# Earthquake Hypocenters in Washington and Northern Oregon, 1987–1989, and Operation of the Washington Regional Seismograph Network

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# Part 1: Earthquake Hypocenters in Washington and Northern Oregon, 1987–1989

## INTRODUCTION

The Geophysics Program at the University of Washington operates a continuously recording, telemetered seismograph network in Washington and northern Oregon (Figs. 1.1 and 1.2). This report is the twelfth in a Washington Division of Geology and Earth Resources (DGER) series designed to provide a chronological compilation of earthquake locations. From 1970 through 1979, only earthquakes in western Washington were included in these DGER reports (Crosson, 1974, 1975; Crosson and Millard, 1975; Crosson and Noson, 1978a, 1978b, 1979; Noson and Crosson, 1980; Noson and others, 1985). Eastern Washington earthquakes from 1969 to 1979 are cataloged in technical reports to the U.S. Department of Energy, available at the University of Washington library. Eastern Washington earthquakes from 1969 through 1974 are cataloged in an appendix to the 1979 annual report (Malone, 1979), while catalogs from 1975 through 1979 are individually provided in annual reports (Malone, 1975, 1976, 1977, 1978, 1979).

Beginning with the report describing earthquakes in 1980 (Qamar and others, 1986), the DGER catalogs cover all of Washington and also include northern Oregon (Qamar and others, 1987a, 1987b). A list of large historical earthquakes in Washington from 1840 to 1965 was compiled by Rasmussen (1967).

Table 1.1 (p. 15) lists hypocentral locations for 480 earthquakes and 134 blasts having coda-duration magnitudes ($M_c$) equal to or exceeding 2.0 that occurred from January 1987 to December 1989. The distribution of earthquake epicenters in Washington and northern Oregon for 1987 through 1989 is shown in Figures 1.3 and 1.4. The term 'epicenter' indicates the point on the Earth's surface directly above the subsurface focus of the earthquake, while 'hypocenter' refers to the subsurface point where the earthquake occurs. Epicenters of 1,726 smaller earthquakes with magnitudes $1.0 \leq M_c < 2.0$ are shown in Figure 1.5, and blasts with magnitudes $M_c \geq 2.0$ in Figure 1.6. Figure 1.7 shows epicenters of large earthquakes ($M_c \geq 3.5$), together with computed focal mechanisms, and Figure 1.8 is a detailed map showing earthquake epicenters ($M_c \geq 1.5$) near Seattle.

## DATA ACQUISITION AND ANALYSIS

The seismograph network in Washington and northern Oregon operated by the University of Washington from 1987 through 1989 consisted of more than 100 short-period, vertical-component, telemetered seismograph stations. Stations operating during 1987, 1988, and 1989 are listed in Table 1.2 (p. 25). Most stations consisted of a seismometer recording vertical ground motion only, an amplifier, a voltage-controlled oscillator, and radio, telephone, or microwave telemetry equipment to transmit the data to the central recording laboratory at the University of Washington. Part 2 of this report, "Operation of the Washington Regional Seismograph Network" describes the seismograph station components, telemetry, and data recording and analysis.

## THE SEISMOGRAPH NETWORK

During 1987 to 1989, the Washington Regional Seismograph Network (WRSN) was extended into southwestern Oregon to improve earthquake detection in western Oregon and the Cascades. In 1989, our ability to detect and locate events on the cone of Mount Rainier was also improved by the installation of two stations, RER and RCS. RCS is located at Camp Schurman on the northeast flank of the mountain, and RER is on the southwest flank on Emerald Ridge. RER was installed to monitor glacial outburst floods on Tahoma Creek, as well as earthquakes.

A microphone was operated in the crater of Mount St. Helens from October 1986 to July 1988 to study crater events producing audible sounds. The microphone signal was routinely monitored by laboratory personnel during working hours, and both the unrectified (SND) and rectified (SIG) signals were recorded digitally. However, as magmatic activity at Mount St. Helens decreased, we found that shallow superficial events such as rockfalls, which were the most likely to produce audible signals, typically did not trigger our digital recording system.

In 1987, a calibrated set of two horizontal Geotech S-13 seismometers that are filtered to provide a Wood-Anderson-type frequency response was installed on the same pier as a standard set of Wood-Anderson seismometers at station SEA in Seattle, which has been in operation since 1966. A third S-13 sensitive to vertical ground motion was also installed. The east-west, north-south, and vertical S-13 components are called SEE, SEN, and SEV respectively. The S-13 signals are recorded digitally, and the signal amplitudes of the horizontal components are used to determine Richter-like local magnitudes ($M_L$).

In 1987, the University of Washington stopped receiving a telemetered signal from station NEW in Newport, WA. NEW is operated by the U.S. Geological Survey (USGS), and is still telemetered to Denver, CO. The USGS supplies phase arrival-time readings from NEW on request.

The three-component (both short and long period) World Wide Standardized Seismograph Network (WWSSN) station at Longmire (LON) stopped recording photographically in 1988 and continued to record as a Digital World Wide Standardized Seismograph Network (DWWSSN) station. We continue to telemeter the World Wide short-period vertical component to the university, as well as another short-period vertical signal (station LO2), which has a WRSN-type frequency response.

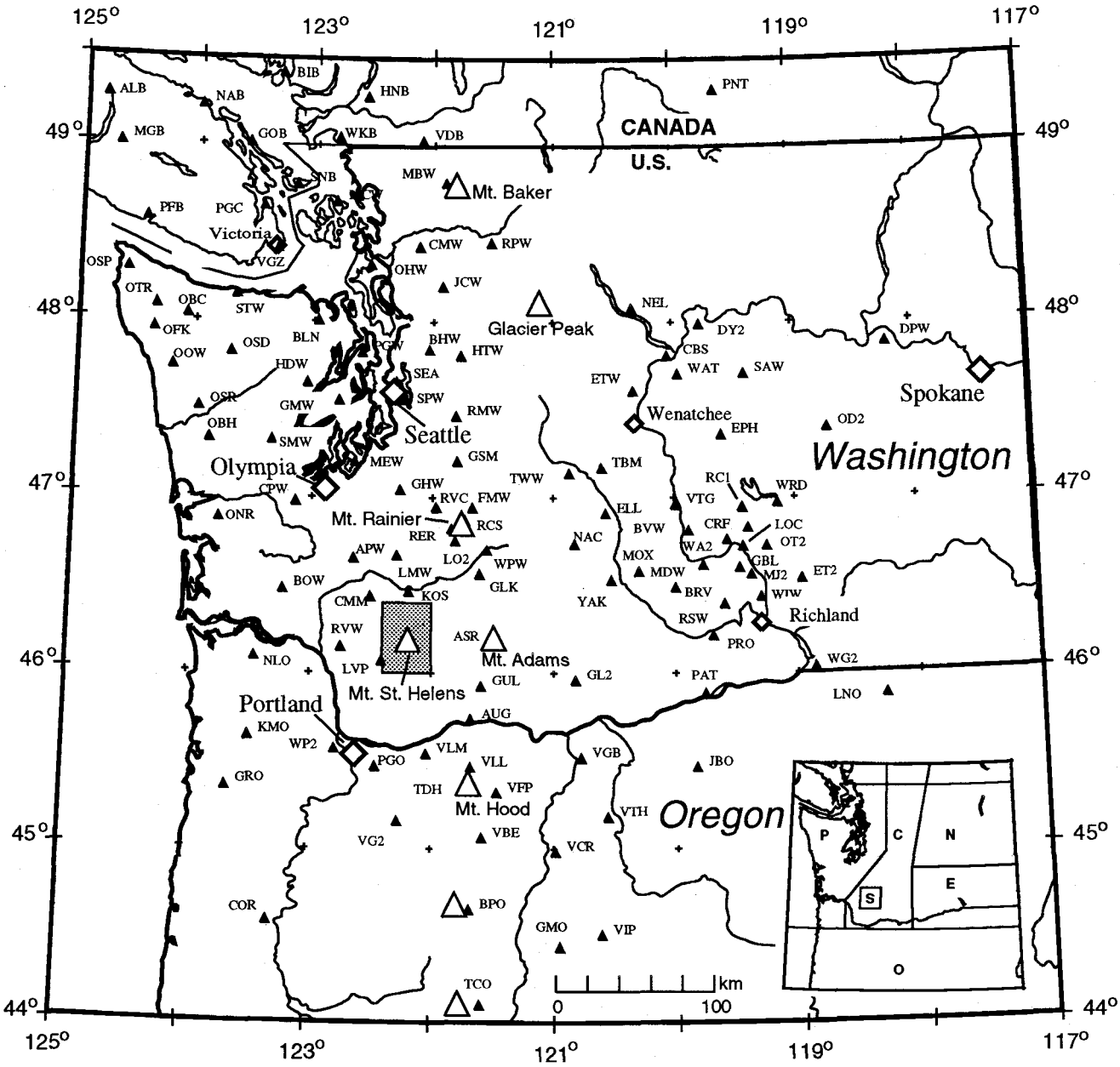



**Figure 1.1.** Locations of stations operating in the Pacific Northwest at the end of 1989. Stations in Washington and Oregon operating between 1987 and the end of 1989 are listed in Table 1.2. Station NCO at Newberry crater, OR, lies 30 km south of the area shown on the map. Canadian stations are operated by the Geological Survey of Canada. Station COR is operated by Oregon State University. Stations in the Mount St. Helens region (patterned box) are shown in Figure 1.2. The inset shows the six regions in which different crustal velocity models are used to locate hypocenters (P, Puget Sound; C, Cascades; S, Mount St. Helens; N, northeast Washington; E, eastern Washington; O, Oregon).

## EARTHQUAKE ANALYSIS

The number of seismic events located each year (Table 1.3) depends on several factors other than the rate of seismicity. In general, any earthquake with magnitude $M_c \geq 2.5$ will be recorded and located anywhere in Washington or northern Oregon, except those in the extreme easternmost portions of those states. Much smaller earthquakes can be located in some parts of Washington or Oregon, depending on the number and spacing of recording stations relative to the earthquake epicenters. Thus, for parts of eastern Washington, our earthquake database is complete only for events with $M_c \geq 2.5$, whereas for most of western Washington, it is complete for $M_c \geq 1.2$ to 1.7. Near Mount St. Helens, the database is probably complete for $M_c \geq 0.7$.

Ignoring the inherent variability of completeness in the database may lead to incorrect interpretations. When used carefully, the data in this report may enhance evaluation of seismic hazard potential, as well as contribute to basic studies in seismology, the structure of the Earth, and tectonics. Part 2 describes the data acquisition and analysis procedures followed by the WRSN, while the "Explanation of Table 1.1" (p. 14) discusses factors that affect the accuracy of an earthquake location.

The magnitude of each earthquake is determined using a technique that depends on signal duration. The method used is described by Crosson (1972), and the magnitude is referred to as coda-duration magnitude or $M_c$ to distinguish it from magnitudes determined by other methods, such as $M_L$ (local or Richter magnitude), $M_S$ (surface wave magnitude), and $m_b$ (body wave magnitude). For most purposes, the differences between these scales are minor. In addition to $M_c$, we routinely calculate $M_L$ for larger events by using the amplitude of recorded waves on horizontal component Wood-Anderson seismograph records.

