentral resolution at the volcano so that events as low as magnitude 1.0 can now be located.

**Interpreting Seismic Signals from Mount Rainier**

Due to the length of time FMW has operated, it remains the primary station for visual monitoring of seismic activity at Mount Rainier. Since 1982, local seismic events appearing on FMW have been classified daily according to type and logged into an on-line data base. This data base includes many surficial events and earthquakes at the volcano that are too small to be located, and so do not appear in the University of Washington earthquake catalogs. The four classes of seismic events are described below:

**1. Low frequency glacier events.** These low-frequency, emergent events have been observed at Mount Rainier since the installation of LON and were initially interpreted as volcanic in origin (Unger and Decker, 1970). Later studies showed they occur high on the mountain at shallow depth, and provided strong evidence that they are generated by stick-slip downslope motion of ice on the subglacial surface (Weaver and Malone, 1976, 1979). Although most common at Mount Rainier, they are also observed at Mount Baker, occasionally at Mount Hood, and were common at Mount St. Helens prior to 1980.

**2. Earthquakes.** Small local earthquakes are seen every month on the FMW visual record, and once or twice a year they occur in swarms of 10 - 30 events over a period of a few hours to 1-2 days (Chris Jonientz-Trisler, personal communication, 1989). Earthquakes in the Mt. Rainier area tend to occur either at shallow depth beneath the summit region, or in the north-south striking seismic zone west of Rainier described in Weaver et al (1990). The summit earthquake activity has varied between 0 and 4 locatable events of magnitude 2.0 and greater per year since 1974, and can be seen in Figure 2. Figure 3 shows the local seismic networks at Mounts Rainier, St. Helens, and Hood. The seismic zone west of Mt. Rainier can be seen in its entirety in Figure 4, which also shows seismic zones near Mt. St. Helens and Mt. Hood. The largest instrumentally recorded earthquake near Mount Rainier was of magnitude 3.9, and occurred in 1973 (Crosson and Frank, 1975).

**3. Rockfall signals.** Many of the steep cliffs at Mount Rainier are sites of frequent rockfall activity, especially in the summer months. Rock and debris avalanche signals have been routinely identified at Mount St. Helens since 1980, but have been recognized at Mount Rainier only recently. Characteristics of signals from debris avalanches include an emergent onset, low maximum amplitude relative to event duration, and indistinct phases (Malone, 1983).

**4. Debris flow signals.** These emergent, low-amplitude signals resemble periods of background noise and were first recognized at Mount Rainier in 1987. As seen on helicorder records from FMW, 12 km from the most common source area, the signals show a dominant frequency of 1-2 Hz and an average duration of 20 minutes (Weaver and others, 1990).

**Seismic detection of mass movements**

As described above, debris flows and rockfalls have been seismically detected at Mount Rainier in recent years. The success with this method has spurred investigations of historic events of these types, and suggests that seismic monitoring may be able to provide warnings of large mass movements in progress.

Twenty-four debris flow seismograms from the 1961-1990 period have been identified from helicorder records from the long-term seismograph stations LON and FMW (Jonientz-Trisler and Driedger, 1990). Eighteen of these have been corroborated with visually observed debris flows. Since the summer of 1987, most flows have originated from small outburst floods from the South Tahoma Glacier on Mount Rainier. Three were seismically observed and reported to USGS geologists as the flows were in progress (C. Jonientz-Trisler, pers. communication, 1990).

On August 16, 1989, a rockfall with an estimated volume between 1 and 5 x $10^5$ $m^3$ fell from the 3400m level on the east side of Curtis Ridge on Mount Rainier. The rockfall was not visually observed due to poor weather, but it generated four discrete seismic signals that were widely recorded across the seismic network in Washington and northern Oregon (Norris, 1989;

Weaver and others, 1990). The signals were similar to those from large rockfalls in the crater of Mt. St. Helens, and computer analysis showed they originated high on the north face of Mt. Rainier. U.S. Geological Survey and University of Washington personnel advised officials at Mount Rainier National Park of the rockfall, who searched their records for any climbers from that area that had not reported in; fortunately there were none. A recent search of archived seismograph records has yeilded two seismograms from the much larger Little Tahoma rockfall sequence in December, 1963 (Crandell and Fahnestock, 1965) which are currently being investigated.

The successful seismic detection of these small to moderate-volume debris flows and rockfalls indicates that larger, more hazardous such events can be detected as well. At present, real-time identification requires continuous visual recording of seismograms from stations within a few km of likely source areas, and the presence of experienced personnel who can quickly discern between such signals and others such as large local earthquakes. However, an automated debris-flow detection system successfully detected eruption-induced debris flows from Redoubt Volcano in 1990 (Brantley, 1990) and computer-based systems of this type may provide real-time warnings of such flows in the future.

## 4. Information Contacts: Geological and Geophysical Data

| Type of Data | Scientist | Agency | Division | Location | Telephone |
|---|---|---|---|---|---|
| **Stratigraphy** | Rick Hoblitt | USGS | GD | CVO | (206) 696-7899 |
| **Lahars** | Kevin Scott | USGS | WRD | CVO | (206) 696-7765 |
| **Debris flows** | Joe Walder<br>Carolyn Dreidger | USGS<br>USGS | WRD<br>WRD | CVO<br>TC | (206) 696-7671<br>(206) 593-6510 |
| **Geodesy** | Gene Iwatsubo<br>Dan Dzurisin | USGS<br>USGS | GD<br>GD | CVO<br>CVO | (206) 696-7883<br>(206) 696-7826 |
| **Seismicity** | C. Jonientz-Trisler | UW | GP | - | (206) 543-7010 |

GD = Geologic Division, USGS
WRD = Water Resources Division, USGS
UW = University of Washington

GP = Geophysics Program (UW)
TC = USGS, Tacoma
CVO = Cascades Volcano Observatory

**Addresses:**

| | |
|---|---|
| CVO: | David A. Johnston Cascades Volcano Observatory, 5400 McArthur Blvd.,Vancouver, WA 98661 |
| TC: | Suite 600, 1201 Pacific Ave., Tacoma WA 98402 |
| UW: | AK-50 Geophysics Program, University of Washington, Seattle, WA 98195 |

## 5. Information Contacts: Administrative

### Mount Rainier National Park

The people listed below work at the Park headquarters, and at least one of them should be notified when potentially hazardous geologic or seismic events occur at Mt. Rainier. They are able to grant permission to install monitoring equipment stations in the Park. Try them in the order listed.

Park headquarters can be reached at (206) 569-2211. A recording will answer and give directions on how to reach various extensions. To reach any of the people below quickly, dial 1 as soon as the first recording is reached; then a second 1 when the next recording answers, followed by the appropriate extension. You can also wait through both sets of recordings for an operator, which may take some time.

| | | |
|---|---|---|
| **Park Naturalist** | Bill Dengler | 246 |
| **Park Supervisor** | Neil G. Guse | 228 |
| **Chief Ranger** | John Jensen | 285 |
| **West side Ranger** | Jon Wolcox | 238 |
| **East side Ranger** | Randy Brooks | 238 |
| **White River Ranger** | Ed Wilson | 239 |

**Address:**

Mount Rainier National Park Headquarters: Tahoma Woods, Star Route, Ashford, WA 98304

**National Forest Lands**

| National Forest | Person | Title | District | Telephone |
|---|---|---|---|---|
| Mt. Baker-Snoqualmie | J.D. McWilliams | Forest Supervisor | - | (206) 775-9702 |
| | Ted Lewis | District Ranger | White River | (206) 825-6585 |
| Gifford Pinchot | Nancy Graybeal* | Forest Supervisor | - | (206) 696-7500 |
| | Randy Shepard | District Ranger | Packwood | (206) 494-5515 |

* Acting Supervisor

**Mount Baker-Snoqualmie National Forest**

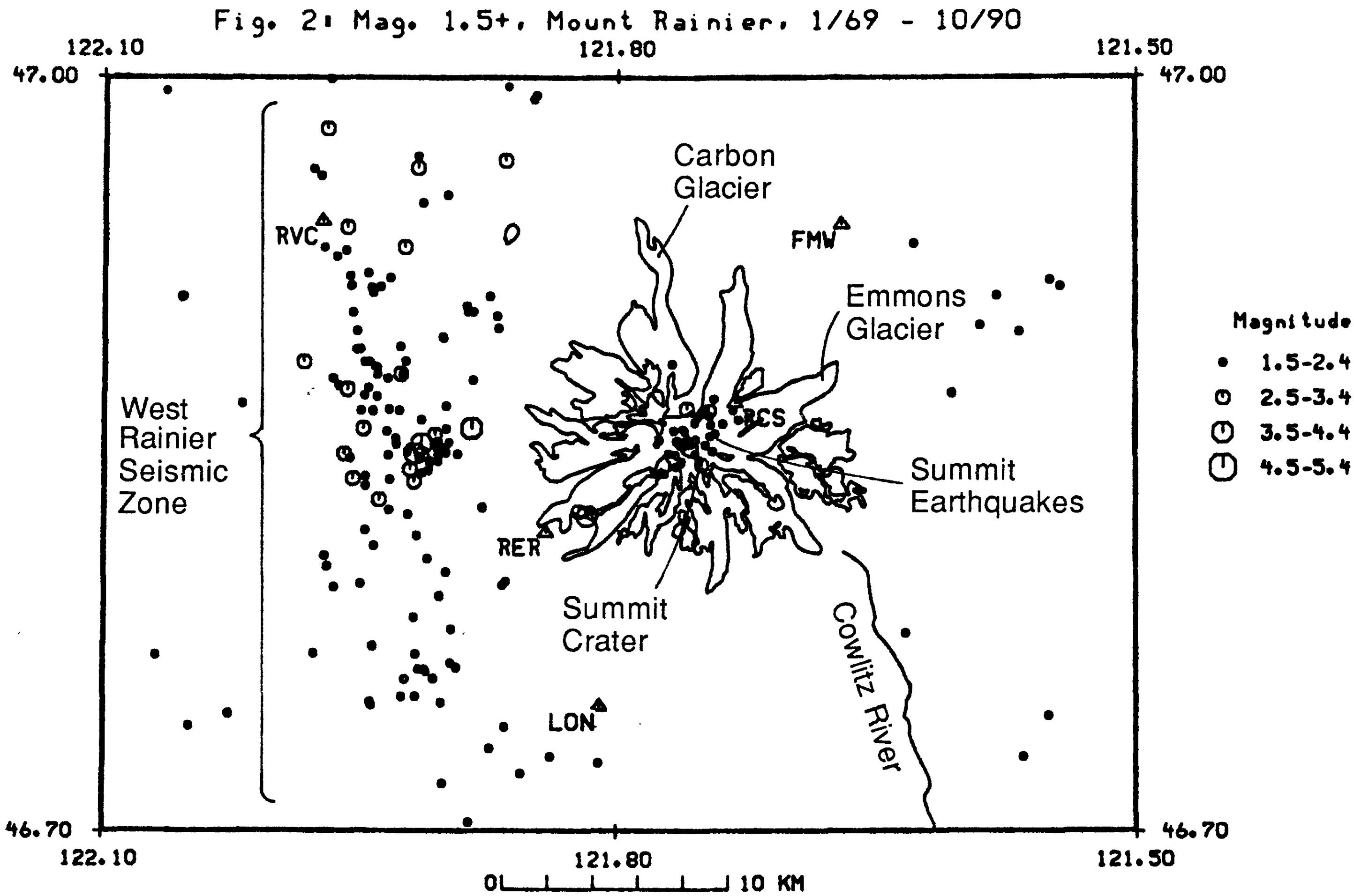
Supervisor's Office: 21905 64th Ave. W., Mountlake Terrace, WA 98043

White River Ranger District: 857 Roosevelt Avenue E., Enumclaw, WA 98022

**Gifford Pinchot National Forest**

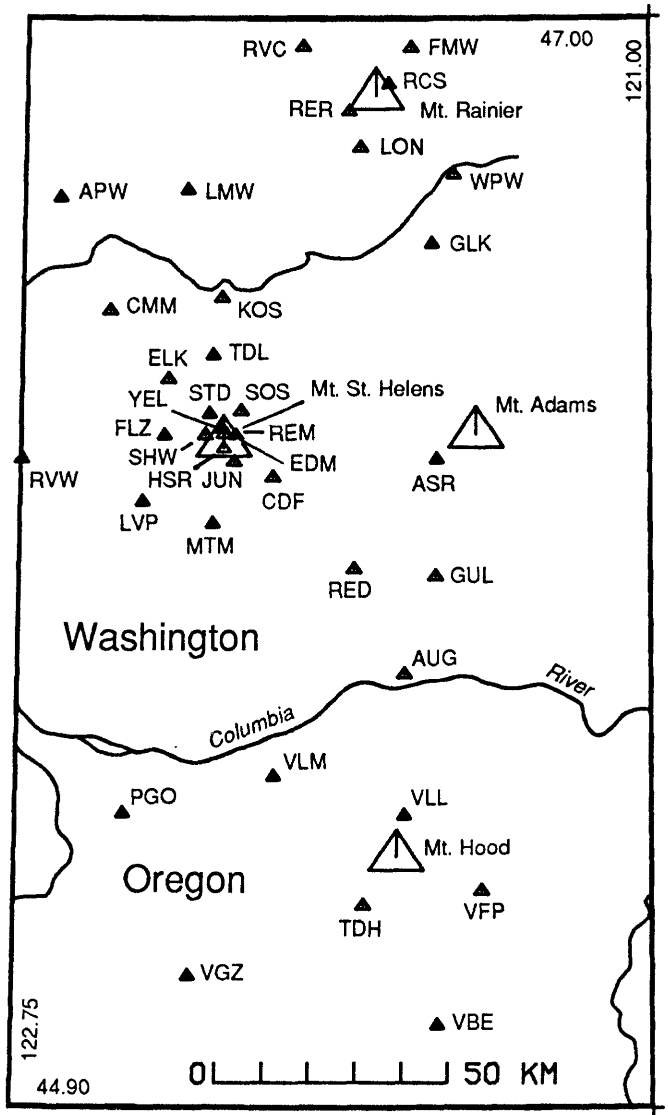
Supervisor's Office: 6926 E. Fourth Plain Blvd., P.O. Box 8944, Vancouver, WA 98668-8944