Explosions are identified in the data set whenever possible. Characteristics useful in identifying explosions are: shallow depths of focus, positive P-wave polarity (direction of first motion) at all stations, clustering of epicenters, occurrence during daytime hours only, well-developed low-frequency surface waves, and, of course, direct verification. When explosions occur in unusual locations and are nonrepetitive, positive identification is difficult. Suspected or possible explosions are indicated in Table 1.1 as type P; confirmed or highly probable explosions are indicated as type X.

**Table 1.3.** Events $M_c \geq 1$ processed, 1987–1989. The number of events processed includes local earthquakes, blasts, probable blasts, and regional and teleseismic events. The St. Helens region is defined in Figure 1.4

| Events $M_c \geq 1$ | 1987 | 1988 | 1989 |
|---|---|---|---|
| All events processed | 1981 | 2249 | 2785 |
| Events lat. 44°–50°N, long. 117°–125°W | | | |
| Blasts and probable blasts | 207 | 302 | 256 |
| Deep earthquakes, depth ≥ 30 km | 30 | 38 | 32 |
| Felt earthquakes | 22 | 19 | 37 |
| Earthquakes, except St. Helens region | 522 | 744 | 723 |
| Earthquakes, St. Helens region | 31 | 45 | 159 |

## DISCUSSION OF EARTHQUAKE ACTIVITY

Table 1.4 (p. 28) includes intensity information on felt earthquakes, and Table 1.5 (p. 30) gives the dates, locations and fault-plane solutions of earthquakes having magnitudes of 3.5 or larger. Figure 1.7 shows the locations and computed focal mechanisms for the events in Table 1.5.

### 1987

No damaging earthquakes occurred in Washington or Oregon during 1987. The largest earthquakes in Washington and Oregon during 1987 were a pair of moderate earthquakes, $M_c$ 4.1 and 4.3, at depths of about 18 km that occurred 2 hours apart on December 2 (07:12 and 09:02 UCT) 16 km northwest of Yakima in central Washington (events 2 and 3, Fig. 1.7). They were followed by seven aftershocks in the next 2 days, three of which were $M_c$ 1.0 or larger. An $M_c$ 3.0 earthquake (not reported felt) at a similar depth occurred on June 11 about 10 km to the north.

### 1988

During 1988, the largest earthquake (event 7, Fig. 1.7) within our network occurred on July 29 and had a coda-duration magnitude of 4.1. It was lo-

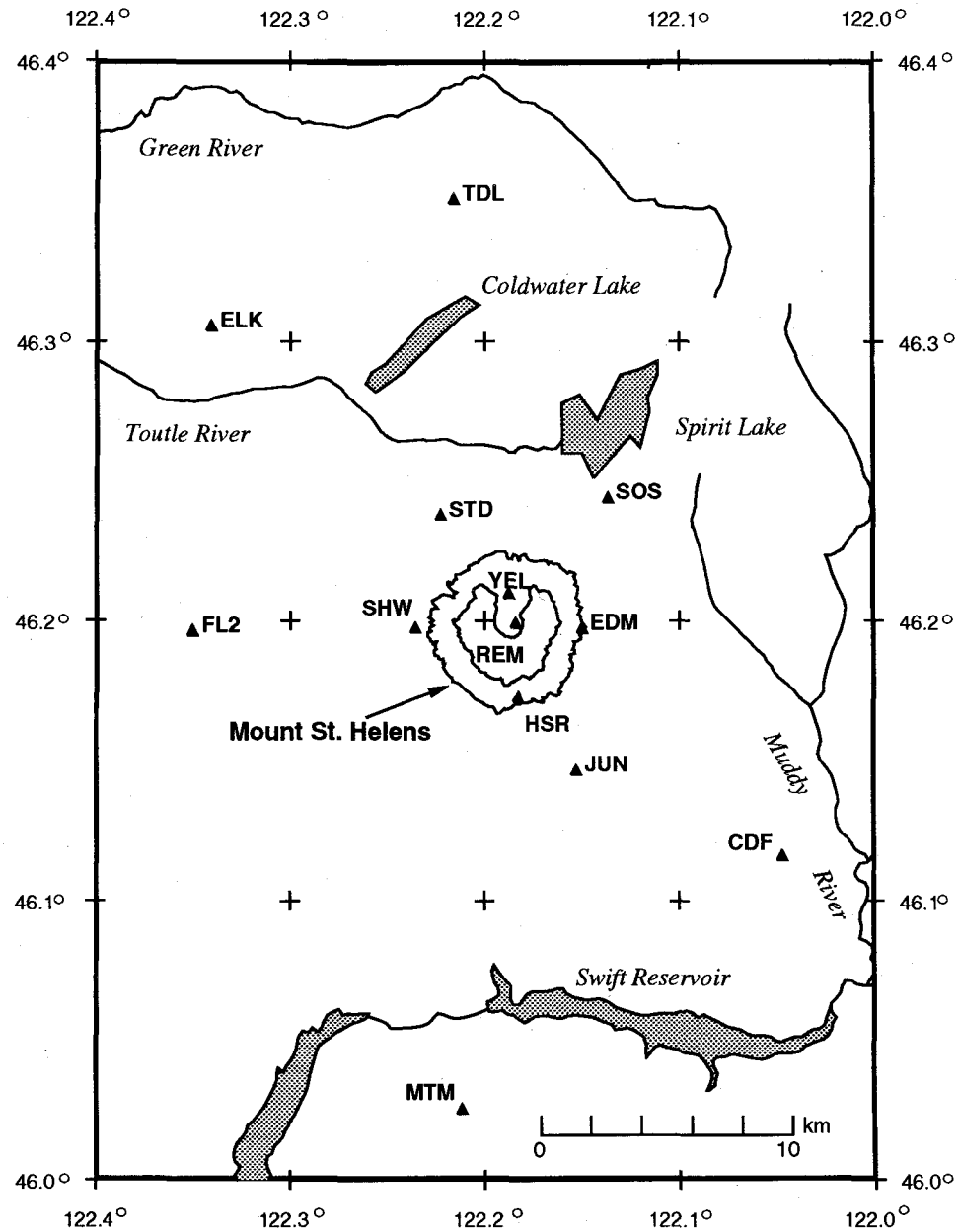



**Figure 1.2.** Locations of seismograph stations operating in the Mount St. Helens region at the end of 1989. Station SHW has operated on the flank of Mount St. Helens since 1972; other stations have been installed since 1980. Station REM is operated by the U.S. Geological Survey but recorded also by the University of Washington. Two elevation contours are shown on the mountain: the outer one is at 5,000 feet, the inner one at 6,400 feet.

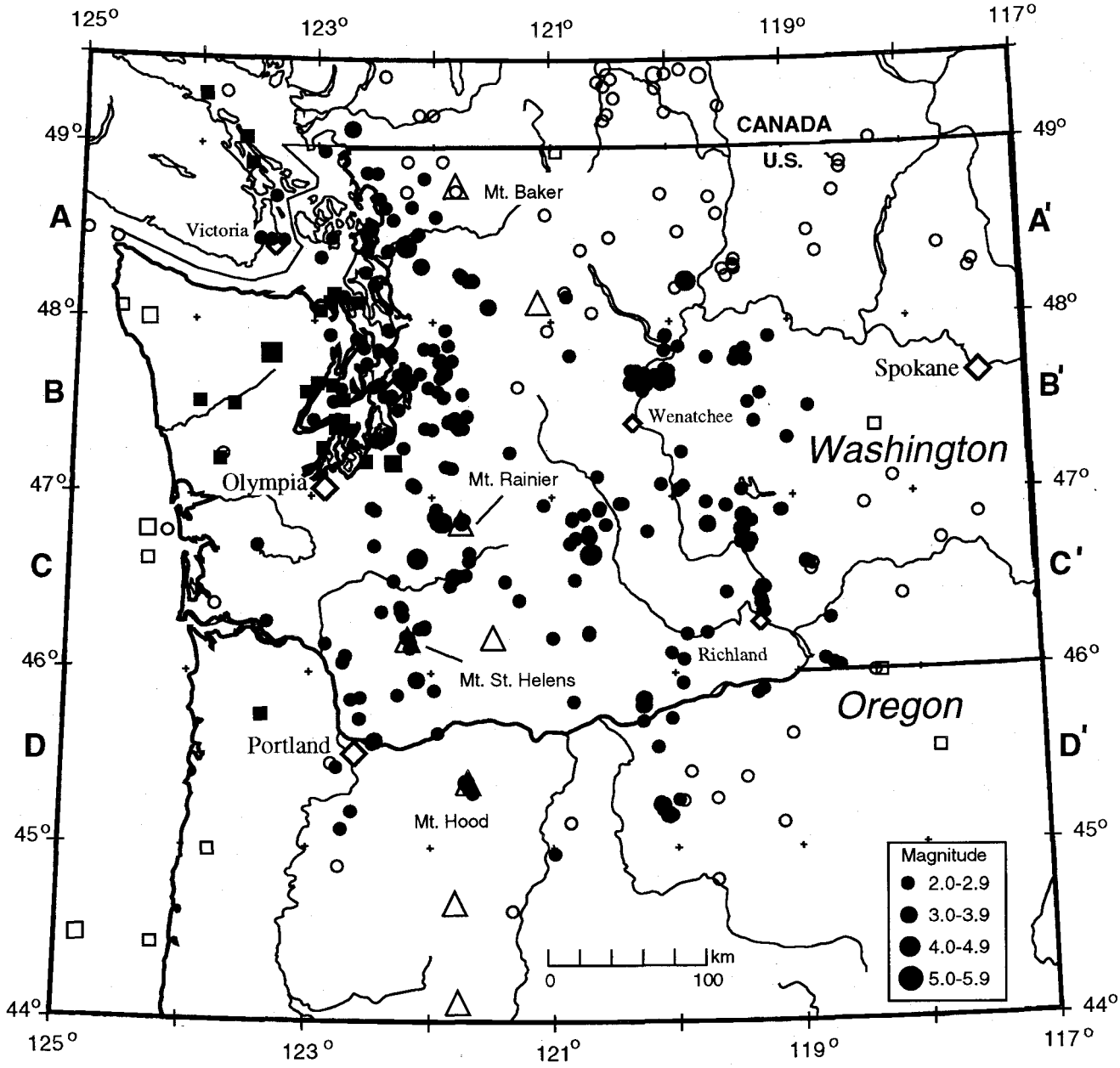



**Figure 1.3.** Locations of earthquake epicenters for Washington and northern Oregon from 1987 to 1989, $M_C \geq 2.0$. Earthquakes shallower than 30 km are indicated by circular symbols, while deeper events are indicated by square symbols. Earthquakes near Seattle are shown in more detail in Figure 1.8. Unfilled symbols indicate less reliable earthquake hypocenters and correspond to earthquakes with at least one D quality factor. (See Table 1.7, p. 11, and "Explanation of Table 1.1", p. 14.) As an example, the depths indicated for earthquakes at the extreme western edge of the map are not reliable. Earthquakes in eastern Washington shown as unfilled squares have unreliable depths. Triangles indicate volcanoes. The east-west end-points of cross sections A–A′, B–B′, C–C′, and D–D′, shown in Figure 1.9, are indicated at the edges of the map.

cated at a depth of about 12 km on the western flank of Mount Rainier, Washington, and was the largest earthquake to occur near Mount Rainier since an $M_C$ 4.7 shock that occurred 25 km southeast of the mountain on April 20, 1974 (Crosson and Lin, 1975). A second earthquake (event 8), magnitude 3.8, occurred 1 hour later in the same vicinity. Both hypocenters were about 12 km west of the summit.

The larger earthquake, at a depth of 12 km, was felt widely around Mount Rainier. The second earthquake, also felt, had a depth of 11 km. An aftershock sequence lasting through August included an aftershock of magnitude $M_C$ 3.0 (not reported felt) on August 12 with a location similar to the two larger shocks. Between July 29 and August 31, the sequence included 26 earthquakes of magnitude 1.0 or larger having epicenters within 5 km of the main shock. Focal mechanism solutions for the three largest earthquakes of the sequence are 'reverse' with their axes of maximum compressive stress oriented north-south.

## 1989

Six earthquakes of magnitude 4 or larger occurred in Washington during 1989. This was the largest number since 1981; in fact, in no year since 1981 were there more than two earth-

quakes with $M_c \geq 4$. Slight damages were reported during several of these earthquakes.

The largest earthquake of 1989, $M_c$ 4.9 ($M_L$ 5.1), occurred 35 km southwest of Mount Rainier near Storm King Mountain on December 24 at a depth of 18 km (event 17, Fig. 1.7). This was the largest earthquake in Washington or Oregon since 1981 when two earthquakes larger than magnitude 5 occurred in southwestern Washington (at Elk Lake in February 1981 and at Goat Rocks in May 1981). The Storm King earthquake was widely felt from Vancouver, WA, to Seattle. Only minor damage was reported, including pictures knocked off the wall in Kent and two glass doors and a window cracked in a building with a poorly braced first story in a wetlands area of Kirkland. Only ten aftershocks (within 5 km of the main shock) were recorded in the next few weeks, none larger than $M_c$ 1.6. At Hanson Dam, about 80 km from the epicenter, the main shock triggered an accelerometer at the crest of the dam, which recorded an acceleration of .09 g.

Two earthquakes larger than magnitude 4 occurred in the subducting Juan de Fuca slab during 1989. The first (event 11, Fig. 1.7) on March 5, $M_c$ 4.5, beneath the Olympic Mountains, about 34 km south of Port Angeles, had a depth of 45 km and was felt from Victoria, BC, to Seattle. The second (event 14), $M_c$ 4.4, occurred beneath the southern part of the Kitsap Peninsula (Fig. 1.8) on June 18 at similar depth and was felt from the central Puget Sound area to Victoria, BC. The March 5 earthquake had a 'normal' fault-plane solution with an east-west axis of minimum compressive stress, whereas the June 18 earthquake had a 'strike-slip' mechanism (Fig. 1.7).

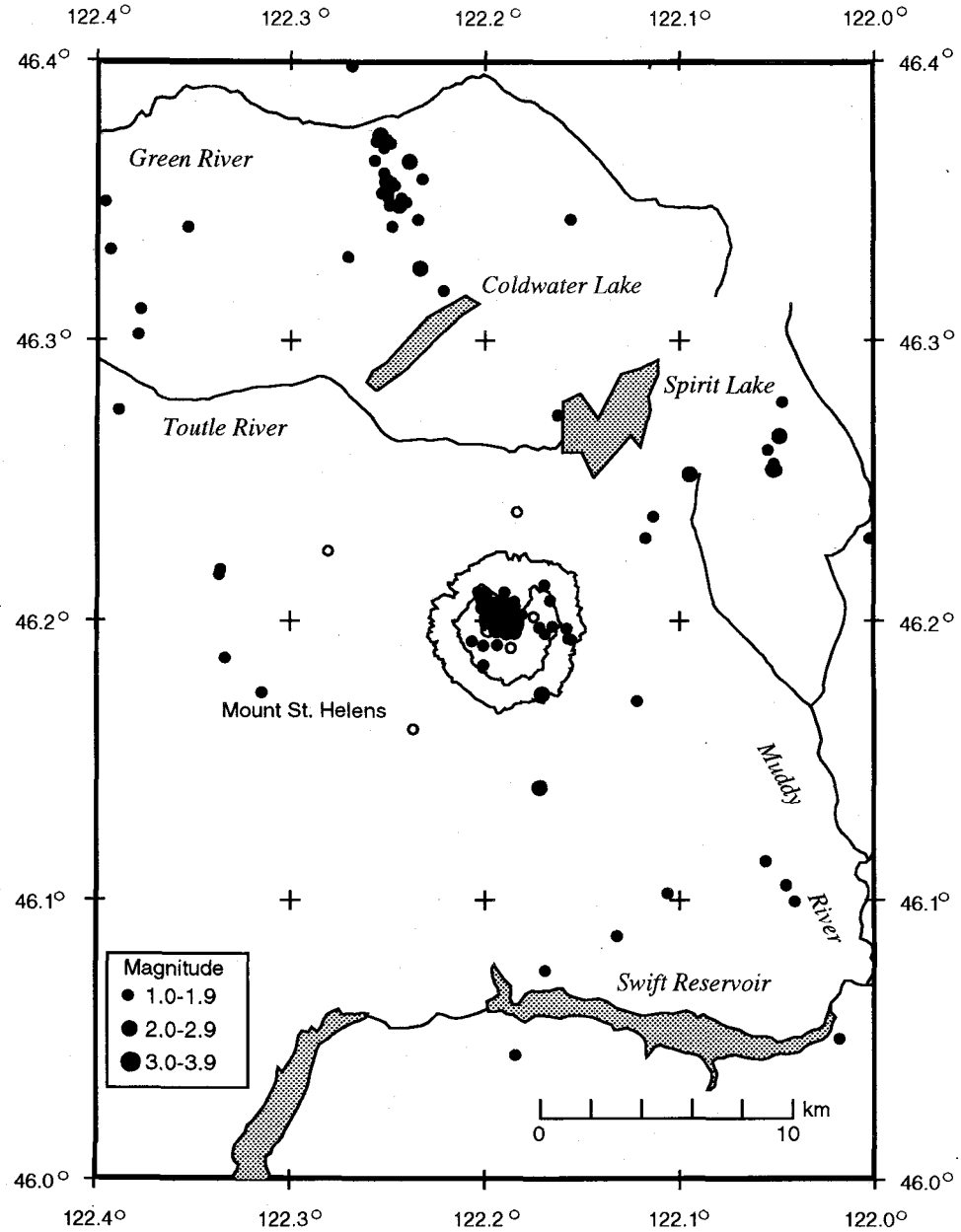



**Figure 1.4.** Locations of earthquake epicenters in the Mount St. Helens region from 1987 to 1989, $M_c \geq 1.0$. Elevation contours as in Figure 1.2. See Figure 1.3 for an explanation of the symbols.

A cluster of shallow (within a few kilometers of the surface) earthquakes about 9 km east of Mount Vernon, WA, began February 6; of the 32 earthquakes, 11 were felt. The two largest were an $M_c$ 4.0 earthquake (event 10, Fig. 1.7) on February 14 and an $M_c$ 4.2 earthquake (event 12, Fig. 1.7) on March 6. The events had epicenters about 2 km northeast of the town of Big Lake just to the east of Mount Vernon. Some damage was reported near Big Lake—many objects fell from shelves at the Big Lake grocery store (more on March 6 than on February 14), and ceiling tiles at the Nazarene Church buckled and broke. Minor chimney damage was reported near the shore of Big Lake. Damage to plaster was reported at the Big Lake elementary school, and a natural gas line broke in the Thunderbird area of Mount Vernon. In cooperation with the USGS and Jim Zollweg (now at Boise State Univ., Boise, ID), we operated a number of portable seismographs in the epicentral region. Teachers and students at the Big Lake school assisted by changing paper in the recording instruments. Focal mechanisms for the two largest events have northwest-southeast-trending P axes (Fig. 1.7) and suggest that a northeast-southwest-striking thrust fault was responsible for the earthquakes, although the local geologic structures generally trend northwest-southeast.

On May 9, an $M_c$ 4.5 earthquake (event 13) 16 km deep, near Omak, 45 km north-northeast of Chelan, was felt in Wenatchee and Chelan and Douglas Counties. In eastern Washington, dishes rattled, cupboard doors swung open, and cans moved toward the edges of shelves, but no damage was

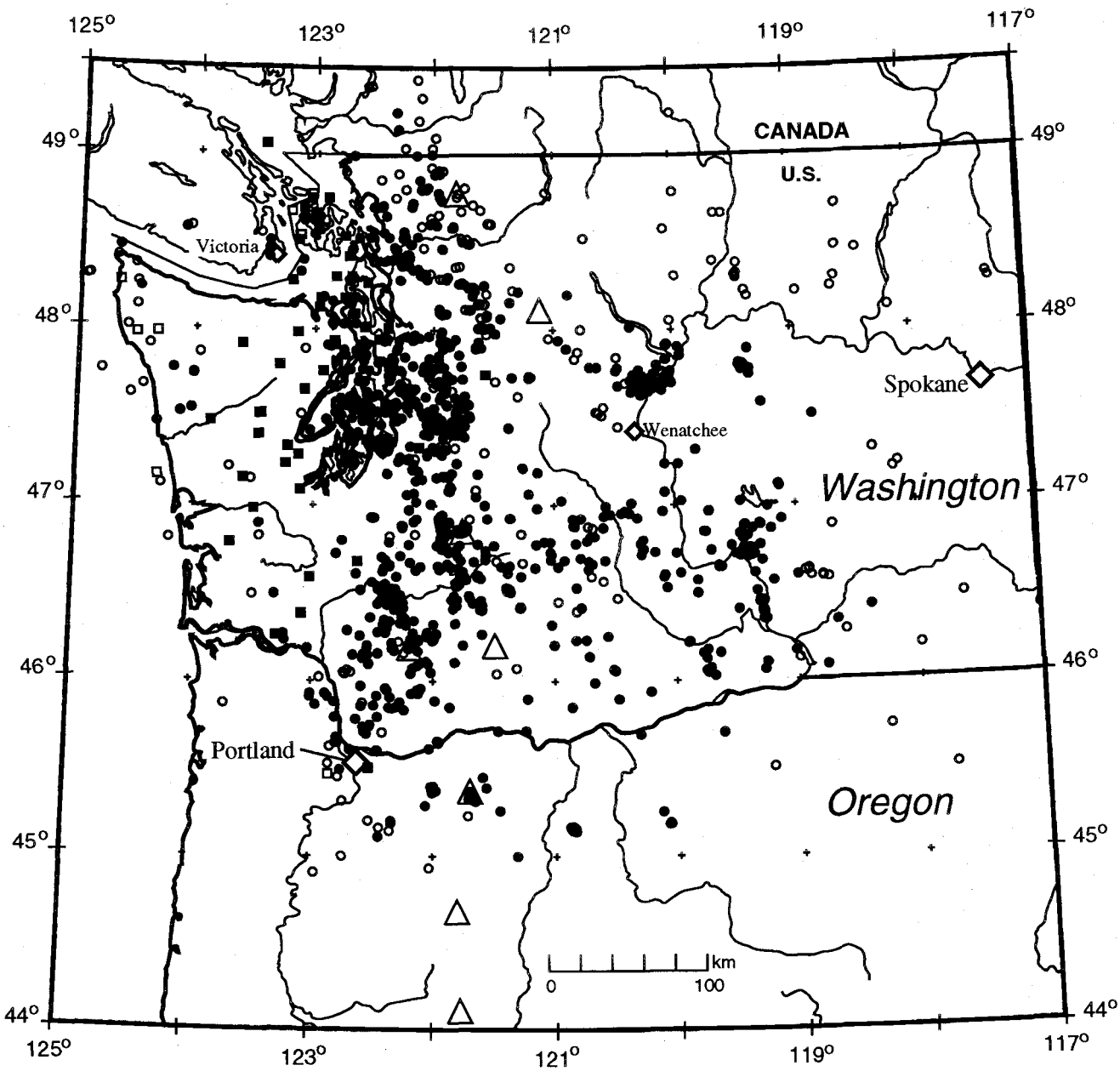



**Figure 1.5.** Locations of epicenters of 1,726 small earthquakes, $1.0 \leq Mc < 2.0$, in Washington and northern Oregon from 1987 to 1989. See Figure 1.3 for an explanation of the symbols.

reported. This was by far the largest earthquake to occur within 30 km of this area since at least 1969; no previously located earthquake in the area has been larger than magnitude 3.3.