Packwood Ranger District: P.O. Box 559, Packwood, WA 98361



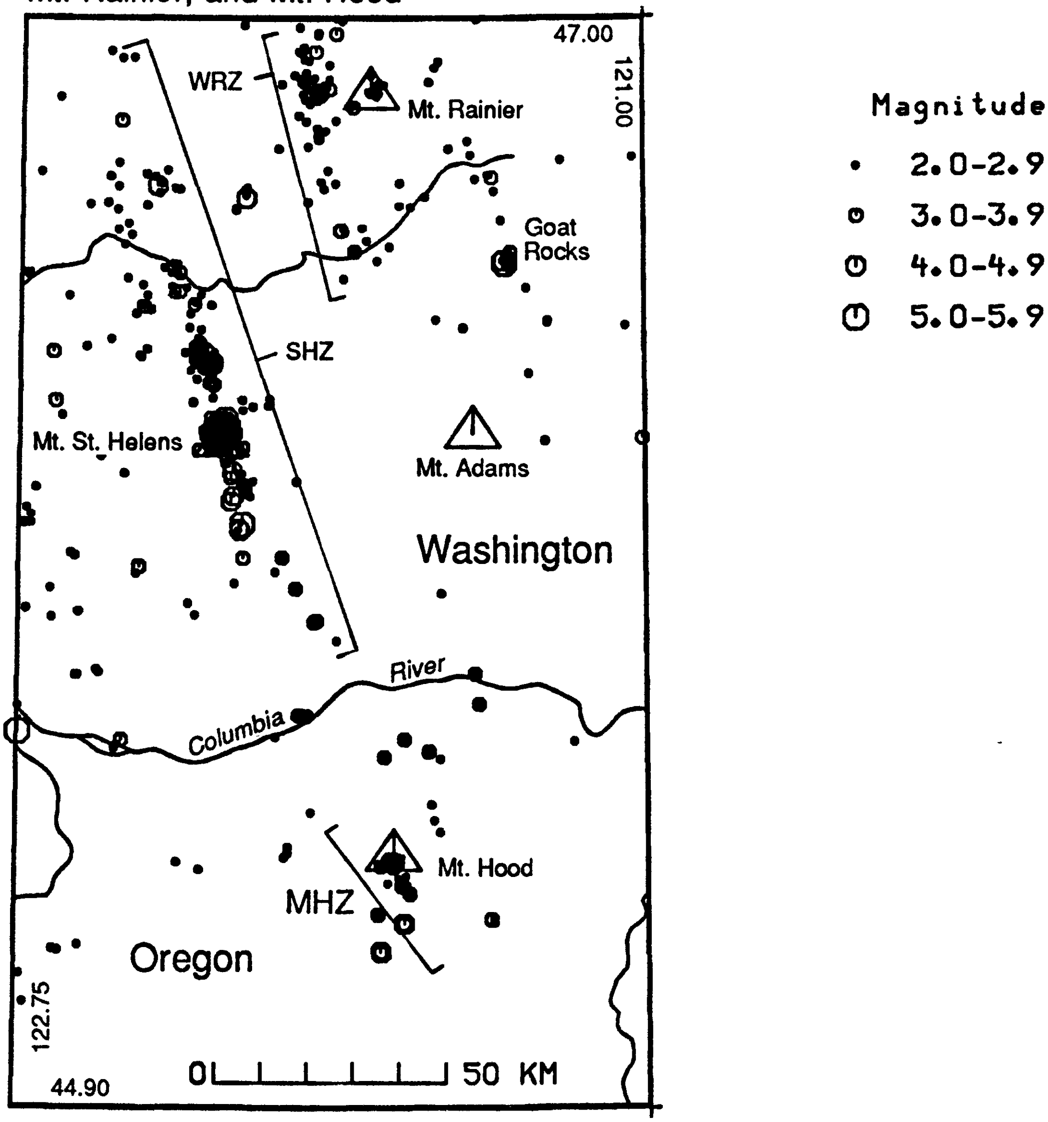

Earthquake epicenters and seismograph stations at Mount Rainier. The dark lines define glacier borders.

Fig. 3: Local Seismic Networks at Mt. Rainier, Mt. St. Helens, and Mt. Hood




(Modified from Weaver and others, 1990).

Fig. 4: Seismic zones near Mt. St. Helens, Mt. Rainier, and Mt. Hood




Seismic zones discussed in the text. WRZ = West Rainier zone, SHZ = St. Helens zone, MHZ = Mt. Hood zone. (Modified from Weaver and others, 1990).

# Mt. St. Helens

Data current as of October 1990

## 1. Pertinent Data:

**Elevation:** (Crater rim, 1980) 8364', 2549m

**Coordinates:** (summit) 46° 11.00' N 122° 11.00' W

**Last Eruption and its products:** Dacite intrusion into dome and new lobe in October, 1986. Several minor tephra emissions have occurred since 1988, some of which resulted in minor ash-falls in towns downwind from the crater.

**USGS Topographic Maps**

| Scale | Map | Date |
|---|---|---|
| 1:250,000 | Hoquiam | 1974 |
| 1:100,000 | Mt. St. Helens | 1978 |
| 1:62,500 | Mt. St. Helens | 1958 |
| 1:24,000 | Mt. St. Helens | 1981 |
| | Mt. St. Helens NE | 1975 |
| | Mt. St. Helens SW | 1975 |
| | Mt. St. Helens SE | 1975 |

## 2. Administrative setting

The Mt. St. Helens National Volcanic Monument encompasses most of the volcano and a large area to the north that includes terrain both within and marginal to the zone of devastation from the May 18, 1980 directed blast. The Monument is administered by the Gifford Pinchot National Forest, which surrounds it on all sides but the west; here, it adjoins state and privately owned lands. Permission to install instrumentation or perform field studies can be obtained through National Monument headquarters at the address listed below.

Most of the volcano lies in Skamania County. The boundary with Cowlitz County runs north-south and passes 2 miles west of the crater.

## 3. Monitoring Status

Mt. St. Helens has been one of the most intensely monitored volcanoes in the world. Within the first week after the initial earthquake on the afternoon of March 20, 1980, a local seismic network was being installed around the mountain and electronic tiltmeters were operating at the Timberline and Spirit Lake campgrounds. By the summer of 1980 the volcano was being monitored from telemetered tilt and seismic stations, trilateration networks, gravity and magnetometer surveys, photogrammetry, gas emission studies, and video surveillance (Lipman and Mullineaux, 1981). Studies of the chemical composition and morphology of eruptive products allowed the magma itself to be monitored for changes in $SiO_2$ and other components that could precede changes in eruptive style.

Most of the significant eruptions since May 18, 1980 have been forecast a few days to 1 - 2 weeks in advance, largely due to the extensive volume of geodetic and seismic data available. As the rate of eruptions has decreased in recent years, some monitoring activities have been curtailed or discontinued. Gas geochemistry is no longer studied on a regular basis, and the outer trilateration networks have been reoccupied less than once a year since 1985.

Due to limitations of space and time, this section focuses mainly on the monitoring of activity in the crater and the cone itself and continuing potential hazards, e.g., magmatic intrusion and extrusion, rockfalls, lahars, explosions, and debris-dammed lakes in the Toutle River drainage.

### Geodetic Monitoring

Mt. St. Helens is geodetically monitored by means of trilateration networks, tiltmeters, and levelling surveys. The trilateration networks are surveyed with electronic distance meters (EDM). In addition, transient faults and cracks have appeared in the crater floor prior to some eruptions, and their rates of growth and movement have been used to forecast an approximate time "window" for the beginnings of eruptions as they approach. The geodetic monitoring program is carried out by scientists from the Cascade Volcano Observatory (CVO) in Vancouver, Washington.

**Trilateration.** Trilateration data from Mount St. Helens are collected from five concentric networks at various distances from the vent, ranging from a far-field network beyond the flanks of the volcano to near-vent networks on the crater floor and dome. The far-field network consists of 25 lines which are measured to detect deep-seated sources of deformation. Geodetic changes with shallower sources are monitored with a near-field network of 31 lines, which connect the outer network to stations on the flanks of the cone (WOVO, 1989).

The crater floor and dome are monitored from three close-in networks. These include a series of lines into the crater from an instrument station on Harry's Ridge 8 km north of the dome, an intra-crater network of short lines, and lines to the dome from instrument stations on the crater rim. The geometry of these inner networks changes with time as instrument and target stations are destroyed by growth of the lava dome, and rock avalanches from the dome and crater walls.

Up through the mid-1980s, the far-field network was reoccupied once a year on the average, and the near-field network was reoccupied quarterly (WOVO, 1989). Since the summer of 1980, measurable deformation has been almost entirely limited to the crater floor and dome. Slight movements were detected on the outer flanks of the cone prior to the explosive eruptions of that period, some of which may have resulted from minor inflation of the cone (Brantley and Topinka, 1984). Since that time, no detectable deformation has been observed outside of the crater from trilateration surveys or tiltmeters.

**Tilt.** As with the trilateration networks, electronic tiltmeters are located at various distances from the vent to detect geodetic change from sources at a variety of depths. Three tiltmeters are located on the outer flanks of Mt. St. Helens, and three to five are sited on the inner crater floor and dome. All use bubble sensors, and are monitored from CVO via radio telemetry. Short levelling lines are also measured to detect vertical uplift of the crater floor near the dome.

**Seismicity**

Mount St. Helens is seismically monitored by the University of Washington Geophysics program in Seattle, and the Cascade Volcano Observatory in Vancouver. Monitoring was begun by the Geophysics program in 1972, when the first short-period telemetered station (SHW) began operating on its western flank.

After the initial earthquake swarm started on March 20 1980, a local network of ten long-term telemetered single-component stations and six three-component, high and low gain temporary sites was installed within three weeks. Approximately ten thousand earthquakes from the March-May earthquake sequence were recorded and digitized in real time by the on-line computer at the University of Washington (Endo and others, *in* Lipman and Mullineaux, 1981). The temporary stations were removed in July 1980, but many of the permanent stations are still in operation today.

The Mt. St. Helens area stations are a subset of the regional seismic network in Washington and northern Oregon, which the Geophysics Program operates jointly with the U.S. Geological Survey. There are 15 stations within 30 km of the mountain, including one in the crater 100 m north of the lava dome, and one on the dome itself (see figure 3). Seismic activity is monitored at the University of Washington from visually recording seismographs and is recorded digitally on a Masscomp computer that operates in an event-triggered mode.

The Cascade Volcano Observatory also monitors local seismicity at Mount St. Helens from a network of 6 stations in the crater and on the pumice plain. These stations are used to locate earthquakes beneath the crater that are too small to be recorded by the UW seismic net, and to detect the passage of small lahars from the crater into the North Fork of the Toutle River. Events are monitored from visual recorders and two PC-based disgital seismic data acquisition systems. One system, known as RSAM, continuously monitors signal amplitudes from the CVO seismic network (Murray and Endo, 1989). The other is a portable, event-triggered system used to record earthquakes, which are then located by analysts using interactive seismic trace-picking software operating on a SUN workstation (Tom Murray, pers. communication, 1990). The RSAM system is most useful in monitoring overall seismicity levels during intense earthquake swarms or strong tremor, which typically overloads conventional event-triggered systems.

Visual recording of stations in and near the crater remains an important monitoring technique for both groups, as steam explosions and other surficial events of low maximum amplitude relative to their duration are not always recorded by the computers. At the University of Washington, local events appearing on the SHW helicorder records have been classified according to type and logged into an on-line computerized data base daily since 1980. CVO maintains an extensive catalog of data on rockfalls, gas emissions, and debris avalanches in the crater with records of their associated seismograms.

Figure 5 shows all earthquakes from the UW earthquake catalog of magnitude 1.5 and above from 1969 through 1989 in the Mt. St. Helens area. The crater is heavily saturated with epicenters from 10 years of seismicity associated with volcanism. Seismicity outside of the crater is dominated by the St. Helens Seismic Zone (SHZ), a 130-km alignment of epicenters that strikes north-northwestward through Mount St. Helens (Weaver and Smith, 1983; Weaver and others, 1990). The SHZ is displayed in its entirety in Figure 4. The localized concentration of epicenters in the SHZ north of Mount St. Helens reflects the 1981 magnitude 5.5 Elk Lake earthquake and its aftershock zone (figure 5). Several hundred aftershocks were located in the following months, and the zone continues to be an active source area for earthquakes.

**Geodetic and Seismic Precursors to Eruptions in the 1980s**

Geodetic data, visual observation, and photogrammetry played an important part in enabling scientists to recognize the danger posed by the bulging north flank of the volcano during April and early May 1980 (Lipman and Mullineaux, 1981). The collapse of the north sector of the volcano on May 18 occurred without any short-term warning, but all significant eruptions since then have been preceded by recognizable geodetic and seismic precursors. The intrusion of magma at shallow depths below the lava dome prior to each eruption causes both horizontal and vertical expansion of the dome and the adjacent crater floor, which is detected by trilateration surveys, tiltmeters, and increases in rates of movement of thrust faults and cracks on the crater floor when they are present. Shallow earthquake activity increases from typical inter-eruption rates of 0 to several locatable earthquakes per day to hundreds or even thousands as magma approaches the surface of the dome. The onset of gradual and then accelerating rates of deformation and seismicity a few days to a few weeks prior to each eruption provides the basis on which eruption forecasts are made.

**Gas Geochemistry**

Gas emission monitoring at Mount St. Helens has been done from both fixed-wing aircraft and ground based measurements. From the summer of 1980 through September 1988, flights were made once or twice weekly, weather permitting, to measure airborne $SO_2$ and $CO_2$ in the plume downwind from the lava dome. $SO_2$ was measured with a correlation spectrometer, and $CO_2$ with a MIRAN 1A infrared spectrophotometer (WOVO, 1989). Ground-based activities have included manual sampling of gas from fumaroles, and hydrogen detection from electronic sensors in the crater and on the outer flanks of the volcano. At present, gas emissions from the lava dome are monitored from manual sampling and automated fuel-cell based sensors that detect $H_2S$ and other gases. Other sensors gather water temperature, pH, and conductivity data from Loowit Creek on the east crater floor. Both sets of sensors continuously transmit data to CVO via radio telemetry. Gas samples are analyzed at CVO with a gas chromatograph (Ken McGee, personal communication, 1990).

**Other Geophysical Monitoring**

A variety of remote sensing techniques have been used to infer the subsurface structure and cooling history of the dome and crater floor. Magnetic field intensity has been measured at 15 sites on the dome and crater floor since March 1984, using a station on the flanks of the volcano as a reference (WOVO, 1989). A total field map of the crater and dome was completed in

August 1984, and is used as a baseline to study changes in the magnetic field in these areas. Some eruptions have resulted in permanent decreases in magnetic field strength at stations near the base of the dome. (WOVO, 1989). Seasonal changes of uncertain origin are also seen at some stations.

Maps showing the electical conductivity properties of the crater floor and dome were produced in the early 1980s from data obtained during low- frequency electromagnetic induction and electrical self-potential studies in the crater.

**Debris-dammed Lakes**

Although man-made outlet channels have stabilized water levels in Spirit, Castle, and Coldwater Lakes, a breakout of any of them remains a potential hazard. Gauges in each lake transmit lake level data hourly to a receiver in Tacoma, Washington via satellite telemetry. Should the levels drop faster than a specified rate, transmissions increase to five-minute intervals and an alert is sounded (Brantley and Topinka, 1984). The Castle Lake and Spirit Lake debris dams are monitored from motion sensors in boreholes in the dams, which detect downslope movements. Groundwater levels are monitored at all three dams.