## EARTHQUAKE DEPTH DISTRIBUTION

In Figure 1.9 (see also Fig. 1.3) are four cross sections showing the depth distribution of earthquakes in Washington and northern Oregon for 1987 to 1989. The separation of earthquakes into two distinct groups, shallow and deep, with an intervening zone between depths of 25 and 35 km that is relatively free of earthquakes is clearly shown, particularly on section B–B′ through the southern Puget Sound. The zone of deep earthquakes is thought to lie near the top of the subducting Juan de Fuca plate (Taber and Smith, 1985). Section D–D′ shows that deep earthquakes are rare south of latitude 46°. The hypocenters of shallow earthquakes in eastern Washington do not attain the depths reached by hypocenters in western Washington. Shallow earthquakes in western Washington occur at noticeably shallower depths near the crest of the Cascades.

## FELT EARTHQUAKES

The principal factors that determine whether an earthquake is felt are the earthquake's magnitude, depth, and proximity to population centers. Shallow earthquakes are usually more readily felt than deep ones, but almost any earthquake in Washington or Oregon whose magnitude exceeds 4.0 is reported felt. On average, 50 percent of magnitude 3.2 earthquakes and 25 percent of magnitude 2.8 earthquakes are re-

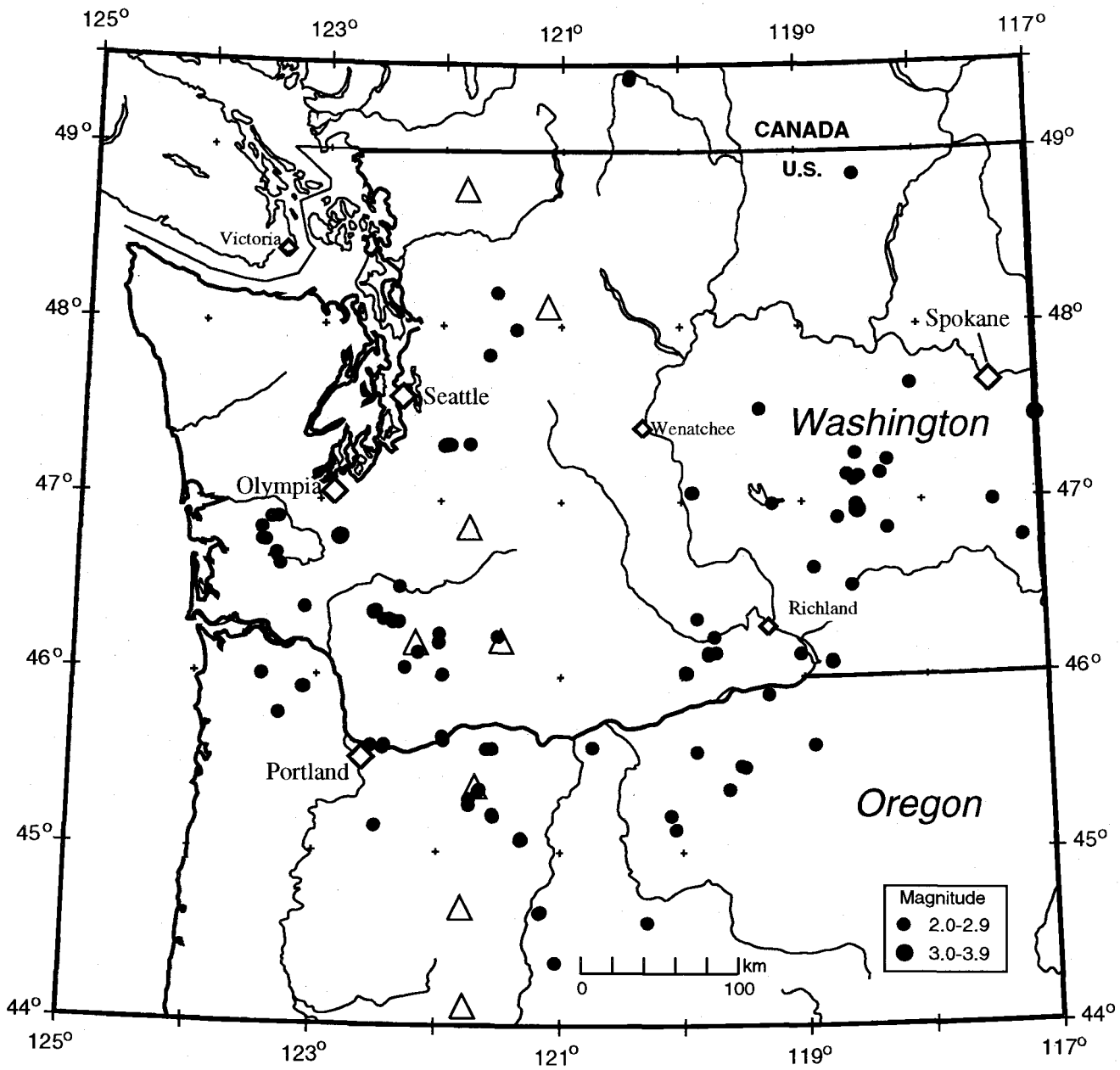


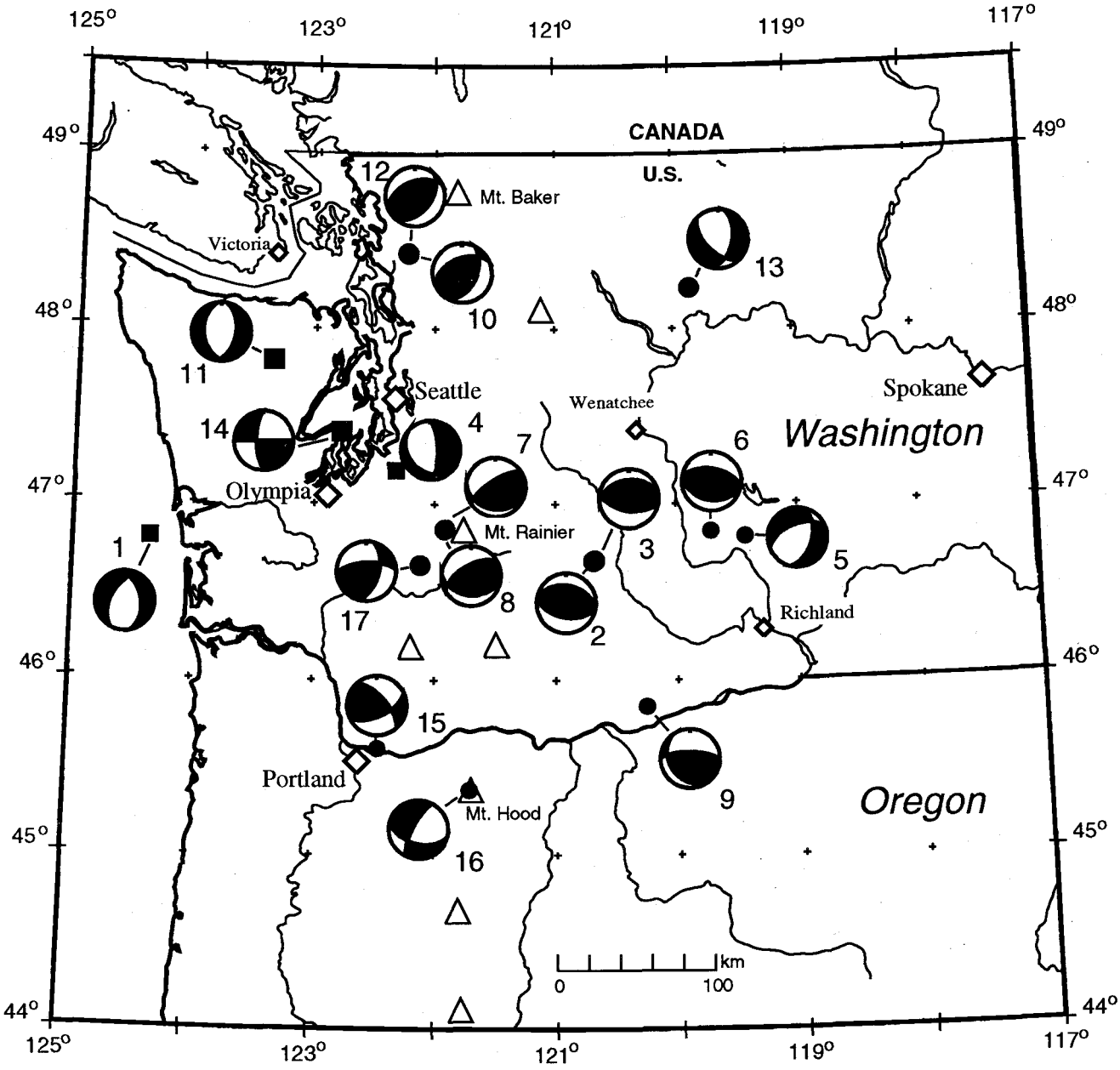

**Figure 1.6.** Locations of blasts and probable blasts in Washington and northern Oregon from 1987 to 1989, $M_c \geq 2.0$.

ported felt. Much smaller earthquakes can be felt by persons at rest very near the epicenter. The smallest earthquake reported felt in the period 1987–1989 had a magnitude of only 1.1.

A list of earthquakes reported felt from 1987 to 1989 is given in Table 1.4 (p. 28). A detailed description of damage reported for some of these earthquakes can be found in the annual USGS publication "United States Earthquakes". The Modified Mercalli (MM) Intensity scale used in Table 1.4 is also described in "United States Earthquakes" and in Richter (1958). Intensities given in Table 1.4 are taken from unpublished data obtained by the USGS or estimated from reports received by the University of Washington (intensities in parentheses) if that was the only available source. Where data are insufficient to estimate intensity, the earthquakes are listed only as 'felt'.

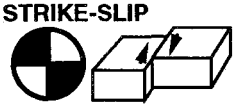
## MOUNT ST. HELENS

After 123 years of inactivity, a March 1980 earthquake swarm at Mount St. Helens initiated 7 years (1980–1986) of frequent magmatic eruptions at the volcano. Mount St. Helens subsequently entered a period marked by changes in both eruptive and seismic activity. Although magmatic eruptions ceased in late October 1986, earthquakes with focal depths greater than 3 km began occurring in mid-1987 (Fig. 1.10). Following the catastrophic eruption of May 1980, until mid-1987, earthquake activity at depths greater than 3 km was confined to some small earthquakes in the 2 months preceding the March 1982 explosive eruption (Weaver and others, 1983). The 1987 increase in deeper earthquakes was eventually followed by an increase in the number of very shallow earthquakes (Fig. 1.10), which lagged the deeper activity by about 2 years.




**FAULT TYPE**

**STRIKE-SLIP**



**REVERSE (THRUST)**

**NORMAL**

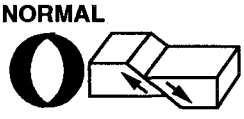


**Figure 1.7.** Locations of epicenters of larger earthquakes ($M_c \geq 3.5$) in Washington and northern Oregon from 1987 to 1989. See Figure 1.3 for an explanation of the symbols. 'Beach ball' symbols show lower hemisphere equal-area fault-plane solutions (Fowler, 1990) for each event. Numbers for each event are keyed to Table 1.5 (p. 30). Fault-plane solutions are based on P-wave first motions. Quadrants indicating 'up' first motions are shaded black. As an example, the beach-ball symbol for event 14 indicates strike-slip faulting, the symbol for event 11 indicates normal faulting, and the symbol for event 12 indicates reverse (or thrust) faulting.

Another feature of the Mount St. Helens 1987–1989 earthquake activity is that virtually all the seismic events were of the high-frequency tectonic type. This is in contrast to the many shallow low-frequency earthquakes preceding most of the eruptions from 1980 to 1986. The prevalence of low-frequency events during dome-building eruptions suggests a connection between magma/fluid transport and low-frequency signals. The lack of such shallow low-frequency events during 1987 to 1989 could indicate that no significant transport of magma or magmatic fluids to the surface occurred during that period.

Earthquake activity deeper than 3 km at Mount St. Helens is of particular interest because many investigators believe that a small magma storage center exists between 7 and 11 km below the cone (Scandone and Malone, 1985; see Moran, 1992, for additional references). The deep earthquakes could be the result of magma transport from this magma chamber. As shown in Figure 1.10, the deep earthquakes from 1987 to 1989 were characterized by periodic bursts or 'swarms' of activity. The rate of deep earthquake activity increased in 1988, and by the second quarter of 1989 individual swarms had be-

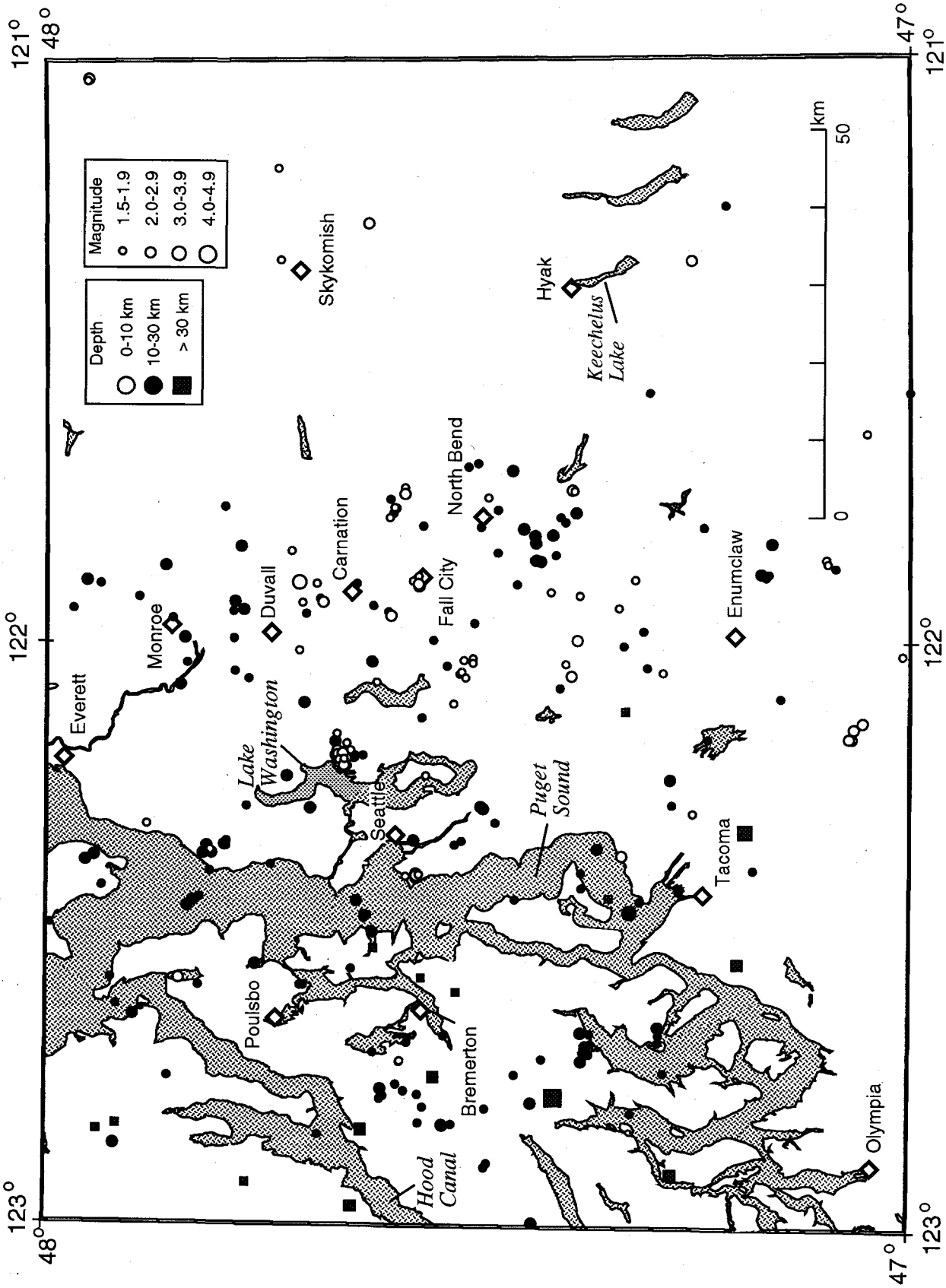



**Figure 1.8.** Locations of epicenters of earthquakes near Seattle during 1987 to 1989, $M_c \geq 1.5$. The deepest earthquake during this period occurred at a depth of 85 km at a point 16 km west-northwest of Skykomish on February 24, 1987. It is not shown on the figure because its magnitude was only 1.0.

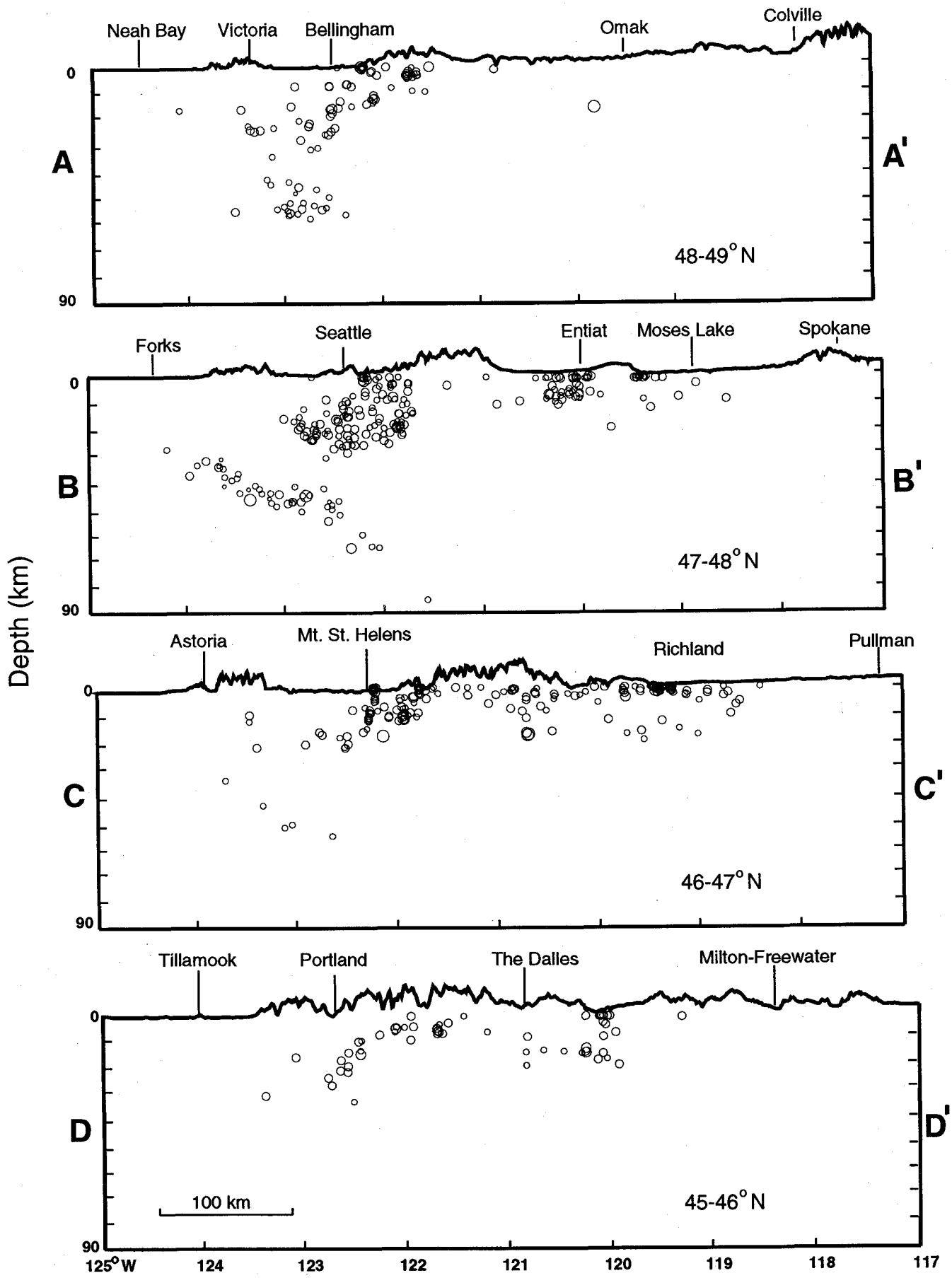

Neah Bay
Victoria
Bellingham
Omak
Colville
A
A'
48-49° N
Forks
Seattle
Entiat
Moses Lake
Spokane
B
B'
47-48° N
Astoria
Mt. St. Helens
Richland
Pullman
C
C'
46-47° N
Tillamook
Portland
The Dalles
Milton-Freewater
D
D'
100 km
45-46° N
Depth (km)
0
90
125° W
124
123
122
121
120
119
118
117