**4. Information Contacts: Geological and Geophysical Data**

| Type of Data | Scientist | Agency | Division | Location | Telephone |
|---|---|---|---|---|---|
| **Geology** | Don Swanson | UW | GL | - | (206) 543-1190 |
| | Mike Doukas | USGS | GD | CVO | (206) 696-7997 |
| **Lahars** | Carolyn Driedger | USGS | WRD | TC | (206) 593-6510 |
| **Geodesy** | Dan Dzurisin | USGS | GD | CVO | (206) 696-7826 |
| **Gas Geochemistry** | Ken McGee | USGS | GD | CVO | (206) 696-7695 |
| **Remote Sensing** | Dan Dzurisin | USGS | GD | CVO | (206) 696-7826 |
| **Seismicity** | C. Jonientz-Trisler | UW | GP | - | (206) 543-7010 |
| | Steve Malone | UW | GP | - | (206) 685-3811 |
| | Bobbi Myers | USGS | GD | CVO | (206) 696-7906 |

GD = Geologic Division, USGS
CVO = Cascade Volcano Observatory, USGS

WRD = Water Resources Division, USGS
TC = USGS, Tacoma, Washington
UW = University of Washington
GL = Dept. of Geological Sciences (UW)
GP = Geophysics Program (UW)

**Addresses:**

| | |
|---|---|
| CVO: | David A. Johnston Cascades Volcano Observatory, 5400 McArthur Blvd., Vancouver, WA 98661 |
| TC: | Suite 600, 1201 Pacific Ave., Tacoma, WA 98402 |
| UW: | AK-50, Geophysics Program, University of Washington, Seattle, WA 98195 |

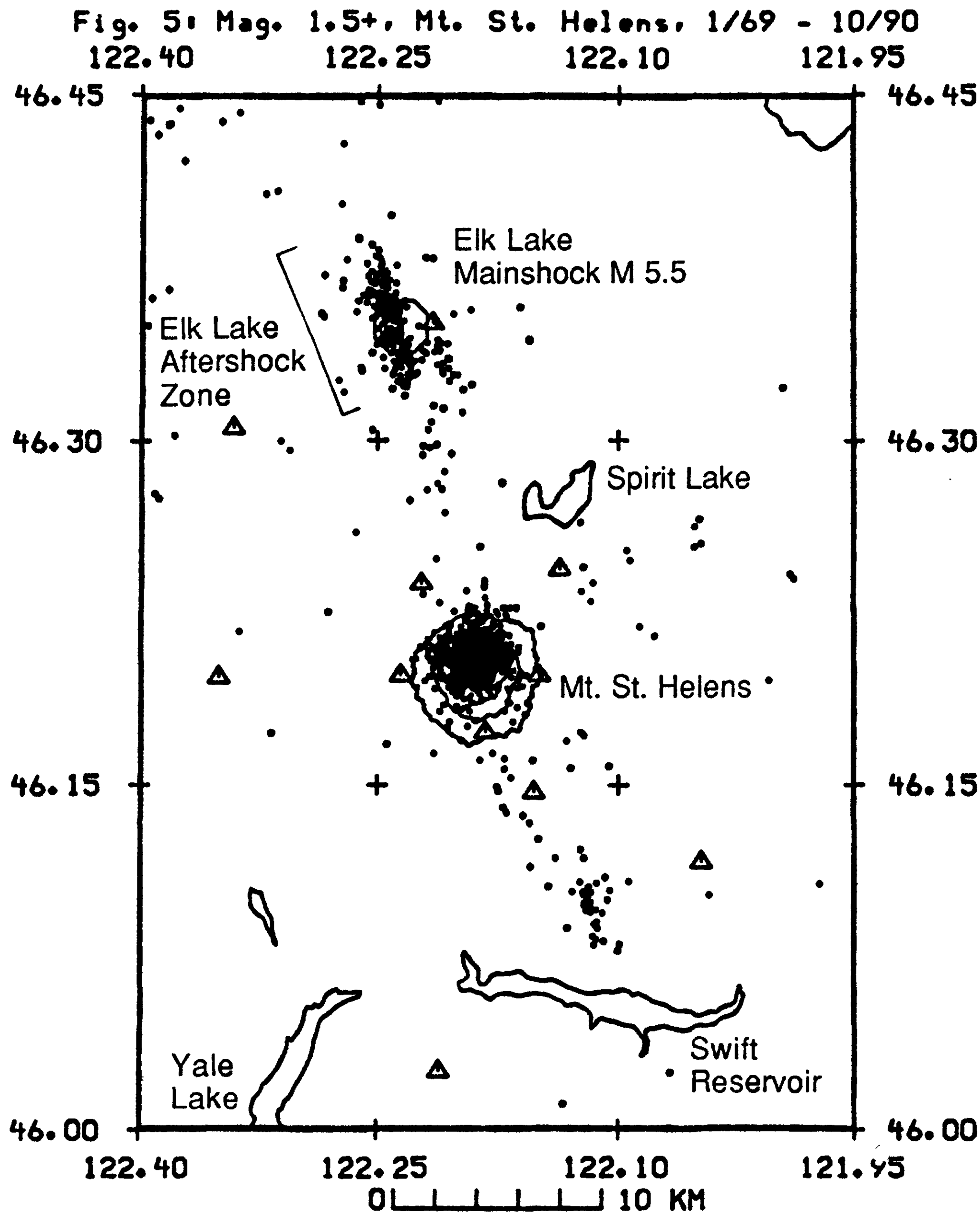
**5. Information Contacts: Administrative**

| National Forest | Person | Title | District | Telephone |
|---|---|---|---|---|
| Gifford Pinchot | Nancy Graybeal* | Forest Supervisor | - | (206) 696-7500 |
| | Diane Roberts | Monument Manager | MSH Nat'l Mon. | (206) 247-5473 |

* Acting Supervisor

**Addresses:**

| | |
|---|---|
| Supervisor's Office: | 6926 E. Fourth Plain Blvd., P.O. Box 8944, Vancouver WA 98668-8944 |
| Monument Manager: | Rt. 1, P.O. Box 369, Amboy, WA 98601 |




Earthquake epicenters in the Mt. St. Helens region from the UW earthquake catalog. To minimize saturation of features in the crater area and the Elk Lake aftershock zone, all epicenters other than the Elk Lake mainshock are shown at the same size, and seismic stations (small triangles) are unlabelled. Lines enclosing the crater are the 5,000, 6,400, and 7,500-foot contours. Mt. St. Helens lies within the Mt. St. Helens seismic zone, which is shown in its entirety in Figure 4.

# Mt. Adams

Data current as of October 1990

## 1. Pertinent Data:

**Elevation:** 12307', 3751m

**Coordinates:** (summit) 46° 12.00' N 121° 29.00' W

**Last Eruption and its products:** Muddy Fork lava flows on north flank, <3500 years B.P. (Harris, 1989).

**USGS Topographic Maps:**

| Scale | Map | Date |
|---|---|---|
| 1:250,000 | Yakima | 1971 |
| 1:100,000 | Mount Adams | 1978 |
| 1:24,000 | Mt. Adams West | 1970 |
| | Mt. Adams East | 1970 |

## 2. Administrative setting

Most of the peak lies in the Mount Adams Wilderness, Gifford Pinchot National Forest. The lower northeast and east slopes are in the Yakima Indian Reservation, and are also managed as wilderness. To obtain instrument sites within the wilderness areas, contact the appropriate USFS District Ranger or the Fire Management Officer for the Yakima Indian Reservation; the addresses are listed below.

A north-south county boundary passes about 2 miles west of the summit, with Skamania County on the west, and Yakima County east. Mount Adams is the only major stratovolcano in Washington that contributes runoff to watersheds east of the Cascade Crest.

## 3. Monitoring Status

Relatively little was known about the structure and volcanic stratigraphy of Mount Adams until recently, and monitoring activites have been limited. In the early 1980's, Wes Hildreth and Judy Fierstien made the first detailed investigation of its geology (Hildreth and Fierstien, 1983).

## Geodetic Monitoring

No geodetic studies have been done at Mount Adams to date.

## Gas Geochemistry

The summit crater area continuously emits small amounts of gases from a variety of sources (Harris, 1989). No geochemical studies have been made.

## Seismic Monitoring

Seismic activity at Mt. Adams is monitored from the regional seismic network jointly operated by the University of Washington Geophysics Program and the U.S. Geological Survey from the University campus in Seattle. Since 1980 at least one station has been operating on the south side of the mountain itself. The current station (ASR) is on Stagman Ridge, 10 km southwest of the summit (figure 3).

Since 1987, seismic events appearing on helicorder records from the ASR station have been classified daily and logged into an on-line computerized data base. Small local earthquakes and low-frequency glacier events such as those seen at Mount Rainier and Mount Baker are rarely seen at Mount Adams and seismicity in the Cascades in this area is low (Weaver and others, 1990). The large differences in rates and character of local seismicity between Mounts Rainier, St. Helens, Adams, and Hood can be seen in Figure 4, which displays earthquakes of magnitude 2.0 and greater in the southern Washington and northern Oregon Cascade range.

The most significant seismic events at Mount Adams in recent years have had surficial sources. On July 15, 1983, a large snow and ice avalanche from the 3350m level of the White Salmon Glacier was recorded on eastern stations of the local Mount St. Helens seismic network and the Mt. Fremont station at Mount Rainier (the ASR station was not displayed on a visual recorder at the time). On the afternoon of September 4, 1988, a small debris flow was reported in progress in Big Muddy Creek, east of Mount Adams. The flow originated from an outburst flood from the Rusk Glacier on the mountain's east side, and a debris flow signal was observed on the

ASR helicorder record. (Jonientz-Trisler and Qamar, 1989). This indicates that debris flows and avalanches may be seismically detected and potentially recognized at Mount Adams in a manner similar to other volcanoes.

**4. Information Contacts: Geological and Geophysical Data**

| Type of Data | Scientist | Agency | Division | Location | Telephone |
|---|---|---|---|---|---|
| Geology | Wes Hildreth | USGS | GD | MP | (415) 329-5231 |
| | Judy Fierstein | USGS | GD | MP | (415) 329-5202 |
| | Don Swanson | UW | GL | - | (206) 543-1190 |
| Holocene debris flows | Jim Vallance | USGS | GD | CVO | * |
| Seismicity | C. Jonientz-Trisler | UW | GP | - | (206) 543-7010 |

* Telephone number not available at time of writing, contact CVO.

GD = Geologic Division, USGS
MP = Western Region Headquarters, USGS, Menlo Park
CVO = Cascades Volcano Observatory
UW = University of Washington
GL = Dept. of Geological Sciences (UW)
GP = Geophysics Program (UW)

**Addresses**

| | |
|---|---|
| MP: | 345 Middlefield Rd., Menlo Park, CA 94025 |
| CVO: | David A. Johnston Cascades Volcano Observatory, 5400 McArthur Blvd., Vancouver, WA 98661 |
| UW: | AK-50, Geophysics Program, University of Washington, Seattle, WA 98195 |

**5. Information Contacts: Administrative**

**National Forest Lands:**

| National Forest | Person | Title | District | Telephone |
|---|---|---|---|---|
| Gifford Pinchot | Nancy Graybeal* | Forest Supervisor | - | (206) 696-7500 |
| | Jim Bull | District Ranger | Mt. Adams | (509) 395-2501 |
| | Cliff Bennett | Fire Resource Asst. | Mt. Adams | (509) 395-2501 |
| | Bill Moran | Fire Management | Mt. Adams | (509) 395-2501 |
| | Jim White | Silviculturist | Mt. Adams | (509) 395-2501 |

* Acting Supervisor

**USFS Addresses:**

| | |
|---|---|
| Supervisor's Office: | 6926 E. Fourth Plain Blvd., P.O. Box 8944, Vancouver WA 98668-8944 |
| Mount Adams Ranger District: | 2455 Highway 141, Trout Lake, WA 98650 |

**Yakima Indian Reservation**

| | |
|---|---|
| Max Corpuz, Fire Management Officer | Bureau of Indian Affairs, P.O. Box 632, Toppenish, WA 98948 |

# Mt. Hood

Data current as of October 1990

**1. Pertinent Data:**

**Elevation:** 11235', 3424m

**Coordinates:** (summit) 45° 23.00' N 121° 42.00' W

**Last Eruption and its products:** Visual report of steam and glow behind Crater Rock followed by meltwater flood in the White River, 1907 (Harris, 1989)

**USGS Topographic Maps:**

| Scale | Map | Date |
|---|---|---|
| 1:250,000 | The Dalles | 1971 |
| 1:100,000 | Mt. Hood | 1983 |
| 1:24,000 | Cathedral Ridge | 1962 |
| | Mt. Hood South | 1962 |

**2. Administrative setting**

Mt. Hood Wilderness, in the Mt. Hood National Forest, Clackamas and Hood River Counties. The Wilderness encompasses all but the south sector of the volcano, and lies within two ranger districts. To install instruments in wilderness areas on National Forest lands, contact the appropriate District Ranger listed below; the request will be referred to the Forest Supervisor for approval.

**3. Monitoring Status**

**Geodetic Monitoring**

A trilateration network was installed at Mount Hood in July 1980, in response to an earthquake swarm that occurred from July 6-12. This network was reoccupied and improved in 1983, and six tilt-levelling stations were constructed and surveyed around the volcano. Comparisons of the 1980 and 1983 trilateration data are complicated by uncertainties over existing atmospheric conditions during the 1980 survey, and the use of a different model EDM (electronic distance meter) in the 1983 and 1984 surveys. However, any errors introduced by these uncertainties would have been too small to mask actual geodetic changes of the scale that would accompany active magma intrusion (Chadwick and others, 1985). The lack of significant geodetic change at Mount Hood was confirmed by a resurvey of both networks in 1984; no geodetic data have been collected since then.

**Gas Geochemistry**

The fumarole fields in the vicinity of Crater Rock were monitored from 1980 through 1982 by visual observation, manual sampling of gases, and one flight with a correlation spectrometer. Gas studies were initiated during the earthquake swarm in July, 1980 that also prompted deformation monitoring. Samples were collected from fumaroles in 1981 and 1982 and analyzed at the Hawaii Volcano Observatory. No chemical or visual changes to the fumaroles were reported during this period. Sulfur dioxide emissions were too low to detect with the correlation spectrometer (Tom Casadevall, personal communication, 1990). There is no current monitoring of gas geochemistry at Mount Hood.

**Seismicity**

Continuous seismic monitoring of Mount Hood began in 1977, when a 16-station seismic network was installed as part of an investigation of the geothermal potential of Mount Hood (Weaver and others, 1982). This network was monitored from the U.S. Geological Survey office in Menlo Park, California, and operated for thirteen months. Ten earthquakes were located at Mount Hood during this interval, which confirmed that the crust beneath the volcano is seismically active. These events lie within the Mt. Hood seismic zone described below.

In December 1978 all but three stations became part of a 32-station USGS regional network in Oregon, also monitored from Menlo Park. During the July, 1980 earthquake swarm at Mt. Hood the University of Washington Geophysics Program and the U.S. Geological Survey in Seattle installed two stations and also began monitoring Mount Hood. The Menlo Park network was disbanded in 1982 for fiscal reasons; since then, the UW/USGS group has had primary responsibility for seismic monitoring of Mount Hood. There are currently three stations within 15 km of the summit, two of which remain from the original 1977 Menlo Park seismic network. These stations are displayed in figures 3 and 6.

Since 1987, local events appearing on visual records from at least one Mount Hood station have been classified and entered into an on-line computerized data base. The seismic events seen include small earthquakes, and rare low-frequency glacier events similar to those at Mount Rainier and Mount Baker. This data base allows tracking of local events that are too small to locate and would otherwise be missed.