**Table 1.7.** Earthquake-location quality factors. Each quality factor is given the highest rating allowed given the definitions below. ERH is the estimated uncertainty, in kilometers, of the epicenter location; ERZ is the estimated uncertainty, in kilometers, in the depth. DMIN is the distance, in kilometers, from the epicenter to the nearest station. In determining the quality factor, the value of DMIN is compared to d1, the earthquake depth or 5 km, whichever is greater, or d2, twice the earthquake depth or 10 km, whichever is greater. See "Explanation of Table 1.1" (p. 14) for a more detailed explanation and definition of other abbreviations

| Factor 1 | | | | Factor 2 | | | |
|---|---|---|---|---|---|---|---|
| Quality | RMS | ERH | ERZ | Quality | NS | GAP | DMIN |
| D | other | other | – | D | other | other | other |
| C | <0.50 | ≤5.0 | – | C | ≥6 | ≤180 | ≤50 |
| B | <0.30 | ≤2.5 | ≤5.0 | B | ≥7 | ≤135 | ≤d2 |
| A | <0.15 | ≤1.0 | ≤2.0 | A | ≥8 | ≤90 | ≤d1 |

come indistinguishable from one another. Table 1.6 gives the number of earthquakes per month at Mount St. Helens and can be compared to a similar table for 1980 to 1986 in Qamar and others (1987b). During 1987 to 1989, the greatest number of seismic events in a single month occurred in October 1989 when 182 earthquakes were located between depths of 0 and 8 km. More than half of these had foci deeper than 4 km, suggesting that the entire magma conduit system was activated. Finally, a minor ash and steam explosion took place on December 7, 1989, the first eruptive activity in 3 years. At the end of 1989, earthquake activity at Mount St. Helens remained relatively high.

Prolonged, volcanic tremor-like seismic signals occurred at Mount St. Helens in both August and December 1989. Such signals normally accompany gas and ash eruptions and are often characterized by swarms of several earthquakes per minute superimposed on continuous ground motion lasting minutes or hours. However, only the December activity was accompanied by an ash explosion.

There is no evidence that the 1989 activity added any new magma to the crater dome. The tremor-like seismic signals in August and December and the December ash eruption may have resulted from meteoric water that came into contact with hot rock within the lava dome and (or) hot gases and steam from subsurface magma (Mastin and Myers, 1992).

Earthquakes in the area surrounding Mount St. Helens were scattered in 1987 to 1989 except for continued activity near Elk Lake along the north to northwest-trending zone of strike-slip faulting known as the St. Helens seismic zone (Weaver and Smith, 1983). Elk Lake is 17 km north of Mount St. Helens (2 km north of Coldwater Lake, Fig. 1.4) and was the site of a magnitude 5.5 earthquake in 1981 (Grant and others, 1984). The largest earthquake near Elk Lake in the period 1987 to 1989 had a coda-duration magnitude of 2.8 and occurred in September 1987.

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**Figure 1.9. (facing page)** East-west cross sections showing depths of earthquakes between longitude 117° and 125°W from 1987 to 1989. Only earthquakes with quality CC or better (defined in Table 1.7) are plotted. Above a depth of 30 km only earthquakes having $M_c \geq 1.8$ are shown. Below 30 km all earthquake locations with $M_c \geq 1.0$ that meet the quality criteria are included. Section A–A′ shows earthquakes between north latitudes 48° and 49°; B–B′ between 47° and 48°; C–C′ between 46° and 47°; and D–D′ between 45° and 46°. The locations of cross section end points are shown on Figure 1.3. In each section earthquakes are projected from the north or south onto a vertical east-west plane. There is 2 to 1 vertical exaggeration below sea level; above sea level the topography is exaggerated 12 to 1.

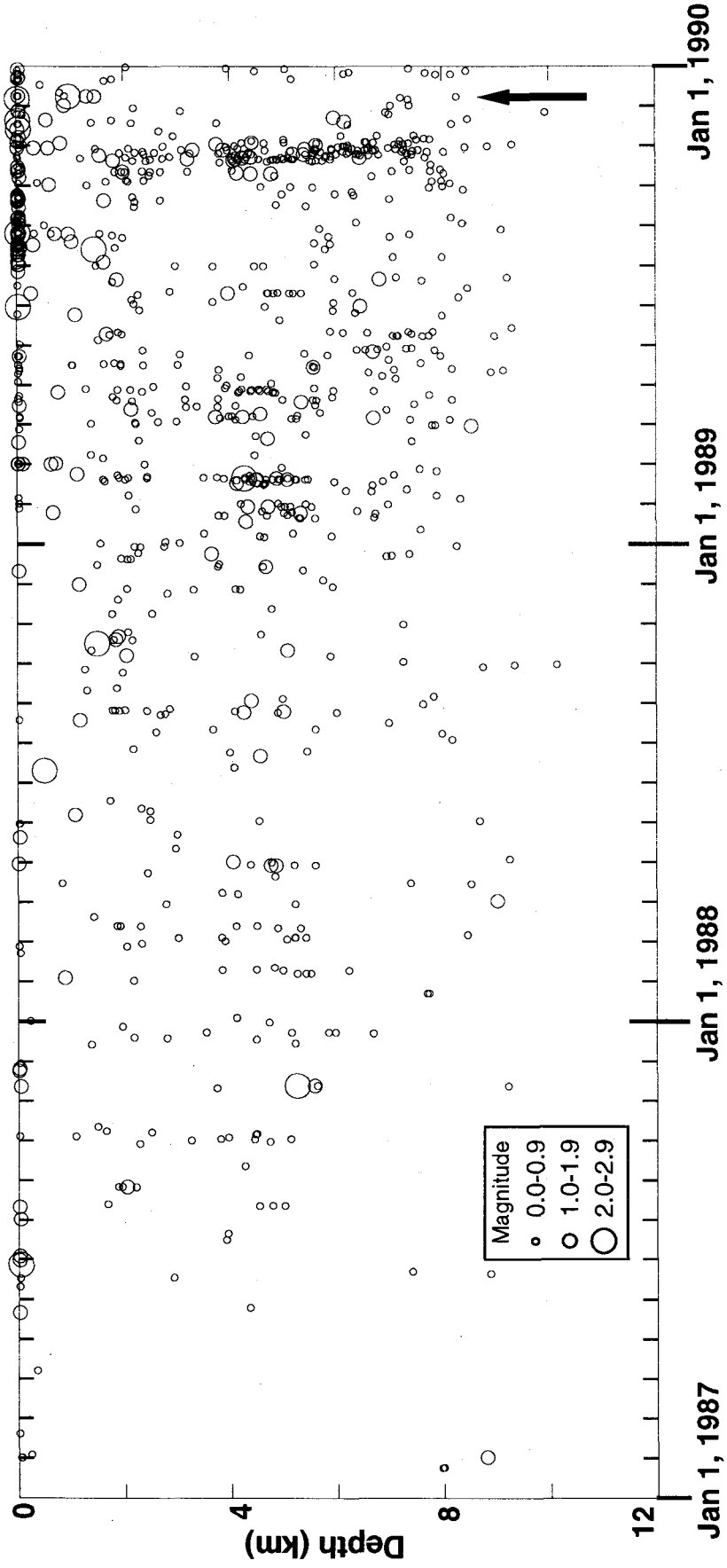


**Figure 1.10.** Depths of earthquakes versus time at Mount St. Helens for the period January 1, 1987 to December 31, 1989. Symbol size is proportional to earthquake magnitude. Only events having magnitude greater than 0.0 are shown. The arrow at the lower right corner indicates a steam and ash explosion on December 7, 1989. (After Malone, 1990.)

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## EXPLANATION OF TABLE 1.1

**Time** – Origin time, calculated for each earthquake on the basis of multi-station arrival times. Time is given in Universal Coordinated Time (UCT) in hours:minutes:seconds. To convert to Pacific Standard Time, subtract 8 hours; for Pacific Daylight Time, subtract 7 hours.

**Latitude** – North latitude of the epicenter in degrees and minutes.

**Longitude** – West longitude of the epicenter in degrees and minutes.

**Depth** – The depth of focus, in kilometers, calculated from the arrival-time data. In some instances, the depth must be fixed to an arbitrary value to obtain a convergent solution. Such depths are noted by an asterisk (*). A $ or a # in this column means that the maximum number of iterations has been exceeded without meeting convergence tests and both the location and depth have been arbitrarily fixed.

**M** – Coda-duration magnitude, $M_c$ (Crosson, 1972). For tectonic earthquakes in Washington, $M_c$ is an estimate of the local Richter magnitude, $M_L$ (Richter, 1958).

**NS/NP** – NS is the number of seismograph stations providing observations actually used to locate the earthquake. A station with arrival-time observations not used because of large residuals, etc., is not counted in this number. NP is the number of P and S phases used to calculate the earthquake location. At least three stations and four phases are required for a location. Generally, more observations improve the quality of the location.

**Gap** – The central angle (relative to an observer at the epicenter) of the largest azimuthal sector containing no stations. For example, if all stations are to the northeast of the epicenter (azimuths between 0° and 90°) the gap is 270°. An azumuthal gap much greater than 180° indicates a poor location.

**RMS** – The weighted root mean square of the arrival-time residuals at all seismograph stations; in general, the RMS value indicates the overall quality of the hypocentral solution. A time residual is the difference between the observed and expected arrival time of a wave at a station, assuming a particular location for the hypocenter. The RMS residual is obtained by squaring each individual station residual, summing the squares, dividing by the number of observations minus the number of computed parameters (usually 4: latitude, longitude, origin time, and earthquake depth), and taking the square root of the quantity. RMS values less than 0.1 second indicate a solution that fits the observed arrival-time data very well. Values greater than 0.5 second usually indicate a poor solution. However, earthquakes located with only three or four readings (in column labeled NS/NP) have RMS values set to zero. The RMS is not a good indicator of the quality of a location unless P- or S-wave arrival-time readings from five or more well-distributed stations are available.

**Q** – Each earthquake location is assigned two quality factors summarizing its general reliability. Each factor is a letter ranging from A (best quality) to D (worst quality). Similar quality factors are used by the USGS for events located with the computer program HYPO71 (Lee and Lahr, 1975; see reference list for Part 2). The first letter is a measure of the hypocenter quality based on the RMS residual. The second letter is determined by the spatial distribution of stations around the epicenter, that is, the number of stations, their azimuthal distribution, and the minimum distance (DMIN) from the epicenter to a station. For a detailed definition, see Table 1.7.

**Model** – The crustal velocity model used in location calculations (refer to Fig. 1.1). For example, P3 indicates version 3 of the Puget Sound velocity model.

| | |
|---|---|
| P3 - Puget Sound model | E3 - southeastern model |
| C3 - Cascade model | O0 - northern Oregon model |
| S3 - St. Helens region model | J1 - oceanic crust model (for offshore events) |
| N3 - northeastern model | |

**Type** – Earthquake type classification

| | |
|---|---|
| F - felt earthquake | H - handpicked from helicorder records |
| R - regional event (outside the WRSN) | L - low-frequency earthquake |
| P - probable explosion | X - confirmed explosion |

**Table 1.1.** Washington Regional Seismograph Network earthquake catalog—Earthquakes and blasts, $M_c \geq 2.0$, between latitudes 44° and 49.5°N and longitudes 117° and 125°W for 1987 to 1989

| Day | Time | Latitude (N) | Longitude (W) | Depth | M | NS/NP | Gap | RMS | Q | Model | Type |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **January 1987** | | | | | | | |
| 2 | 08:05:35.80 | 47 32.33 | 122 49.51 | 18.56 | 2.4 | 29/36 | 42 | 0.15 | BA | P3 | |
| 10 | 13:26:14.80 | 47 51.67 | 121 52.12 | 18.54 | 2.0 | 21/24 | 81 | 0.14 | AA | P3 | |
| 11 | 05:28:19.85 | 47 54.48 | 119 10.17 | 0.56 | 2.0 | 14/15 | 90 | 0.19 | BC | N3 | |
| 12 | 12:17:29.47 | 49 23.99 | 119 42.09 | 0.02* | 3.7 | 21/25 | 236 | 0.32 | CD | N3 | R |
| 15 | 17:58:13.18 | 47 49.71 | 122 26.58 | 19.55 | 2.7 | 20/29 | 46 | 0.15 | AA | P3 | |
| 15 | 22:51:33.35 | 46 07.65 | 119 01.65 | 2.61 | 2.3 | 21/22 | 106 | 0.22 | BC | E3 | P |
| 16 | 18:19:16.53 | 47 19.82 | 119 01.79 | 7.63 | 2.2 | 22/25 | 94 | 0.15 | BC | N3 | |
| 22 | 19:22:36.20 | 49 13.67 | 119 32.84 | 0.05* | 2.3 | 12/22 | 244 | 0.69 | DD | N3 | R |
| 23 | 05:56:37.48 | 45 53.97 | 121 58.44 | 9.06 | 2.3 | 34/44 | 72 | 0.15 | AC | C3 | |
| 30 | 02:48:43.40 | 46 13.25 | 120 42.03 | 4.76 | 2.0 | 24/29 | 41 | 0.46 | CC | C3 | |
| 31 | 00:03:00.32 | 45 52.84 | 119 19.55 | 0.38$ | 2.1 | 21/25 | 159 | 0.28 | BC | E3 | |
| | | | | **February 1987** | | | | | | | |
| 2 | 01:47:25.01 | 47 47.69 | 119 24.58 | 0.04* | 2.2 | 21/26 | 91 | 0.23 | BC | N3 | |
| 5 | 01:14:46.24 | 45 38.11 | 121 57.36 | 0.04* | 2.1 | 25/29 | 168 | 0.23 | BC | C3 | X |
| 13 | 20:01:53.82 | 49 26.97 | 120 31.98 | 14.18 | 3.0 | 12/15 | 262 | 0.62 | DD | C3 | R |
| 14 | 01:58:02.42 | 49 26.18 | 119 52.20 | 26.13 | 2.3 | 12/12 | 238 | 0.46 | DD | N3 | R |
| 17 | 09:39:51.79 | 46 50.63 | 120 33.21 | 7.25 | 2.1 | 31/37 | 47 | 0.22 | BB | E3 | |
| 21 | 06:54:01.40 | 46 12.04 | 120 59.76 | 2.86 | 2.3 | 39/45 | 59 | 0.31 | CC | C3 | |
| 25 | 20:29:51.23 | 46 31.34 | 122 18.58 | 16.96 | 2.0 | 39/53 | 29 | 0.18 | BA | C3 | |
| 28 | 14:56:10.54 | 47 49.99 | 120 02.89 | 0.54 | 2.6 | 25/31 | 89 | 0.27 | BA | N3 | F |
| | | | | **March 1987** | | | | | | | |
| 11 | 17:33:33.14 | 47 34.46 | 122 20.32 | 12.64 | 2.3 | 28/32 | 69 | 0.13 | AA | P3 | |
| 17 | 16:34:54.58 | 48 15.36 | 121 45.66 | 3.28$ | 2.8 | 27/35 | 59 | 0.38 | CC | P3 | F |
| 19 | 18:40:30.44 | 48 15.18 | 121 45.13 | 3.75$ | 2.1 | 17/25 | 61 | 0.32 | CC | P3 | F |
| 29 | 01:48:06.91 | 47 50.69 | 122 34.61 | 8.33$ | 2.2 | 6/10 | 180 | 0.28 | BC | P3 | H |
| | | | | **April 1987** | | | | | | | |
| 3 | 01:22:36.28 | 46 56.94 | 119 33.48 | 1.78 | 2.4 | 31/36 | 46 | 0.20 | BC | E3 | |
| 5 | 01:06:44.73 | 48 15.36 | 121 44.74 | 1.69 | 2.8 | 18/18 | 61 | 0.28 | BC | P3 | F |
| 7 | 15:25:01.88 | 47 29.79 | 122 16.84 | 25.69 | 2.6 | 37/39 | 48 | 0.14 | AA | P3 | |
| 10 | 18:48:44.88 | 46 50.12 | 123 28.93 | 5.69$ | 2.1 | 6/06 | 127 | 0.35 | CC | P3 | P |
| 11 | 17:21:59.46 | 46 48.20 | 120 12.65 | 3.35 | 2.0 | 28/31 | 39 | 0.28 | BC | E3 | |
| 15 | 13:22:10.64 | 47 29.62 | 122 17.05 | 22.87 | 2.5 | 43/57 | 47 | 0.19 | BA | P3 | |
| 28 | 06:42:46.51 | 47 36.61 | 122 45.80 | 20.37 | 2.8 | 32/40 | 28 | 0.20 | BA | P3 | F |
| | | | | **May 1987** | | | | | | | |
| 6 | 18:56:01.36 | 45 59.85 | 123 27.08 | 9.66 | 2.0 | 7/07 | 176 | 0.08 | BC | P3 | P |
| 11 | 21:50:26.90 | 46 43.73 | 117 47.03 | 26.45* | 2.4 | 11/11 | 237 | 0.42 | CD | E3 | |
| 12 | 19:08:18.31 | 47 16.66 | 122 14.05 | 12.13$ | 2.1 | 38/45 | 44 | 0.35 | CC | P3 | |
| 16 | 09:08:35.68 | 45 44.00 | 122 35.17 | 21.11 | 2.3 | 33/36 | 82 | 0.14 | AB | C3 | F |
| 16 | 21:12:21.75 | 46 56.73 | 119 33.30 | 0.86 | 2.1 | 27/30 | 46 | 0.19 | BC | E3 | |
| 24 | 06:19:56.10 | 48 21.77 | 122 57.00 | 14.97* | 2.0 | 28/39 | 37 | 0.28 | BB | P3 | |
| 24 | 13:44:07.48 | 45 52.29 | 122 16.50 | 7.09 | 2.2 | 31/37 | 57 | 0.18 | BC | C3 | |
| 25 | 23:04:18.15 | 49 23.24 | 120 28.11 | 4.29$ | 2.1 | 9/12 | 276 | 0.42 | DD | C3 | |
| 28 | 22:17:48.15 | 45 36.48 | 118 55.30 | 3.82 | 2.3 | 13/13 | 225 | 0.21 | BD | E3 | P |
| | | | | **June 1987** | | | | | | | |
| 1 | 17:53:19.44 | 47 56.61 | 122 21.99 | 28.62 | 2.1 | 22/29 | 59 | 0.12 | AA | P3 | |
| 2 | 23:00:45.73 | 49 24.54 | 120 25.53 | 2.83$ | 2.2 | 11/16 | 250 | 0.47 | DD | C3 | X |
| 8 | 06:15:10.93 | 47 23.11 | 121 59.73 | 6.53* | 2.0 | 29/32 | 42 | 0.13 | AC | P3 | |
| 11 | 19:50:16.98 | 46 46.65 | 120 41.64 | 17.23 | 3.0 | 33/42 | 29 | 0.35 | CA | E3 | |
| 12 | 19:05:40.69 | 49 25.93 | 120 25.09 | 0.02* | 2.8 | 7/07 | 252 | 0.18 | BD | C3 | X |
| 16 | 06:15:38.20 | 47 46.88 | 121 55.80 | 20.99 | 2.0 | 23/28 | 55 | 0.18 | BA | P3 | |
| 16 | 20:51:13.27 | 45 38.56 | 119 03.23 | 8.69$ | 2.3 | 9/11 | 243 | 0.33 | DD | E3 | |
| 17 | 02:32:57.29 | 46 21.41 | 122 15.05 | 11.43 | 2.0 | 31/41 | 41 | 0.17 | BA | S3 | |
| 18 | 10:15:59.77 | 47 32.29 | 122 49.57 | 18.73 | 2.4 | 32/39 | 42 | 0.15 | BA | P3 | F |
| 19 | 05:47:41.66 | 46 47.65 | 124 21.04 | 37.95 | 3.9 | 37/43 | 221 | 0.24 | BD | P3 | F |
| 21 | 10:53:45.59 | 47 26.87 | 121 48.35 | 21.78 | 2.3 | 33/39 | 74 | 0.14 | AA | P3 | |
| 26 | 14:42:38.88 | 47 48.79 | 122 20.97 | 14.95 | 2.7 | 31/45 | 44 | 0.24 | BB | P3 | |
| 26 | 15:38:04.91 | 46 03.29 | 122 43.56 | 16.91 | 2.0 | 35/40 | 69 | 0.17 | BA | C3 | |
| 27 | 13:12:45.97 | 46 11.76 | 122 11.11 | 0.04* | 2.1 | 6/06 | 88 | 0.28 | BC | S3 | |
| 30 | 02:04:26.95 | 44 57.87 | 120 59.57 | 9.27 | 2.8 | 22/24 | 133 | 0.35 | CC | O0 | |
| 30 | 03:19:22.02 | 48 06.41 | 122 52.12 | 45.59 | 2.4 | 27/33 | 40 | 0.14 | AA | P3 | |