**The Mount Hood Seismic Zone**

Most locatable earthquakes in the Mt. Hood area occur in an 8 km long, north-northwest trending zone from the Barlow Pass area to 1 km west of the summit; this is shown in Figure 6. Seismicity within the zone is characterized by small swarms or foreshock-mainshock-aftershock sequences occurring every few months, with most events smaller than magnitude 2.0. Earthquake sequences with mainshocks greater than magnitude 3.0 have occurred in 1972, 1978, 1982, 1989, and 1990 (Weaver and others, 1982; University of Washington earthquake catalog, 1990). The possibility of larger earthquakes occurring in the zone is suggested by the presence of a 1974 M 4.0 event nearby; station density in the area was low at that time and its actual location may be within the zone.

The most recent earthquake sequence occurred on October 19, 1990. The locatable events included one foreshock, an M 3.5 mainshock, and twelve aftershocks. Seismicity within the zone appears to be related to regional tectonics of the area rather than volcanic activity at Mount Hood.

The intermittent nature of seismicity within the zone has only been understood in recent years. On July 6, 1980, a magnitude 2.8 earthquake occurred within the zone and was followed by 7 more events of magnitudes 1.6 and 2.8 within one-half hour (Rite and Iyer, 1981). With the catastrophic eruption of Mt. St. Helens having occurred only a few weeks earlier, it was interpreted as a seismic crisis by the USGS. The USGS issued a Hazard Watch on Mt. Hood on July 11, and rapidly set in motion a program of enhanced seismic, deformation, and gas monitoring (Rite and Iyer, 1981). Two permanent and two temporary seismograph stations were added to the existing regional network in Oregon by the University of Washington and the USGS in Seattle. On July 12, the swarm activity decreased rapidly in the manner which has since been recognized as typical for earthquake swarms at Mount Hood (C. Jonientz-Trisler, personal comm., 1990), and no significant deformation or gas activity was observed during the latter half of the month (CVO, unpub. data, 1980; Rite and Iyer, 1981). The Hazard Watch was lifted on August 4, 1980.

## 4. Information Contacts: Geological and Geophysical Data

| Type of Data | Scientist | Agency | Division | Location | Telephone |
|---|---|---|---|---|---|
| **Geology** | Willie Scott | USGS | GD | CVO | (206) 696-7909 |
| **Lahars/Pyroclastic Flows** | Ken Cameron | USGS | WRD | CVO | (206) 696-7920 |
| | Tom Pierson | USGS | WRD | CVO | (206) 696-7893 |
| **Geodesy** | Gene Iwatsubo | USGS | GD | CVO | (206) 696-7883 |
| | William Chadwick | USGS | GD | MP | (415) 329-4960 |
| **Seismicity** | C. Jonientz-Trisler | UW | GP | - | (206) 543-7010 |

GD = Geologic Division, USGS
WRD = Water Resources Division, USGS
CVO = Cascades Volcano Observatory, USGS
MP = Western Region Headquarters, USGS, Menlo Park
UW = University of Washington
GP = Geophysics Program (UW)

**Addresses:**

CVO: David A. Johnston Cascades Volcano Observatory, 5400 McArthur Blvd., Vancouver, WA 98661

UW: AK-50, Geophysics Program, University of Washington, Seattle, WA 98195

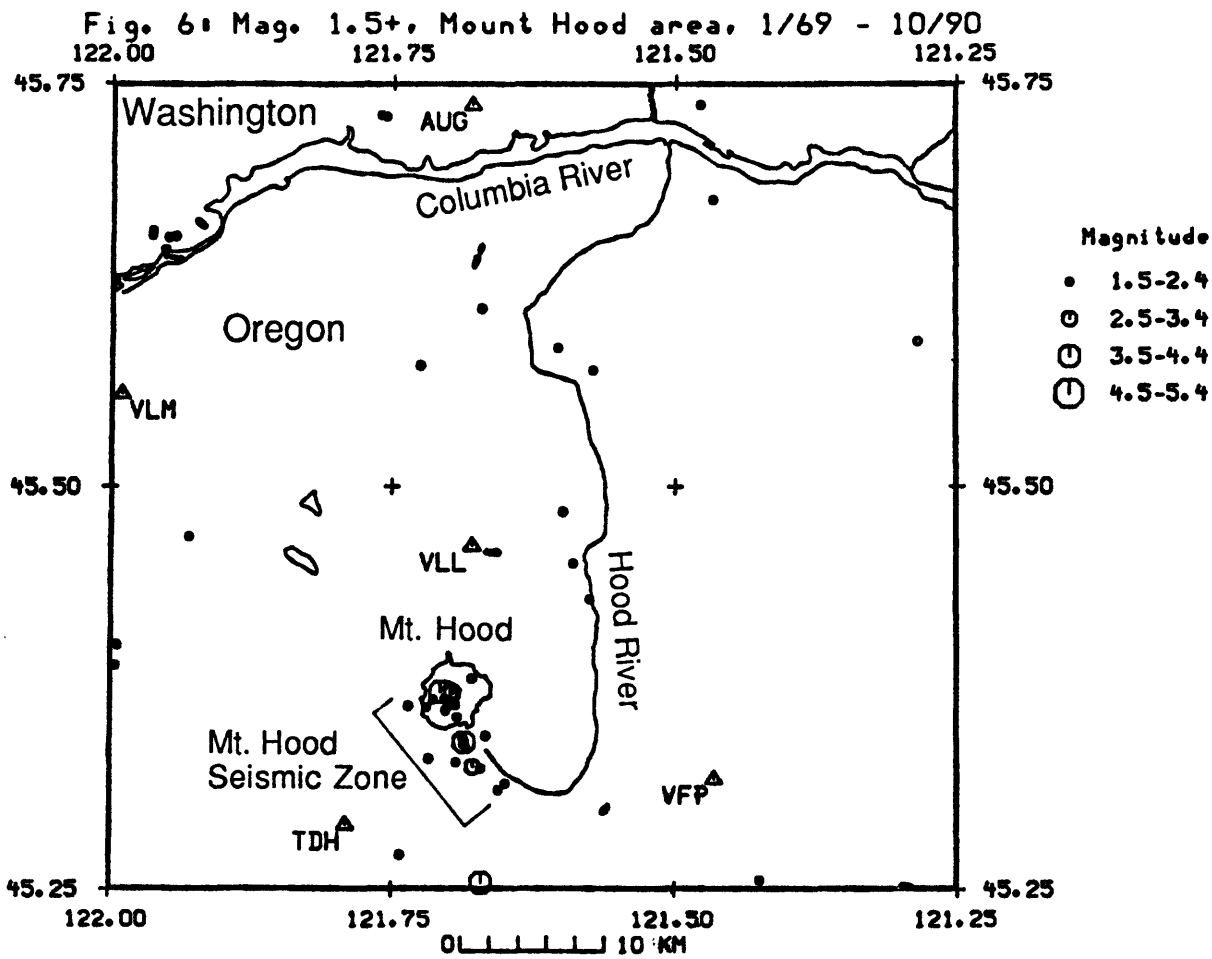
MP: Office of Earthquakes, Volcanoes, and Engineering, U.S. Geological Survey, 345 Middlefield Rd., Menlo Park, CA 94025

### 5. Information Contacts: Administrative

| National Forest | Person | Title | District | Telephone |
|---|---|---|---|---|
| Mt. Hood | Michael S. Edrington | Forest Supervisor | - | (503) 666-0700 |
| | Donna Lamb | District Ranger | Zigzag | (503) 622-3191 |
| | Charles Parker | District Ranger | Hood River | (503) 666-0701 |
| | Richard Wands | Duty Officer | - | (503) 666-0755 |

**Addresses**

| | |
|---|---|
| Supervisor's Office: | 2955 NW Division St., Gresham, OR 97030 |
| Zigzag Ranger District: | 70220 E. Highway 26, Zigzag, OR 97041 |
| Hood River Ranger District: | 6780 Highway 35, Hood River-Parkdale, OR 97041 |




Earthquake epicenters in the Mt. Hood region from the UW earthquake catalog, and seismograph stations operated by the UW/USGS in Seattle.

# Mt. Jefferson

Data current as of October 1990

## 1. Pertinent Data:

**Elevation:** 10497', 3199m

**Coordinates:** (summit) 44° 41.00' N 121° 48.00' W

**Last Eruption:** Holocene activity near S. flank, described in text; last activity on main cone between 40,000 - 140,000 yrs. B.P. (Beget, 1982)

**USGS Topographic Maps:**

| Scale | Map | Date |
| --- | --- | --- |
| 1:250,000 | Bend | 1971 |
| 1:100,000 | Madras | 1983 |
| 1:62,500 | Mount Jefferson | 1961 |

## 2. Administrative setting

The western half of Mt. Jefferson lies in the Mt. Jefferson Wilderness in the Willamette National Forest, and the eastern half is managed by the Confederated Tribes of Warm Springs. The summit forms the junction of Jefferson, Marion, and Linn Counties.

Permission to install instruments in wilderness lands administered by the Forest Service is granted by the Forest Supervisor. The request should be made through the local District Ranger. In lands administered by the Confederated Tribes of Warm Springs, the first step should be to contact the General Manager of Natural Resources at the address listed below in the Administrative contacts section. The request may be referred to the Tribal Council, which makes decisions relating to land management.

## 3. Monitoring Status

As Mount Jefferson itself has not shown geologic evidence of Holocene volcanic activity, monitoring activities have been limited. No deformation or gas geochemistry studies have been done to date. Although Jefferson itself may be extinct, postglacial volcanic activity less than 10 km south of the summit has produced the Forked Butte cinder cone and its associated basalt lava flow, an andesite flow near Bear Butte, and a young pumice cone northeast of Goat's Peak (Luedke and Smith, 1982; Harris, 1989).

**Seismicity**

Mount Jefferson is monitored from the seismic network jointly operated by the University of Washington Geophysics Program and the U.S. Geological Survey in Seattle. The nearest station is on Bald Peter, 9 km ESE of the summit of Jefferson, which has operated since 1979. Few locatable earthquakes have occurred in this section of the High Cascades since 1969, and none of magnitude 2 or larger are known to have occurred within 10 km of the summit of Mt. Jefferson. Figure 7 shows the locations of Holocene volcanic centers in the High Cascades from Mt. Jefferson to the California border that are discussed in this report.

**4. Information Contacts: Geological and Geophysical Data**

| Type of Data | Scientist | Agency | Division | Location | Telephone |
|---|---|---|---|---|---|
| Geology | Willie Scott | USGS | GD | CVO | (206) 696-7909 |
| | Jim Beget | UA | Geophysical Institute | | (907) 474-5301 |
| Seismicity | Chris Jonientz-Trisler | UW | GP | | - |

CVO = Cascades Volcano Observatory
UA = University of Alaska, Fairbanks
UW = University of Washington
GP = Geophysics Program (UW)

**Addresses:**

CVO: David A. Johnston Cascades Volcano Observatory, 5400 McArthur Blvd., Vancouver, WA 98661

UW: AK-50, Geophysics Program, University of Washington, Seattle, WA 98195

UA: Geophysical Institute, University of Alaska, Fairbanks, AK 99775-0800

## 5. Information Contacts: Administrative

### U.S. Forest Service

| National Forest | Person | Title | Ranger District | Telephone |
|---|---|---|---|---|
| **Willamette** | Mike Kerrick | Forest Supervisor | - | (503) 465-6533 |
| | William Funk | District Ranger | Detroit | (503) 854-3366 |

**Addresses, Willamette National Forest:**

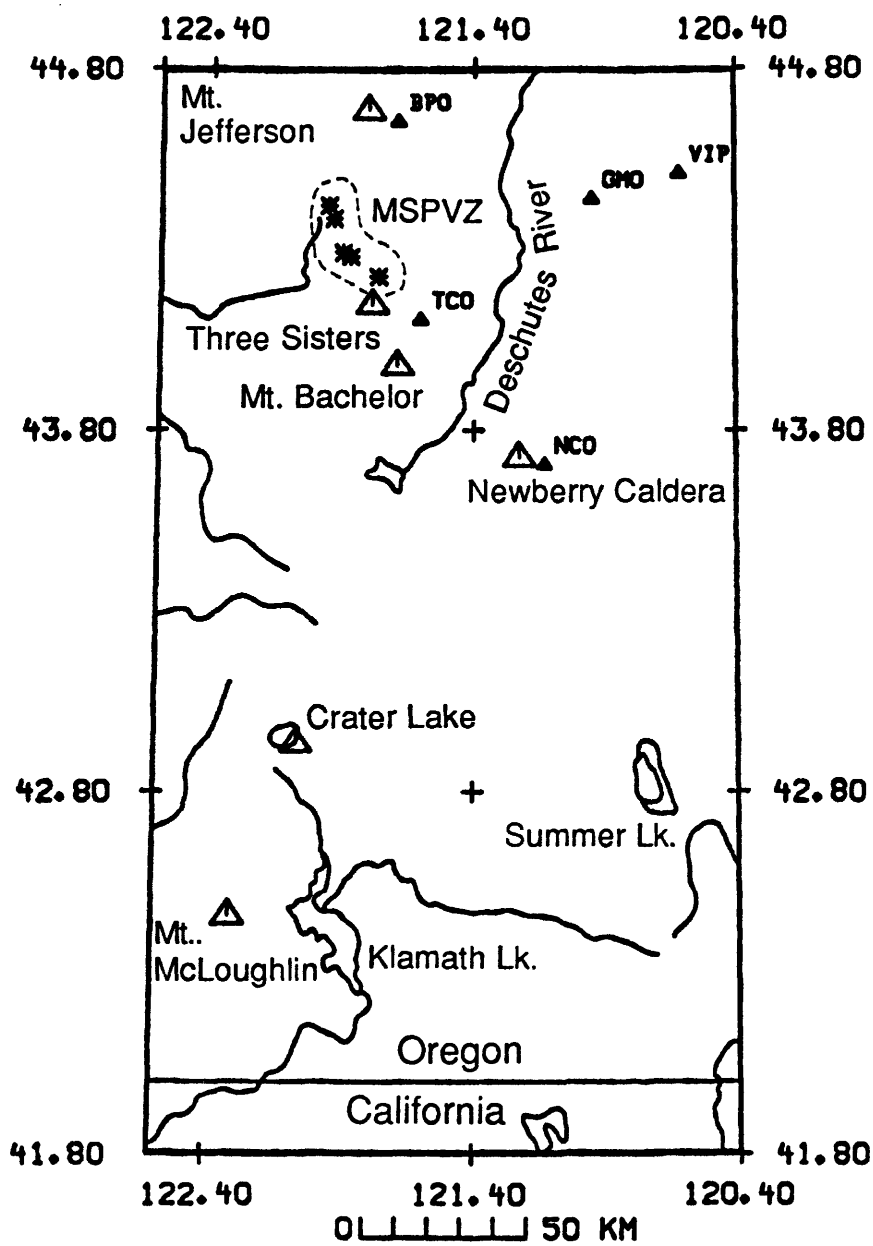
Supervisor's Office: 211 E. 7th Ave., P.O. Box 10607, Eugene, OR 97440

Detroit Ranger District: H.C. 73, P.O. Box 320, Mill City OR, 97360

### The Confederated Tribes of Warm Springs

General Manager of Natural Resources: Charles Calica, P.O. box C, Warm Springs, OR 97761 (503) 553-3549

**Figure 7: High Cascade Volcanoes and Seismograph Stations**




Major stratovolcanoes and vent zones in the High Cascades south of Mount Hood where Holocene eruptions have occurred, or occurred nearby. The area within the dotted line represents the McKenzie - Santiam Pass vent zone (MSPVZ).

# McKenzie Pass-Santiam Pass Vent Zone

Data current as of October 1990

## 1. Pertinent Data:

**Elevation:**

6872', 2095m (Belknap Crater)

6305', 1922m (Little Belknap)

6737', 2053m (Yapoah Cone)

**Coordinates:**

Belknap Crater: 44° 17.09' N 121° 50.50' W

Little Belknap Crater: 44° 16.96' N 121°" 49.44' W

Yapoah Crater: 44° 13.03' N 121° 46.98' W

**Last Eruption and its products:** Basalt lava flows from base of Belknap shield at appx. 1500 yrs. B.P. (Taylor, 1981)

**USGS Topographic Maps:**

| Scale | Map | Date |
|---|---|---|
| 1:250,000 | Bend | 1971 |
| 1:100,000 | McKenzie River | 1983 |
| 1:62,500 | Three Fingered Jack | 1959 |
| | Three Sisters | 1959 |

## 2. Description

"McKenzie Pass-Santiam Pass Vent Zone" is used in this report as an informal name for the broadly northwest-trending zone of Holocene basaltic shield volcanoes and cinder cones from immediately north of the North Sister to west of Santiam Pass (see Figure 7). Although the area lacks the popular familiarity of nearby stratovolcanoes such as Mount Jefferson, as many as 125 vents may have been active in postglacial time (Harris, 1989). In the McKenzie Pass area itself, voluminous basalt flows totalling 220 square kilometers in areal extent have been erupted in the last 3000 years. The large volume and young age of these flows implies that more volcanic activity may occur here in the future. Vents often occur in discrete north or north-northeast trending alignments, such as those on Sand Mountain, the summit of Belknap Crater, and the group from Collier Cone to Yapoah Cone north of the North Sister.

**3. Administrative setting**

The vent zone lies within the Three Sisters and Mt. Washington Wildernesses, in the Willamette and Deschutes National Forests. The largest eruptive center, Belknap Crater, lies just northwest of the junction of Deschutes, Linn, and Lane Counties.

**4. Monitoring Status**

As no known volcanic activity has occurred at any of the vents in this region in historic time, monitoring is limited to the few seismograph stations operating in the Oregon High Cascades.

**Seismicity**

The vent zone lies at the current southern edge of the seismic network jointly operated by the University of Washington and the U.S. Geological Survey from the University campus in Seattle. The closest currently operating station is near Three Creek Lake, 23 km southeast of Belknap Crater (TCO in figure 7). From June 1980 through October 1981, one station from a seismic network monitored by the USGS office in Menlo Park was located at Trout Creek Butte, 15 km southeast of Belknap Crater. Due to the apparent low regional seismicity and sparse, discontinuous station coverage, few earthquakes have been located in the central and southern Oregon Cascades (Kollman and Zollweg, 1984).

**5. Information Contacts: Geological and Geophysical Data**

| Type of Data | Scientist | Agency | Division | Location | Telephone |
|---|---|---|---|---|---|
| Geology | Willie Scott | USGS | GD | CVO | (206) 696-7909 |
| | Edward Taylor | OSU | GE | - | (503) 737-1232 |

| | | | | | |
|---|---|---|---|---|---|
| **Seismicity** | C. Jonientz-Trisler | UW | GP | - | (206) 543-7010 |

GD = Geologic Division, USGS
UW = University of Washington
GP = Geophysics Program
OSU = Oregon State University
CVO = Cascades Volcano Observatory
GE = Dept. of Geology (OSU)

| | |
|---|---|
| CVO: | David A. Johnston Cascades Volcano Observatory, 5400 McArthur Blvd., Vancouver, WA 98661 |
| UW: | AK-50, Geophysics Program, University of Washington, Seattle, WA 98195 |
| OSU: | Department of Geology, Oregon State University, Corvallis, OR 97331 |
| MP: | Office of Earthquakes, Volcanoes, and Engineering, U.S. Geological Survey, 345 Middlefield Rd., Menlo Park, CA 94025 |

## 6. Information Contacts: Administrative

**U.S. Forest Service**

| National Forest | Person | Title | Ranger District | Telephone |
|---|---|---|---|---|
| **Willamette** | Mike Kerrick | Forest Supervisor | - | (503) 465-6533 |
| | Randy Dunbar | District Ranger | McKenzie | (503) 822-3381 |
| **Deschutes** | Joseph Cruz | Forest Supervisor | - | (503) 388-2715 |
| | Karen Shimamoto | District Ranger | Sisters | (503) 549-2111 |

**USFS Addresses**

**Willamette National Forest**

| | |
|---|---|
| Supervisor's Office: | 211 E. 7th Ave., Eugene, OR 97440 |
| McKenzie Ranger District: | 57600 McKenzie Highway, McKenzie Bridge, OR 97413 |

**Deschutes National Forest**

| | |
|---|---|
| Supervisor's Office: | USDA Forest Service, 1645 Highway 20, Bend, OR 97701 |
| Sisters Ranger District: | P.O. Box 249, Sisters, OR 97759 |

# Three Sisters - Mt. Bachelor

Data current as of October 1990

## 1. Pertinent Data:

**Elevations:**

North Sister 10085', 3074m

Middle Sister 10047', 3062m

South Sister 10358', 3157m

Mt. Bachelor 9065', 2763m

**Coordinates:**

North Sister 44° 10.00' N 121° 46.12' W

Middle Sister 44° 08.92' N 121° 46.96' W

South Sister 44° 06.22' N 121° 46.07' W

Mt. Bachelor 43° 58.75' N 121° 41.23' W

**Last Eruption in area:** Pumice eruption followed by extrusion of rhyodacite domes and flows on S.E. flank of South Sister, appx. 1900 yrs. B.P. (Scott, 1986)

**USGS Topographic Maps:**

| Scale | Map | Date |
|---|---|---|
| 1:250,000 | Bend | 1971 |
| | Crescent | 1970 |
| 1:100,000 | Bend* | 1978 |
| | Lapine | 1986 |
| 1:62,500 | Three Sisters | 1959 |
| | Broken Top | 1959 |
| 1:24,000 | Bachelor Butte | 1963 |

*Land use map, no topographic data

## 2. Administrative setting

The Sisters form a common, north-south trending border between the Willamette and Deschutes National Forests, and between Linn and Deschutes Counties. The Three Sisters Wilderness encompasses the Three Sisters volcanoes, as well as nearby ones such as the Husband and Broken Top. Permission to install instruments in wilderness areas is granted by the Forest Supervisor of each national forest.

Mt. Bachelor is in the Deschutes National Forest, Deschutes County, and has no wilderness status. Developed ski runs occupy much of its north face, and a lift station has been built on its summit.

Researchers working in the Squaw Creek drainage northeast of South Sister should be aware of the potential for floods from Carver Lake, on the north flank of South Sister. This hazard is described in more detail later in this section.

## 3. Monitoring Status

### Geodetic Monitoring

As the South Sister is the only volcano of the trio that shows well documented Holocene volcanic activity, it is the only one that is geodetically monitored. A trilateration network of 23 lines and four levelling lines radial to the summit were surveyed in September, 1985. The outer endpoints of each levelling line will be used as references against which relative vertical movements of benchmarks closer to the volcano can be detected. All lines were remeasured in September 1986, and no significant changes had occurred to any of them (Yamashita and Doukas, 1987; Iwatsubo and others, 1988).

The most recent eruption of Mount Bachelor occurred sometime between 6600 and 12,000 years ago, producing basalt lava flows and a cinder cone along its north and northwest flanks (Harris, 1989). Weak fumarolic activity has been reported on its north slope. Mount Bachelor is not geodetically monitored.

### Seismicity

These volcanoes lie at the current southern edge of the seismic network jointly operated by the University of Washington and the U.S. Geological Survey from the University campus in Seattle. The only currently operating station in the area is at Three Creek Lake, 10 km ENE of the South Sister and 16 km north of Bachelor (TCO in Figure 7). Two previous stations in the area were located on Trout Creek Butte, 12 km NE of the North Sister, and at Wanoga Butte, 13 km SE of Mount Bachelor. These were part of a 32-station seismic network in Oregon operated by the USGS office in Menlo Park from 1980 through 1981 (Weaver and others, 1990). Due to low seismicity and sparse station coverage, few earthquakes have been reliably located in the region (Kollman and Zollweg, 1984). The location of these four volcanoes Oregon is shown in Figure 7.

**Moraine-dammed Lakes**

The Three Sisters region contains a number of lakes impounded by glacial moraines, some of which have failed and released floods into local drainages. The greatest hazard is posed by Carver Lake, on the north flank of South Sister. The glacial moraine impounding the lake could be breached if any large disturbance to the water (such as slumping of glacier ice or morainal debris marginal to the lake) creates waves large enough to erode the lake outlet. A similar breakout of a lake on Broken Top volcano washed out the Cascade Lakes Highway in 1966 (Antonius Laenen, personal communication, 1990). The degree of hazard this presents depends on the rapidity of the breakout and the percentage of the lake that is emptied. A rapid, complete breakout could exceed the effects of a 100-year flood in the Squaw Creek drainage northwest of the South Sister, and cause significant damage in the town of Sisters (Laenen and others, 1987). The Forest Service has posted notices of this hazard in the Squaw Creek drainage, but the lake and creek are not monitored.

**4. Information Contacts: Geological and Geophysical Data**

| Type of Data | Scientist | Agency | Division | Location | Telephone |
|---|---|---|---|---|---|
| Geology | Willie Scott | USGS | GD | CVO | (206) 696-7909 |
| | Charles Bacon | USGS | GD | MP | (415) 329-5246 |
| | Don Swanson | UW | GL | - | (206) 543-1190 |
| | Edward Taylor | OSU | GE | - | (503) 737-1232 |

| | | | | | |
|---|---|---|---|---|---|
| **Lake breakouts** | Antonius Laenen | USGS | WRD | PT | (503) 231-2025 |
| **Geodesy** | Ken Yamashita | USGS | GD | CVO | (206) 696-7894 |
| | Dan Dzurisin | USGS | GD | CVO | (206) 696-7826 |
| **Seismicity** | C. Jonientz-Trisler | UW | GP | - | (206) 543-7010 |

GD = Geologic Division, USGS
WRD = Water Resources Division, USGS
CVO = Cascade Volcano Observatory
UW = University of Washington
GP = Geophysics Program (UW)
GL = Dept. of Geological Sciences (UW)
MP = Western Region Headquarters, USGS, Menlo Park
OSU = Oregon State University
GE = Dept. of Geology (OSU)
PT = USGS, Portland office

**Addresses:**

CVO: David A. Johnston Cascades Volcano Observatory, 5400 McArthur Blvd., Vancouver, WA 98661

UW: AK-50, Geophysics Program, University of Washington, Seattle, WA 98195

MP: Office of Earthquakes Volcanoes, and Engineering, U.S. Geological Survey, 345 Middlefield Rd., Menlo Park, CA 94025

OSU: Department of Geology, Oregon State University, Corvallis, OR 97331

PT: U.S. Geological Survey, 10615 S.E. Cherry Blossom Drive, Portland, OR 97216

## 5. Information Contacts: Administrative

**Federal Lands:**

| National Forest | Person | Title | District | Telephone |
|---|---|---|---|---|
| **Willamette** | Mike Kerrick | Forest Supervisor | - | (503) 822-3381 |
| | Randy Dunbar | District Ranger | McKenzie | (503) 822-3381 |
| **Deschutes** | Joseph Cruz | Forest Supervisor | - | (503) 549-2111 |
| | Karen Shimamoto | District Ranger | Sisters | (503) 549-2111 |
| | Walt Schloer | District Ranger | Bend | (503) 388-5664 |

**Addresses- Willamette National Forest:**

| | |
|---|---|
| Supervisor's Office: | 211 E. 7th Ave., P.O. Box 10607, Eugene, OR 97440 |
| McKenzie Ranger District: | 57600 McKenzie Highway, McKenzie Bridge, OR 97413 |

**Deschutes National Forest**

| | |
|---|---|
| Supervisor's Office: | 1645 E. Highway 20, Bend, OR 97701 |
| Sisters Ranger District: | P.O. Box 249, Sisters, OR 97759 |
| Bend-Fort Rock Ranger District: | 1230 N.E. Third St., Bend OR 97701 |

# Newberry Caldera

Data current as of October 1990

## 1. Pertinent Data:

**Elevation:** (Paulina Peak) 7984', 2434m

**Coordinates:** (Paulina Peak) 43° 43.30' N 121° 13.48' W

**Last Eruption and its products:** Big Obsidian flow, appx. 1300 yrs. B.P. (MacLeod and others, 1981)

**USGS Topographic Maps:**

The area covered by the 1:24,000 scale quadrangles listed below includes the caldera and the adjacent outer slopes out to 5-10 km. The actual area of the volcano is much larger. The maps encircle the caldera in a clockwise direction beginning at its northwest corner.

| Scale | Map | Date |
|---|---|---|
| 1:250,000 | Crescent | 1970 |
| 1:100,000 | Lapine | 1986 |
| 1:24,000 | Lava Cast Forest | 1963 |
| | Fuzztail Butte | 1967 |
| | Evans Well | 1967 |
| | China Hat | (not available) |
| | East Lake | 1963 |
| | Paulina Peak | 1963 |

## 2. Administrative setting

Virtually all of this very large volcano lies in the Deschutes National Forest. Deschutes County occupies all but the extreme southern slopes, which are divided between Klamath County on the west and Lake County on the east. Some land along the shores of Paulina and East Lakes belongs to privately owned resorts, open to the public. Access to and around this volcano is unusually good due to a widespread network of forest roads and trails, and the availability of boats for rental on both lakes during the summer months. The location of the Newberry Caldera can be seen in figure 7.

During the fall of 1989 a bill was submitted to Congress to create a Newberry Volcanoes National Monument, which would limit commercial development within the caldera but allow some logging and development of geothermal resources on the volcano's outer slopes. National

Monument status may place more controls on cultural and research activity within the caldera.

## 3. Monitoring Status

### Geodetic Monitoring

Geodetic monitoring of Newberry began in August 1985, when USGS staff from the Cascades Volcano Observatory established a trilateration network centered on Paulina Peak. Nine distances were measured to points inside the caldera, and two more to points on its outer south slope. Horizontal angles were referenced to one of the southern points. The instrument station at Paulina Peak is located on an existing USC & GS triangulation station (Iwatsubo and others, 1988).

A leveling traverse was also made across the caldera from the Paulina Lake Campground eastward to the Cinder Hill campground, along the road between them. Benchmarks were established in bedrock or large boulders along the road at intervals of 1 km or more, while instrument stations were placed on the pavement with the sites marked by nails. The traverse was run twice, with closures approaching first-order standards (Yamashita and Doukas, 1987).

The levelling lines were remeasured in August, 1986, and the trilateration network was remeasured in September. No significant changes were observed from the 1985 surveys in any of the levelling or trilateration lines (Yamashita and Doukas, 1987, Iwatsubo and others, 1988).

### Gas Geochemistry

Hot springs occur in both Paulina and East Lakes; the best known are those that occur along the lake shores. None are routinely monitored, but recreational users of the area provide an informal monitoring resource. The hydrothermal system underneath Newberry Volcano has been commercially prospected and may be developed as a source of electrical power in the future.

**Seismicity**

Newberry Caldera lies near the current southern edge of the seismic network operated by the University of Washington and the U.S. Geological Survey from the University campus in Seattle. Local seismicity at Newberry has been monitored since 1987 from one station on its east slope, outside the caldera. This Newberry station (NCO, Figure 7) is displayed daily on a helicorder. The only previous station in the area was operated at Pine Mountain, 28 km northeast of Paulina Peak, from December 1979 through 1981. It was part of a 32-station Oregon network that was monitored from the USGS office in Menlo Park, California. Due to the apparently low seismicity and sparse, discontinuous station coverage in the region, few earthquakes have been reliably located in the Central Oregon Cascades (Kollman and Zollweg, 1984).

## 4. Information Contacts: Geological and Geophysical Data

| Type of Data | Scientist | Agency | Division | Location | Telephone |
|---|---|---|---|---|---|
| Geodesy | Ken Yamashita | USGS | GD | CVO | (206) 696-7894 |
| Geology | Willie Scott | USGS | GD | CVO | (206) 696-7909 |
| Seismicity | C. Jonientz-Trisler | UW | GP | - | (206) 543-7010 |

GD = Geologic Division, USGS
CVO = Cascades Volcano Observatory
UW = University of Washington
GP = Geophysics Program (UW)

**Addresses:**

CVO: David A. Johnston Cascades Volcano Observatory, 5400 McArthur Blvd., Vancouver, WA 98661

UW: AK-50, Geophysics Program, University of Washington, Seattle, WA 98195

## 5. Information Contacts: Administrative

### U.S. Forest Service

| National Forest | Person | Title | Ranger District | Telephone |
|---|---|---|---|---|
| | Joseph Cruz | Supervisor | - | (503) 388-2715 |
| Deschutes | Walt Schloer | District Ranger | Bend | (503) 388-5664 |
| | George Chesley | District Ranger | Fort Rock | (503) 388-5664 |

**Addresses, Deschutes N.F:**

| | |
|---|---|
| Supervisor's Office: | 1645 E. Highway 20, Bend, OR 97701 |
| Bend-Fort Rock Ranger District: | 1230 N.E. Third Ave., Bend, OR 97701 |

# Crater Lake (Mt. Mazama) and southern Oregon High Cascades

Data current as of October 1990

## 1. Pertinent Data

**Elevation:**

6176', 1882m (Crater Lake water level)

8156', 2486m (Hillman Peak, highest point on caldera rim)

**Coordinates:** 42° 56.00' N 122° 03.36' W (Crater Lake center)

**Last Eruption and its products:** Wizard Island cinder cone and andesite lava flows at appx. 6000 yrs. B.P. (Harris, 1989)

**USGS Topographic Maps**

| Scale | Map | Date |
|---|---|---|
| 1:250,000 | Medford | 1976 |
| 1:100,000 | Crater Lake | 1989 |
| | Diamond Lake* (S. Cascades) | 1978 |
| | Oakridge (S. Cascades) | 1985 |
| 1:62,500 | Crater Lake National Park and Vicinity | 1956 |
| 1:24,000 | Prospect NW | (no date avail.) |
| | Prospect NE | (no date avail.) |

*Land use only, no topographic data

## 2. Administrative setting

Crater Lake National Park, Klamath County, Oregon. The Park is enclosed in National Forest lands on all sides, including the Umpqua on the north, the Winema on the northeast, east, and south, and the Rogue River on the southwest, west, and northwest. A small section of the Sun Lakes State Forest abuts the southern border of the Park. The location of Crater Lake is shown in Figure 7.

An extensive region of the High Cascades between Crater Lake and Mount Bachelor to the north contains around 30 known Holocene vents but few major stratovolcanoes (Luedke and

Smith, 1982). This region lies within the Bend, McKenzie, Diamond Lake, and Chemult Ranger Districts of the Deschutes, Willamette, Umpqua, and Winema National Forests, respectively. Addresses and District Rangers for these areas are listed in the Administrative Contacts section below, in addition to those bordering Crater Lake.

**3. Monitoring status:**

**Geodetic Monitoring**

The USGS began geodetic monitoring at Crater Lake in 1981. Staff from the Cascades Volcano Observatory (CVO) measured three lines across the lake for slope distance and vertical angle, using both existing benchmarks and new ones installed during the survey. This EDM network was reoccupied in 1982, 1983, 1984, and 1988, and no significant changes have been found in the line lengths (Chadwick and others, 1985; Dan Dzurisin, personal communication, 1989).

In August 1985, CVO staff installed local triangular tilt-levelling networks on road surfaces on the northeast, southeast, and west rims of the caldera (Yamashita and Doukas, 1987). Each station was double run to first order closure standards, and should yeild a tilt resolution of around 2 microradians. These networks were reoccupied in August 1986, and as with the trilateration data, no significant geodetic changes were found.

**Seismicity**

Crater Lake is not currently monitored for local seismicity. One station of a previous USGS seismic network in Oregon was operating southwest of Crater Lake during 1980 and 1981, and very little seismicity was detected in the area. The closest currently operating stations are on the east side of the Newberry Caldera, 122 km to the northeast, and 150 km to the south in the Mt. Shasta and Medicine Lake seismic networks operated by the USGS office in Menlo Park. Figure 7 shows currently operating seismic stations in the central and southern Oregon High Cascades, and the Mount Shasta and Medicine Lake stations can be seen in Figure 8.

## 4. Information Contacts: Geological and Geophysical Data

| Type of Data | Scientist | Agency | Division | Location | Telephone |
|---|---|---|---|---|---|
| **Geology/Hazards** | Willie Scott | USGS | GD | CVO | (206) 696-7909 |
| **Geodesy** | Dan Dzurisin | USGS | GD | CVO | (206) 696-7826 |
| **Eruption History** | Charles R. Bacon | USGS | GD | MP | (415) 329-5246 |
| **Seismicity** | C. Jonientz-Trisler | UW | GP | - | (206) 543-7010 |
| | Steve Walter | USGS | GD | MP | (415) 329-4748 |

GD = Geologic Division, USGS
UW = University of Washington
GP = Geophysics Program
CVO = Cascades Volcano Observatory
MP = Western Region Headquarters, USGS, Menlo Park

**Addresses:**

| | |
|---|---|
| CVO: | David A. Johnston Cascades Volcano Observatory, 5400 McArthur Blvd., Vancouver, WA 98661 |
| UW: | AK-50, Geophysics Program, University of Washington, Seattle, WA 98195 |
| MP: | Office of Earthquakes, Volcanoes, and Engineering, U.S. Geological Survey, 345 Middlefield Rd., Menlo Park, CA 94025 |

## 5. Information Contacts: Administrative

### Crater Lake National Park

The following people should be notified in the event of unusual seismic or volcanic activity at or near Crater Lake. They are also the primary contacts for obtaining permission to install monitoring equipment in the Park. The office number is (503) 594-2211 and each person's extension is listed below.

| | | |
|---|---|---|
| **Chief Ranger** | George Buckingham | 300 |
| **Park Superintendent** | Robert Benton | 100 |
| **Chief, Resource Management** | Jim Milestone | 310 |

**National Forests: Mount Bachelor to Crater Lake**

| National Forest | Person | Title | Ranger District | Telephone |
|---|---|---|---|---|
| **Deschutes** | Joseph Cruz | Forest Supervisor | - | (503) 388-2715 |
| | Walt Schloer | District Ranger | Bend | (503) 388-5664 |
| **Winema** | Lee Coonce | Forest Supervisor | - | (503) 883-6714 |
| | Mary Hunt | District Ranger | Chemult | (503) 365-2229 |
| | Rob Shull | District Ranger | Klamath | (503) 883-6824 |
| **Rogue River** | Steven Deitemeyer | Forest Supervisor | - | (503) 776-3600 |
| | Bob Wilcox | District Ranger | Prospect | (503) 560-3623 |
| **Umpqua** | Robert Devlin | Forest Supervisor | - | (503) 672-6601 |
| | Dan Schindler | Dist. Ranger | Diamond Lake | (503) 498-2531 |

**Addresses:**

**Crater Lake National Park Headquarters:** P.O. Box 7, Crater Lake, Oregon, 97604

**Deschutes National Forest**

Supervisor's Office: 1645 E. Highway 20, Bend, OR 97701

Bend-Fort Rock Ranger District: 1230 N.E. Third Ave., Bend, OR 97701

**Winema National Forest**

Supervisor's Office: 2819 Dahlia St., Klamath Falls, OR 97601

Chemult Ranger District: P.O. Box 150, Chemult, OR 97731

Klamath Ranger District: 1936 California Ave., Klamath Falls, OR 97601

**Rogue River National Forest**

Supervisor's Office: P.O. Box 520, Medford, OR 97501

Prospect Ranger District: Prospect Ranger District, Prospect, OR 97536

**Umpqua National Forest**

Supervisor's Office: P.O. Box 1008, Roseburg, OR 97470

Diamond Lake Ranger District: HC-60, Box 101, Idlewyld Park, OR 97747

# Mt. McLoughlin

Data current as of October 1990

## 1. Pertinent Data:

**Elevation:** 9495', 2894m

**Coordinates:** (summit) 42° 27.30' N 122° 18.36' W

**Last Eruption and its products:** Andesite flows from vents near the base of the cone estimated at 1500 - 2000 years B.P. (Maynard, 1974)

**USGS Topographic Maps:**

| Scale | Map | Date |
|---|---|---|
| 1:250,000 | Medford | 1976 |
| 1:100,000 | Medford* | 1978 |
| 1:62,500 | Mt. McLoughlin | 1955 |

*No topographic data

## 2. Administrative setting

A common county and National Forest boundary runs north-south near Mount McLoughlin, passing about 2 miles east of the summit. The Rogue River National Forest and Jackson County lie on the west side of this boundary, and the Winema National Forest and Klamath County are on the east.

## 3. Monitoring Status

No local monitoring of seismicity or deformation has been attempted at Mount McLoughlin. Although the upper section of the cone has been extensively glaciated and has not been active in Holocene time, several andesite lava flows around the base of Mount McLoughlin are Holocene in age (Maynard, 1974). The location of Mt. McLoughlin is shown in figure 7.

The closest seismic stations are 100 km to the south in the Mount Shasta and Medicine Lake areas, at the northern margin of the regional seismic network operated by the USGS office in Menlo Park (Figure 8). From December 1979 through 1981, this network extended north into

Oregon as far as Mount Hood and included several stations in the southern Oregon Cascades (Kollman and Zollweg, 1984). Due to the lack of station coverage since 1981 and apparently low regional seismicity, few earthquakes have been reliably located in the southern Oregon Cascades.

**4. Information Contacts: Geological and Geophysical Data**

| Type of Data | Scientist | Agency | Division | Location | Telephone |
|---|---|---|---|---|---|
| **Geology** | Willie Scott | USGS | GD | CVO | (206) 696-7909 |
| **Seismicity** | Steve Walter | USGS | GD | MP | (415) 329-4748 |

GD = Geologic Division, USGS
CVO = Cascades Volcano Observatory
MP = Western Region Headquarters, USGS, Menlo Park

**Addresses:**

| | |
|---|---|
| CVO: | David A. Johnston Cascades Volcano Observatory, 5400 McArthur Blvd., Vancouver, WA 98661 |
| MP: | Office of Earthquakes, Volcanoes, and Engineering, U.S. Geological Survey, 345 Middlefield Rd., Menlo Park, CA 94025 |

**5. Information Contacts: Administrative**

**U.S. Forest Service**

| National Forest | Person | Title | Ranger District | Telephone |
|---|---|---|---|---|
| Rogue River | Steven W. Deitemeyer | Forest Supervisor | - | (503) 776-3600 |
| | Chuck Anderson | District Ranger | Butte Falls | (503) 865-3581 |
| Winema | Lee Coonce | Forest Supervisor | - | (503) 883-6714 |
| | Rob Shull | District Ranger | Klamath | (503) 883-6824 |

**Addresses, Rogue River National Forest**

| | |
|---|---|
| Supervisor's Office: | P.O. Box 520, Medford, OR 97501 |
| Butte Falls Ranger District: | Butte Falls, OR 97522 |

**Addresses, Winema N.F.**

| | |
|---|---|
| **Supervisor's Office:** | 2819 Dahlia St., Klamath Falls, OR 97601 |
| **Klamath Ranger District:** | 1936 California Ave., Klamath Falls, OR 97601 |

# Mt. Shasta

Data current as of October 1990

## 1. Pertinent Data:

**Elevation:** 14162', 4317m

**Coordinates:** (summit) 41° 24.30' N 122° 11.30' W

**Last Eruption and its products:** Pyroclastic flows and lahars down Ash Creek on the east flank of Shasta at appx. 200 years B.P. (Harris, 1989)

**USGS Topographic Maps:**

The 1:24,000 quadrangles listed below encircle the mountain in a clockwise direction, from northwest to southwest. All are provisional versions, but are available for purchase.

| Scale | Map | Date |
|---|---|---|
| 1:250,000 | Weed | 1958 |
| 1:100,000 | Mt. Shasta | 1979 |
| 1:62,500 | Mt. Shasta | 1954 |
| | Weed | 1954 |
| 1:24,000 | Hotlum | 1956 |
| | Mt. Shasta | 1956 |
| | Ash Creek Butte | 1956 |
| | Elk Spring | 1986 |
| | McCloud | 1986 |
| | City of Mount Shasta | 1986 |

## 2. Administrative setting

The volcano lies in the Mount Shasta Wilderness, in the Shasta-Trinity National Forest, Siskiyou County. The Wilderness encompasses the volcano down to its middle elevations on most sides, somewhat lower on the northwest. It is administered by the Mount Shasta and McCloud Ranger Districts and the boundary between them divides the volcano in half along a roughly north-south line. The lower slopes lie in a mixture of National Forest and private lands. A section of the north and northeast perimeter is in the Klamath National Forest.

To install instruments in wilderness areas on National Forest lands, contact the appropriate District Ranger listed below; the request will be referred to the Forest Supervisor for approval.

## 3. Monitoring Status

### Geodetic Monitoring

Geodetic surveillance of Mount Shasta began in July 1981, when a trilateration network and five tilt-levelling stations were installed around the volcano. Resurveys of the trilateration network were performed in 1982 and 1984. Small, general extensions with values within expected measurement error were seen on many lines in 1982. These extensions were negated or reversed by somewhat larger contractions seen in 1984, which resulted in a minor net overall contraction between 1981 and 1984. This reversal in behavior is probably an artifact of differences in weather and surface temperatures during the two surveys rather than an actual geodetic change at the volcano, although slight overall areal contraction of the volcano between 1981 and 1984 cannot be ruled out (Chadwick and others, 1985).

Tilt-levelling studies corroborated the lack of significant deformation at Mount Shasta between 1981 and 1984. The levelling stations consist of four triangular arrays with an average length of 40m per side and one quadrilateral array (Dzurisin and others, 1982). They were reoccupied in conjunction with the trilateration net measurements in 1982 and 1984. Neither network has been reoccupied since then.

### Seismicity

Seismic activity in the vicinity of Mount Shasta and the Medicine Lake Caldera is monitored from a local network of 10 stations, 6 of which are within 40 km of the summit of Mount Shasta (see figure 8). These stations are a subset of the regional network in northern California operated by the U.S. Geological Survey office in Menlo Park.

The seismicity in the Mount Shasta region has been characterized by scattered earthquakes and occasional earthquake swarms located in the Cascades near or beyond the margins of the volcano. The largest events in three swarms have exceeded magnitude 4.0 and the number of events has varied from a few to hundreds. Earthquake activity under Mount Shasta itself has been mostly limited to isolated events below the southeast flank of the volcano, although several magnitude 2.0 earthquakes occurred underneath the northwest flank of the cone of Shastina in 1985. As Figure 8 shows, Mount Shasta is not a significant seismic source in the region.

The local seismic network was installed after an earthquake swarm near Stephen's Pass, 26 km northeast of the summit, in August 1978. It included several events of magnitude 4.0 and above as well as hundreds of smaller events (Bennett and others, 1979) and remains the largest instrumentally recorded earthquake swarm in the Mount Shasta area to date. The two other earthquake swarms with mainshocks exceeding magnitude 4.0 occurred northeast of the mountain near Tennant in January 1981, and southeast of the mountain at Stouts Meadow in June 1982 (Figure 8). Small swarms occurred near the town of McCloud on the mountain's south flank in 1985 and 1987, and another about 20 km northeast of the summit in 1988. The most recent significant activity was another smaller swarm near Stout's Meadow in May 1989, located several km west of the 1982 swarm. The most active day was May 23 when the two largest events of magnitude 3.8 and 3.6 and 11 smaller events occurred (Steve Walter, written communication, 1990).

**Gas Geochemistry**

Samples of gases, water, and hydrothermal deposits were taken from the Sulfur Spring thermal area just south of the summit in July, 1981. The fumarole field there covers several tens of square meters and appears to be a stable, long-lived feature (CVO, unpub. data, 1981). Another fumarole field lies north of the summit but was not visited due to difficult access. Niether field has been monitored in recent years.

**Gravity and Magnetic Studies**

Both precision gravity and magnetic field intensity studies were initiated at Mount Shasta during the summer of 1981, near the same time that the tilt and trilateration networks were being installed (Jachens and others, 1981). Six gravity-monitoring sites were emplaced on Mount Shasta above the 2200m level. Five of them are located at tilt stations; the sixth is at a trilateration survey benchmark. The reference station is located at the old ski lodge on the south flank of the mountain. Due to the lack of significant activity detected by seismic or deformation monitoring and fiscal limitations, no further gravity or magnetic studies have been done at Mount Shasta.

**4. Information Contacts: Geological and Geophysical Data**

| Type of Data | Scientist | Agency | Division | Location | Telephone |
|---|---|---|---|---|---|
| **Volcanic Hazards** | Dan Miller | USGS | GD | CVO | (206) 696-7885 |
| **Geology** | Bob Christiansen | USGS | GD | MP | (415) 329-5228 |
| **Holocene debris flows** | Waite Osterkamp | USGS | WRD | DV | (303) 236-5036 |
| | James Blodgett | USGS | WRD | SAC | (916) 978-4648 |
| **Geodesy** | Gene Iwatsubo | USGS | GD | CVO | (206) 696-7883 |
| | William Chadwick | USGS | GD | MP | (415) 329-4960 |
| **Seismicity** | Steve Walter | USGS | GD | MP | (415) 329-4748 |
| **Gravity Studies** | Robert Jachens | USGS | GD | MP | (415) 329-5300 |
| | Dan Dzurisin | USGS | GD | CVO | (206) 696-7826 |

GD = Geologic Division, USGS
WRD = Water Resources Division, USGS
CVO = Cascades Volcano Observatory, USGS
MP = Western Region Headquarters, USGS, Menlo Park
DV = USGS, Lakewood, CO
SAC = USGS, Sacramento, CA

**Addresses:**

CVO: David A. Johnston Cascades Volcano Observatory, 5400 McArthur Blvd., Vancouver, WA 98661

MP: Western Region Headquarters, U.S. Geological Survey, 345 Middlefield Rd., Menlo Park, CA 94025

DV: Box 25046, Denver Federal Center, Denver, CO 80225

SAC: Federal Building, 2800 Cottage Way, Sacramento, CA 95825

## 5. Information Contacts: Administrative

### U.S. Forest Service

| National Forest | Person | Title | District | Telephone |
|---|---|---|---|---|
| Mt. Shasta | Robert Tyrell | Forest Supervisor | - | (916) 246-5222 |
| | Ken Showalter | District Ranger | Mt. Shasta | (916) 926-4511 |
| | Steve Clausen | District Ranger | McCloud | (916) 964-2184 |
| Klamath | Barbara Holder | Forest Supervisor | - | (916) 842-6131 |
| | Tom Farmer | District Ranger | Goosenest | (916) 388-5664 |

### Addresses

**Mt. Shasta National Forest**

Supervisor's Office: U.S.D.A. Forest Service, Shasta-Trinity National Forests, 2400 Washington Avenue, Redding, CA 96001

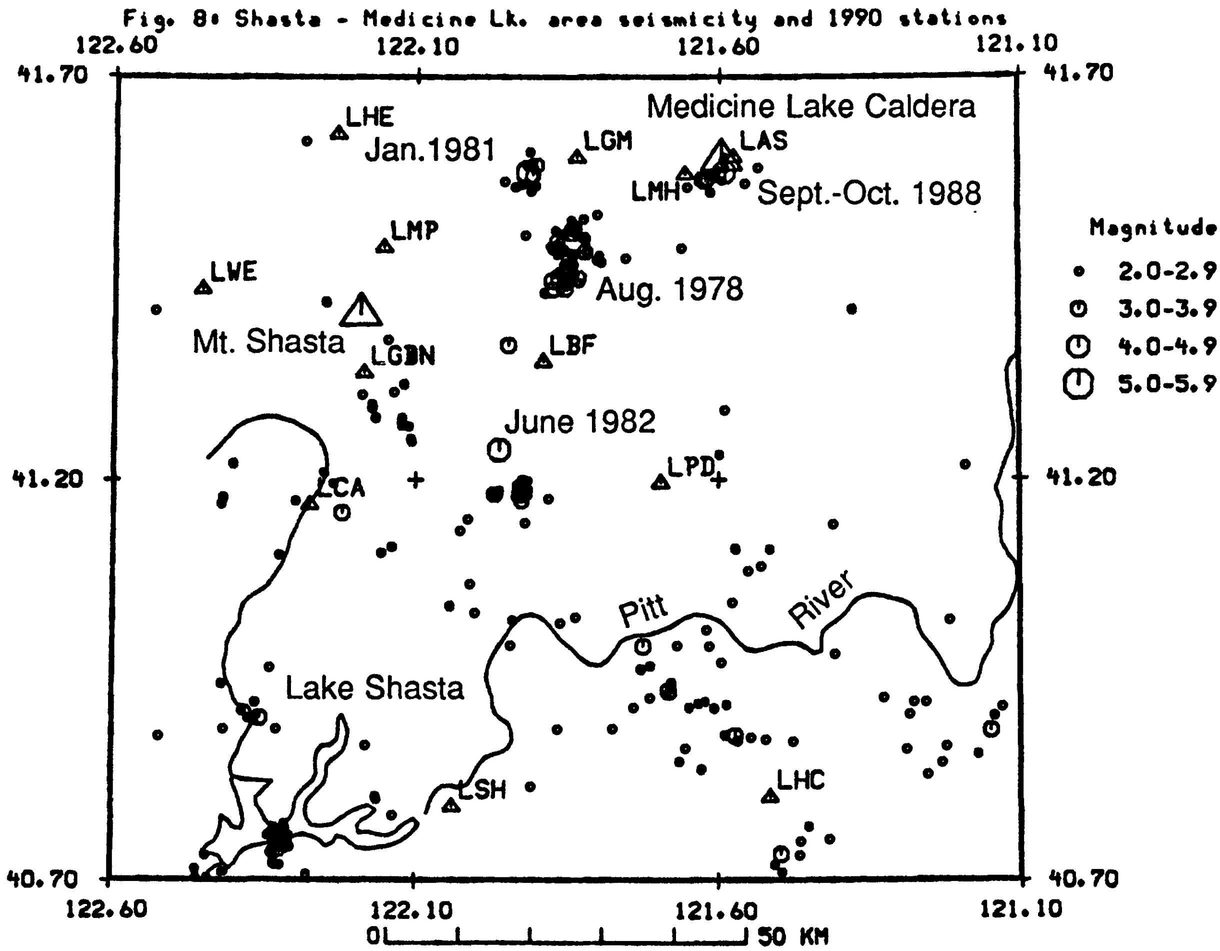
Mt. Shasta Ranger District: 204 West Alma, Mt. Shasta, CA 96067

McCloud Ranger District: Drawer 1, McCloud, CA 96057

**Klamath National Forest**

Supervisor's Office: Klamath National Forest Headquarters, 1312 Fairland Road, Yreka, CA 96097

Goosenest Ranger District: 37085 Highway 97, Macdoel, CA 96058




Earthquake epicenters and local Mt. Shasta - Medicine Lake seismic network operated by the USGS in Menlo Park. The locations of earthquake swarms near Mt. Shasta and at Medicine Lake discussed in the text are labelled with their dates of occurrence.

# Medicine Lake Caldera

Data current as of October 1990

## 1. Pertinent Data:

**Elevation:**

Mount Hoffmann: (highest point on caldera rim) 7913', 2412m

Little Mount Hoffman: (highest point on west rim of caldera) 7309', 2228m

**Coordinates:**

Glass Mountain: 41° 36.00' N 121 ° 30.13' W

Little Mount Hoffman: 41° 34.64' N 121° 39.33' W

**Last Eruption and its products:** Rhyolite-dacite pumice falls, domes, and flows of Glass Mtn. and Little Glass Mtn., possibly within the last 1100 years (Heiken, 1981)

**USGS Topographic Maps:**

The 1:24,000-scale quadrangles listed below roughly encircle the caldera in a clockwise direction, starting on its northwest side.

| Scale | Map | Date |
|---|---|---|
| 1:250,000 | Alturas | 1971 |
| 1:100,000 | McArthur | 1984 |
| | Tule Lake | 1984 |
| 1:62,500 | Medicine Lake | 1952 |
| | Timber Mountain | 1952 |
| 1:24,000 | Bonita Butte | (no date) |
| | Schonchin Butte | (no date) |
| | Coldwell Butte | (no date) |
| | West of Kephart | 1988 |
| | Medicine Lake | 1988 |
| | Little Glass Mountain | 1988 |

## 2. Administrative setting

This large, shield-like composite volcano is geologically similar to the Newberry volcano in central Oregon. It drew scientific attention during late September through November of 1988 when the first earthquake swarm seen in 8 years of instrumental seismic monitoring in the region occurred beneath the caldera. Due to its large areal extent, the volcano occupies parts of three

National Forests. The entire east half of the volcano and all of the caldera are within the Doublehead Ranger District of the Modoc National Forest. The northwest quadrant of its outer slopes lie in the Klamath National Forest, and the southeast quadrant is in the Shasta National Forest. All three National Forest boundaries meet at Little Mount Hoffman, the highest point on the west rim of the caldera. The location of the caldera is shown in Figure 8.

Most sections of the volcano are open to the public, and field studies and installation of instrumentation is allowed with permission of the local District Ranger. Permission of the Forest Supervisor is required before such work begins in the Burnt Lava Flow, Medicine Lake Flow, and Glass Mountain- Glass Flow, which have been designated as Geologic Areas. Lava flows from vents on the northern outer slopes occupy the Lava Beds National Monument, sections of which have wilderness status. Persons planning to do studies in the Monument should contact Bernard Stoffel, the Acting Chief of Resource Management, at the address listed in the Administrative Contacts section below.

## 3. Monitoring Status

### Geodetic Monitoring

In a fortunate coincidence, a leveling line was installed and measured across the Medicine Lake Caldera in August 1988, a few weeks before the earthquake swarm in September. The line was established along the USFS road that crosses the caldera at its west rim, follows the northern margin of Medicine Lake, and turns southward along the east side of the lake. Benchmarks range from 1.5 to 2.25 km apart. Data from a 1954 National Geodetic Survey were used as a baseline against which the 1988 data were compared. The central part of the caldera had subsided nearly 18 cm relative to its western and southern rims since 1954, and the area of subsidence extended outside of the caldera. The network was reoccupied in October 1988, following the swarm, and an additional slight subsidence of 8mm +/- 5mm was observed in the central part of the caldera (Dzurisin and others, 1990). Preliminary data from a reoccupation during the summer of 1989 shows that the subsidence is continuing.

**Seismicity**

Few earthquakes had been located in the Medicine Lake area prior to the swarm that began in the caldera on September 29, 1988. 49 earthquakes were detected on the first day of the swarm; the second day included both the highest daily earthquake count (146 events) and the largest event of magnitude 4.1. The activity decreased to about 10 events per day from Sept. 30 to October 4, and following a brief increase to 33 events on October 4, further declined to 5 or less per day of magnitude < 2.0 (Steve Walter, written communication, 1989). The location of the swarm is noted in Figure 8.

In response to the earthquake swarm, the U.S. Geological Survey installed a local seismic network within and around the caldera on October 22 to supplement existing stations. The network consisted of six short-period vertical stations, one 3-component station, and one low-gain station. This network operated until April 1990, when it was discontinued due to lack of further significant seismicity. Four stations were removed, and telemetry from the remaining two was rerouted through the Mount Shasta local network in May 1990, making them an eastward extension of that network. The currently operating stations in and near the Medicine Lake Caldera can be seen in Figure 8.

**Gas Geochemistry**

Minor fumarolic activity occurs at the Medicine Lake volcano, but is not routinely monitored. The largest feature is a nearly barren patch of hot ground, several hundred square meters in area, located immediately north of the Glass Mountain lava flows No changes were observed in this or other hydrothermal areas following the September-October 1988 earthquake swarm, although not all were visited (McLelland and Duncker, 1988).

**4. Information Contacts: Geological and Geophysical Data**

| Type of Data | Scientist | Agency | Division | Location | Telephone |
|---|---|---|---|---|---|
| Geodesy | Gene Iwatsubo | USGS | GD | CVO | (206) 696-7894 |
| | Dan Dzurisin | USGS | GD | CVO | (206) 696-7883 |

| | | | | | |
|---|---|---|---|---|---|
| **Geology** | Julie Donnelly-Nolan | USGS | GD | MP | (415) 329-5210 |
| **Seismicity** | Steve Walter | USGS | GD | MP | (415) 329-4748 |

GD = Geologic Division, USGS
MP = Western Region Headquarters, USGS
CVO = Cascades Volcano Observatory

**Addresses:**

MP: Office of Earthquakes, Volcanoes, and Engineering, U.S. Geological Survey, 345 Middlefield Rd., Menlo Park CA 94025

CVO: David A. Johnston Cascades Volcano Observatory, 5400 McArthur Blvd., Vancouver, WA 98661

## 5. Information Contacts: Administrative

**U.S. Forest Service**

| National Forest | Person | Title | Ranger District | Telephone |
|---|---|---|---|---|
| **Modoc** | Douglas Smith | Forest Supervisor | - | (916) 233-5811 |
| | Bernie Weisgerber | District Ranger | Doublehead | (916) 667-2246 |
| **Klamath** | Barbara Holder | Forest Supervisor | - | (916) 842-6131 |
| | Tom Farmer | District Ranger | Goosenest | (503) 388-5664 |
| **Shasta** | Robert Tyrell | Forest Supervisor | - | (916) 246-5222 |
| | Steve Clausen | District Ranger | McCloud | (916) 964-2184 |

**Addresses**

**Modoc National Forest:**

Supervisor's Office: 441 N. Main St., P.O. Box 661, Alturas, CA 96101

Doublehead Ranger District: P.O. Box 818, Tulelake, CA 96134

**Klamath National Forest**

Supervisor's Office: 1312 Fairlane Rd., Yreka, CA 96097

Goosenest Ranger District: 37805 Highway 97, Macdoel, CA 96058

**Shasta-Trinity National Forest**

McCloud Ranger District: McCloud Ranger District, Drawer 1, McCloud, CA 96057

**Lava Beds National Monument**

| Person | Title | Telephone |
|---|---|---|
| Doris Bowen | Superintendent, Lava Beds Nat'l Mon. | (916) 667-2282 |
| Bernard Stoffel | Acting Chief, Resource Management | (916) 667-2282 |

**Address:** Lava Beds National Monument, P.O. Box 867, Tule Lake, CA 96134

# Lassen Peak

Data current as of October 1990

## 1. Pertinent Data

**Elevation:** 10457', 3187m

**Coordinates:** 40° 27.45' N 121° 29.44' W (summit)

**Last Eruption and its products:** Visual reports of "steam clouds" in February, 1921 (Harris, 1989).

**USGS Topographic Maps:**

The 1:24,000-scale quadrangles listed below encircle Lassen Peak in a clockwise direction, starting on its northwest side.

| Scale | Map | Date |
|---|---|---|
| 1:250,000 | Susanville | 1962 |
| 1:000,000 | Lassen Nat'l Park and Vicinity | 1957 |
| 1:100,000 | Burney | 1976 |
| | Lake Almanor | 1989 |
| 1:62,500 | Manzanita Lake | 1956 |
| | Prospect Peak | 1957 |
| | Lassen Peak | 1956 |
| | Mount Harkness | 1956 |
| 1:24,000 | Medicine Mountain | 1988 |
| | West Prospect Peak | 1985 |
| | Prospect Peak SE | 1975 |
| | Lassen Peak | 1985 |
| | Reading Peak | 1985 |
| | Mount Harkness | 1985 |

## 2. Administrative setting

Mount Lassen Volcanic National Park, which is surrounded by the Lassen National Forest. Forest lands along the eastern border of the Park lie within the Caribou Wilderness. Shasta County encompasses all but the southern margin of the volcano, which is crossed in an E-W direction by its border with Tehama County. Persons interested in conducting geological or geophysical field studies that are outside the bounds of those currently involved with routine monitoring should contact the Park Superintendent, Gilbert Blinn, for permission. His phone number and address are listed below in the Administrative Contacts section.

## 3. Monitoring status

### Geodetic Monitoring

Both trilateration and tilt-levelling survey networks were installed at Lassen Peak in July, 1981, as part of an effort to increase geodetic surveillance at several Cascade volcanoes. The tilt-levelling network at Lassen consists of 3 triangular stations, at distances from the summit chosen to allow for detection of edifice-wide deformation. One station may also be sensitive to movement of the Chaos Crags. The trilateration network is based on eight instrument stations, one of which is located on Chaos Crags, northwest of Lassen dome. The network of EDM lines connect the instrument stations to each other and to the eight targets up on the slopes of the dome.

Both networks were reoccupied in 1982 and 1984, with results very similar to those seen at Mount Shasta during those two years. Most trilateration lines showed small extensions within measurement error between 1981 and 1982 that were negated or reversed by somewhat larger contractions during the 1984 survey; the discrepancy between the two surveys is attributed to differences in atmospheric conditions rather than actual deformation of the dome during that period (Chadwick and others, 1985). The concurrent reoccupations of the tilt stations also did not reveal any consistent deformation trends. No trilateration or tilt data have been obtained since 1984.

### Gravity

Twelve gravity stations were installed and surveyed around Lassen Peak in the summer of 1981, including five on the dome and its flanks, and two on Chaos Crags. A U.S. Coast and Geodetic Survey benchmark 1 km northwest of Manzanita Lake was used as a reference station. Measurements were also taken at approximately 400 sites within 15 km of Lassen as part of a regional gravity survey of the volcanic field in its vicinity (Jachens and others, 1983).

**Seismicity**

Seismic activity at Lassen Peak is monitored by the U.S. Geological Survey from the USGS Western Region Headquarters in Menlo Park, California. The currently operating seismic stations around Lassen Peak can be seen in Figure 9.

The first station in the area was installed near the town of at Mineral, 15 km south-southeast of Lassen, in 1927 (Weaver and others, in press, 1990). In 1939 the University of California at Berkeley and Lassen Volcanic National Park jointly upgraded the station to continuous operation, installing two horizontal Wood-Anderson seismometers. High-gain, short-period vertical components were added to the site in 1948 and 1968.

In 1976, the National Park Service funded a local network of five stations around Lassen Peak, which were telemetered to the U.S. Geological Survey office in Menlo Park. Some changes in station geometry have occurred over time; the current network consists of eight stations within 20 km of Lassen Peak.

Regional seismicity in the Lassen area is dominated by two zones of diffuse earthquake activity, which can be seen in Figure 9. One zone strikes north-south and roughly follows the western margin of the Cascades and the eastern margin of the Klamath Mountains and the Great Valley. The other zone begins along the eastern margin of the northern Sierra Nevada and trends northwest past the southern shore of Lake Almanor to just north of Lassen Peak. Weaver et. al. (1990) have proposed that the continuation of this zone beneath Lassen Peak implies that rocks of the Sierra underlie the Quaternary cover of Cascade lavas, and the earthquakes are not related to Cascade volcanism. However, local concentrations of shallower seismicity (maximum depth 7 km) beneath the geothermal areas south of Lassen and Chaos Crags domes may represent a local influence of the volcanic system of the old Mt. Tehama caldera complex on the Sierra-Lassen seismic zone. Earthquakes outside of the caldera are often as deep as 18 km (Steve Walter, written communication, 1990). Few earthquakes occur underneath Lassen dome itself, and none have occurred beneath the 1,000 year old Chaos Crags.

**Long-period events**

An unusual feature of Lassen seismicity is the group of 16 long-period earthquakes that have appeared since 1982. These earthquakes, which locate approximately 5 km west-southwest of Lassen Peak and Chaos Crags at depths between 13 and 23 km, have spectral peaks between 2 and 4 Hz. (Steve Walter, written communication, 1990) Long-period events occurring at mid-crustal depth are rarely observed at Cascade volcanoes; outside of these at Lassen, only two have been observed at Medicine Lake and one beneath Mount Rainier to date. Their significance is uncertain, but at other volcanoes the occurrence of such events has been attributed to movement of magma in the crust.

**Gas Geochemistry**

Gas studies at Lassen Peak started in July 1981 and have focused both on the hydrothermal areas in the old Mt. Tehama caldera and on the summit of Lassen dome. Fumaroles in the Bumpass Hell hydrothermal basin were sampled manually by CVO staff scientists and analyzed at the Hawaii Volcano Observatory. An automated hydrogen sensor was installed in August 1981, which transmitted data to the Cascades Volcano Observatory via satellite-based radio telemetry. Current gas monitoring equipment in the basin include the hydrogen sensor and two automated fuel-cell based sensors for $H_2S$ and other reduced gases. Data on gas composition, temperature, and water conductivity are monitored from the Cascades Volcano Observatory via satellite-based radio telemetry (Ken McGee, personal communication, 1990).

Hydrothermal activity on the dome is limited to areas of altered ground and weak fumaroles that emit mostly air (CVO, unpub. data, 1981; Tom Casadevall, personal communication, 1990).

**4. Information Contacts: Geological and Geophysical Data**

| Type of Data | Scientist | Agency | Division | Location | Telephone |
|---|---|---|---|---|---|
| **Geodesy** | Gene Iwatsubo | USGS | GD | CVO | (206) 696-7883 |
| | William Chadwick | USGS | GD | MP | (415) 329-4960 |
| **Gravity Studies** | Robert Jachens | USGS | GD | MP | (415) 329-5300 |
| | Dan Dzurisin | USGS | GD | CVO | (206) 696-7826 |

| | | | | | |
|---|---|---|---|---|---|
| **Geology** | Patrick Muffler<br>Michael Clynne | USGS<br>USGS | GD<br>GD | MP<br>MP | (415) 329-5239<br>(415) 329-5236 |
| **Debris flows** | Michael Sorey | USGS | WRD | MP | (415) 329-4420 |
| **Seismicity** | Steve Walter | USGS | GD | MP | (415) 329-4748 |
| **Hazards Assessment** | Dan Miller | USGS | GD | CVO | 206) 696-7885 |
| **Gas Geochemistry** | Ken McGee<br>Michael Sorey | USGS<br>USGS | GD<br>WRD | CVO<br>MP | (206) 696-7695<br>(415) 329-4420 |

GD = Geologic Division, USGS
UW = University of Washington
CVO = Cascade Volcano Observatory
MP = Western Region Headquarters, USGS, Menlo Park
WRD = Water Resources Division, USGS

**Addresses:**

| | |
|---|---|
| CVO: | David A. Johnston Cascades Volcano Observatory, 5400 MacArthur Blvd.,Vancouver, WA 98661 |
| UW: | AK-50, Dept. of Geophysics, University of Washington, Seattle, WA 98195 |
| MP: | Office of Earthquakes, Volcanoes, and Engineering, U.S. Geological Survey, 345 Middlefield Rd., Menlo Park, CA 94025 |

5. **Information Contacts: Administrative**

**National Forest Lands:**

| National Forest | Person | Title | Ranger District | Telephone |
|---|---|---|---|---|
| Lassen | Richard Henry | Forest Supervisor | - | (916) 257-2151 |
| | Keith Crummer | District Ranger | Almanor | (916) 258-2141 |
| | Deb Romberger | District Ranger | Hat Creek | (916) 336-5521 |
| | Bob Andrews | District Ranger | Eagle Lake | (916) 336-5521 |

**Addresses:**

**Mount Lassen National Park**

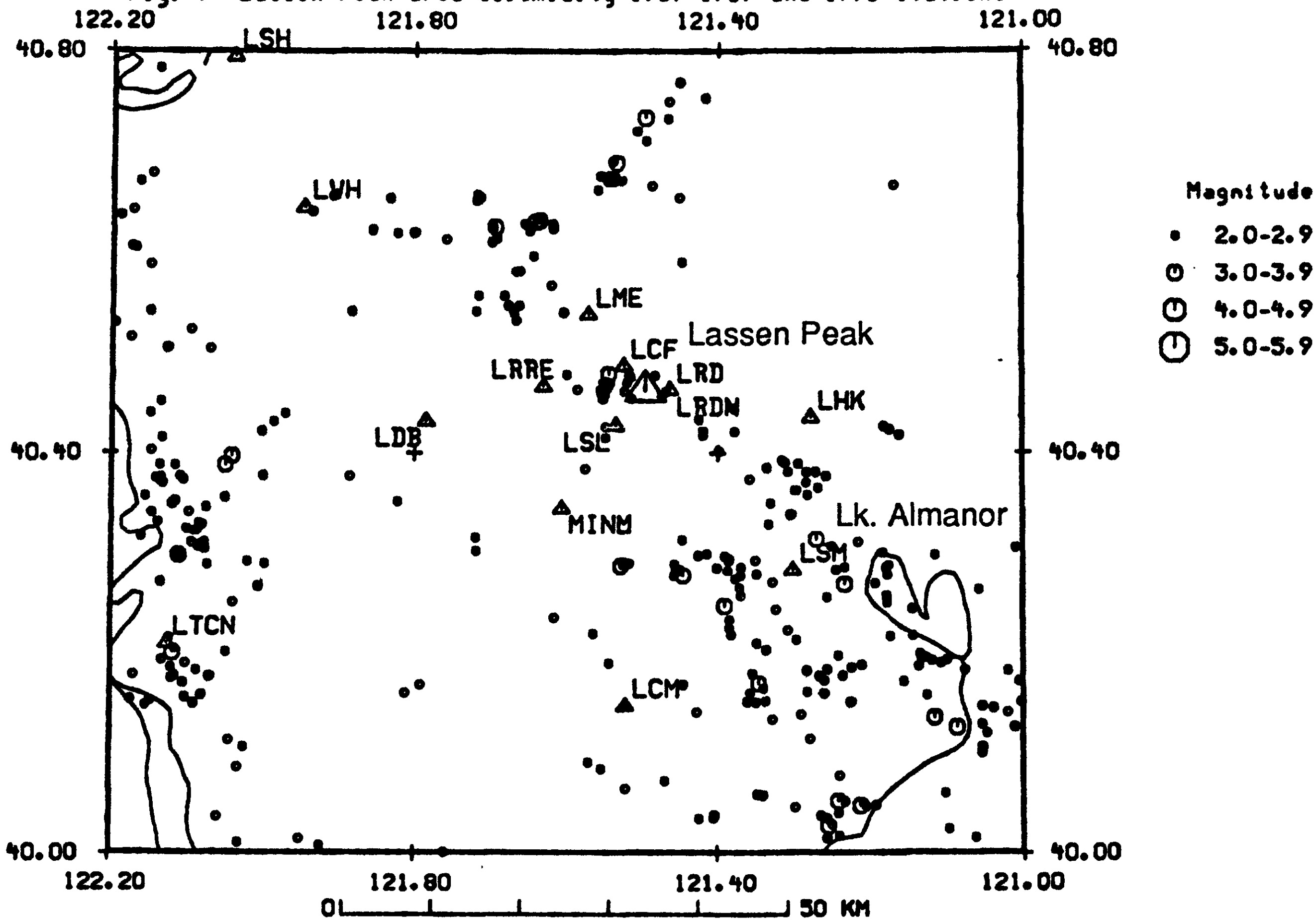
Park Headquarters — P.O. Box 100, Mineral, CA, 96063

**Lassen National Forest:**

Supervisor's Office: — 55 South Sacramento St., Susanville, CA 96130

| | |
|---|---|
| Almanor Ranger District: | P.O. Box 757, Chester, CA 96020 |
| Hat Creek Ranger District: | P.O. Box 220, Fall River Mills, CA 96028 |
| Eagle Lake Ranger District: | 55 South Sacramento St., Susanville, CA 96130 |

Fig. 9: Lassen Peak area seismicity 1969-1989 and 1990 stations




Earthquake epicenters in the Lassen Peak area, and current seismic stations operated by the USGS in Menlo Park.

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