**Table 1.1.** Washington Regional Seismograph Network earthquake catalog *(continued)*

| Day | Time | Latitude (N) | Longitude (W) | Depth | M | NS/NP | Gap | RMS | Q | Model | Type |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **July 1987** | | | | | | | |
| 1 | 02:13:02.59 | 48 54.74 | 122 13.31 | 16.93 | 2.2 | 14/20 | 249 | 0.27 | BD | P3 | |
| 1 | 23:21:52.63 | 47 39.97 | 118 04.30 | 8.03 | 2.4 | 16/17 | 288 | 0.37 | CD | N3 | P |
| 5 | 23:51:59.04 | 48 16.79 | 122 34.09 | 25.63 | 2.4 | 18/26 | 76 | 0.19 | BA | P3 | |
| 16 | 17:47:37.11 | 46 57.76 | 120 26.28 | 16.78 | 2.3 | 29/37 | 34 | 0.28 | BA | E3 | |
| 16 | 23:21:59.11 | 47 28.10 | 117 01.44 | 0.04* | 3.0 | 9/11 | 305 | 0.51 | DD | N3 | P |
| 17 | 00:52:59.81 | 46 21.79 | 122 32.42 | 4.23 | 2.1 | 30/34 | 50 | 0.20 | BB | C3 | P |
| 20 | 16:50:05.80 | 46 48.17 | 120 41.81 | 11.65 | 2.3 | 30/33 | 29 | 0.34 | CB | C3 | |
| 25 | 10:10:18.48 | 47 25.99 | 122 59.45 | 15.60* | 2.7 | 43/48 | 39 | 0.17 | BB | P3 | |
| 27 | 16:18:33.74 | 45 18.67 | 121 39.36 | 6.54 | 2.4 | 36/40 | 81 | 0.33 | CB | O0 | |
| 27 | 23:12:53.55 | 45 35.89 | 120 44.27 | 0.03* | 2.4 | 25/25 | 96 | 0.35 | CB | C3 | X |
| 28 | 01:40:07.76 | 46 22.98 | 123 06.69 | 0.02* | 2.0 | 29/30 | 100 | 0.25 | BC | P3 | P |
| | | | | **August 1987** | | | | | | | |
| 4 | 21:38:51.50 | 47 08.45 | 118 31.20 | 9.92 | 2.1 | 18/18 | 192 | 0.38 | CD | N3 | P |
| 6 | 21:12:42.55 | 48 07.80 | 122 45.83 | 22.44* | 2.7 | 19/22 | 83 | 0.14 | AA | P3 | F |
| 6 | 21:54:25.97 | 48 41.84 | 122 27.48 | 13.13$ | 2.0 | 11/13 | 170 | 0.41 | CC | P3 | |
| 7 | 22:20:18.76 | 46 25.47 | 118 07.31 | 0.04* | 2.1 | 15/17 | 226 | 0.37 | CD | E3 | |
| 8 | 13:32:36.59 | 47 38.94 | 120 14.84 | 0.51 | 2.2 | 24/28 | 50 | 0.44 | CB | N3 | |
| 9 | 03:32:09.96 | 45 08.67 | 120 51.62 | 27.97* | 2.4 | 31/37 | 194 | 0.31 | CD | O0 | F |
| 12 | 17:52:32.15 | 47 08.29 | 118 31.70 | 8.58 | 2.0 | 17/17 | 199 | 0.23 | BD | N3 | P |
| 17 | 12:35:50.40 | 47 43.20 | 120 19.71 | 0.02* | 2.0 | 22/27 | 94 | 0.17 | BC | N3 | |
| 18 | 05:15:47.76 | 45 08.63 | 120 51.65 | 25.17 | 2.1 | 21/24 | 194 | 0.37 | CD | O0 | |
| 21 | 01:16:13.54 | 45 36.30 | 122 32.84 | 0.02* | 2.4 | 12/15 | 212 | 0.35 | CD | C3 | P |
| 21 | 20:55:34.89 | 47 07.05 | 120 37.23 | 9.14 | 2.0 | 29/34 | 59 | 0.41 | CA | N3 | |
| 22 | 21:22:11.48 | 47 09.47 | 118 20.39 | 5.98* | 2.3 | 21/21 | 208 | 0.31 | CD | N3 | P |
| 27 | 01:54:28.03 | 46 48.71 | 119 25.86 | 0.04* | 2.2 | 30/33 | 50 | 0.28 | BA | E3 | |
| 27 | 22:48:05.59 | 48 17.97 | 119 32.25 | 0.92 | 2.2 | 6/07 | 258 | 0.10 | BD | N3 | |
| 28 | 03:57:22.82 | 48 58.34 | 120 57.10 | 35.63$ | 2.4 | 5/06 | 259 | 0.24 | CD | C3 | |
| 28 | 13:23:38.87 | 48 54.77 | 122 46.30 | 15.52 | 2.0 | 13/15 | 244 | 0.23 | BD | P3 | |
| 28 | 23:12:49.73 | 46 58.81 | 118 32.98 | 2.37 | 2.5 | 27/27 | 199 | 0.32 | CD | E3 | P |
| | | | | **September 1987** | | | | | | | |
| 3 | 04:09:59.44 | 47 56.96 | 121 02.03 | 0.78$ | 2.1 | 30/35 | 109 | 0.46 | CD | C3 | |
| 3 | 18:59:40.97 | 49 20.77 | 120 32.13 | 3.99$ | 2.0 | 8/09 | 273 | 0.80 | DD | C3 | R |
| 4 | 06:14:51.71 | 46 51.56 | 121 45.62 | 2.10 | 2.1 | 33/39 | 43 | 0.24 | BC | C3 | |
| 4 | 23:15:47.92 | 44 48.93 | 119 41.08 | 12.57 | 2.4 | 23/23 | 235 | 0.40 | CD | O0 | |
| 8 | 05:02:15.66 | 45 11.47 | 120 04.32 | 13.01 | 3.1 | 37/37 | 140 | 0.51 | DC | O0 | F |
| 8 | 18:34:19.81 | 46 56.62 | 118 24.50 | 9.19 | 2.1 | 17/18 | 214 | 0.36 | CD | E3 | |
| 9 | 07:13:08.16 | 45 11.13 | 120 02.21 | 17.91 | 2.3 | 23/23 | 183 | 0.27 | BD | O0 | |
| 9 | 07:32:09.74 | 45 11.68 | 120 03.87 | 0.03* | 2.4 | 25/25 | 178 | 0.43 | CC | O0 | |
| 11 | 13:13:10.93 | 46 21.19 | 122 15.07 | 12.46 | 2.8 | 42/45 | 27 | 0.16 | BA | S3 | |
| 14 | 04:24:12.27 | 46 43.19 | 122 28.49 | 18.40* | 2.6 | 48/54 | 35 | 0.17 | BA | P3 | |
| 16 | 20:10:42.25 | 49 05.72 | 122 42.00 | 12.34 | 3.3 | 23/37 | 76 | 0.24 | BB | P3 | F |
| 18 | 18:50:30.38 | 49 05.56 | 122 41.65 | 3.57$ | 2.6 | 18/21 | 253 | 0.44 | DD | P3 | |
| 20 | 06:55:52.44 | 48 08.37 | 122 45.27 | 21.47 | 2.8 | 22/27 | 83 | 0.20 | BB | P3 | F |
| 20 | 08:53:13.20 | 48 03.38 | 122 57.11 | 55.42 | 2.8 | 29/34 | 85 | 0.23 | BA | P3 | |
| 25 | 06:54:32.24 | 47 50.11 | 122 27.18 | 16.78 | 2.1 | 24/29 | 47 | 0.17 | BA | P3 | |
| 27 | 14:18:24.14 | 47 43.79 | 120 02.70 | 2.68 | 2.0 | 20/24 | 98 | 0.24 | BB | N3 | |
| 27 | 16:17:33.32 | 48 24.82 | 120 44.63 | 5.23 | 2.0 | 9/10 | 187 | 0.09 | BD | C3 | |
| 28 | 17:16:50.56 | 48 15.52 | 119 30.67 | 0.03* | 2.1 | 13/15 | 195 | 0.35 | CD | N3 | |
| 29 | 16:20:26.48 | 45 10.57 | 120 03.67 | 20.09 | 2.7 | 24/25 | 181 | 0.35 | CD | O0 | F |
| | | | | **October 1987** | | | | | | | |
| 2 | 02:33:01.50 | 45 44.06 | 122 34.86 | 18.93 | 2.6 | 42/47 | 60 | 0.19 | BB | C3 | F |
| 5 | 22:08:37.94 | 47 23.48 | 121 44.38 | 2.50 | 2.1 | 25/29 | 97 | 0.31 | CB | P3 | |
| 5 | 22:20:12.63 | 47 04.25 | 120 05.48 | 0.71 | 2.6 | 32/32 | 57 | 0.32 | CC | N3 | |
| 7 | 00:11:13.90 | 46 20.58 | 119 15.38 | 0.02* | 2.0 | 13/16 | 158 | 0.21 | BC | E3 | |
| 11 | 20:38:45.41 | 45 10.77 | 120 04.88 | 3.25$ | 2.0 | 12/13 | 164 | 0.40 | CC | O0 | |
| 15 | 07:21:11.80 | 46 20.85 | 122 24.49 | 8.58 | 2.0 | 33/44 | 53 | 0.18 | BA | S3 | |
| 16 | 18:21:56.14 | 48 43.78 | 120 03.53 | 0.83$ | 2.1 | 14/16 | 212 | 0.36 | DD | N3 | |
| 18 | 11:21:37.79 | 46 52.07 | 121 43.92 | 0.04* | 2.0 | 22/27 | 58 | 0.17 | BB | C3 | |
| 19 | 20:44:43.92 | 46 50.66 | 118 17.55 | 0.03* | 2.3 | 26/26 | 176 | 0.32 | CD | E3 | P |
| 22 | 19:17:25.31 | 46 01.38 | 119 58.66 | 0.02* | 2.2 | 17/17 | 94 | 0.36 | CC | E3 | P |
| 26 | 19:36:52.16 | 46 01.20 | 119 58.11 | 0.02* | 2.2 | 19/19 | 94 | 0.27 | BC | E3 | P |
| 29 | 23:46:16.64 | 46 46.73 | 117 10.44 | 0.02* | 2.2 | 14/14 | 280 | 0.57 | DD | E3 | P |

**Table 1.1.** Washington Regional Seismograph Network earthquake catalog *(continued)*

| Day | Time | Latitude (N) | Longitude (W) | Depth | M | NS/NP | Gap | RMS | Q | Model | Type |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **November 1987** | | | | | | | |
| 3 | 04:09:16.80 | 47 15.32 | 119 54.85 | 5.79 | 2.0 | 17/19 | 96 | 0.30 | BC | N3 | |
| 5 | 17:12:04.92 | 47 58.95 | 121 22.78 | 3.62$ | 2.3 | 12/13 | 129 | 1.13 | DC | C3 | P |
| 5 | 18:22:28.84 | 48 08.68 | 120 52.22 | 0.99 | 2.0 | 18/19 | 147 | 0.38 | CC | C3 | |
| 6 | 00:39:03.12 | 44 39.53 | 121 09.46 | 0.10 | 2.5 | 12/13 | 89 | 0.33 | CC | O0 | P |
| 8 | 00:58:07.19 | 48 50.77 | 122 33.85 | 18.58 | 2.4 | 28/44 | 60 | 0.24 | BB | P3 | |
| 8 | 22:08:31.20 | 47 55.11 | 122 51.76 | 19.67 | 2.2 | 21/25 | 87 | 0.14 | AA | P3 | |
| 9 | 17:27:55.73 | 45 20.27 | 121 41.33 | 6.06 | 2.0 | 32/35 | 70 | 0.37 | CB | O0 | |
| 10 | 20:20:06.92 | 46 53.67 | 123 24.19 | 5.51 | 2.1 | 10/10 | 172 | 0.19 | BC | P3 | P |
| 11 | 21:55:29.96 | 45 34.65 | 121 34.38 | 2.21 | 2.0 | 23/23 | 55 | 0.36 | CC | C3 | P |
| 12 | 08:35:10.37 | 46 11.97 | 122 11.04 | 5.24 | 2.1 | 16/16 | 74 | 0.07 | AA | S3 | |
| 17 | 22:58:18.27 | 46 59.28 | 117 24.51 | 40.65$ | 2.4 | 9/09 | 267 | 0.27 | CD | E3 | P |
| 18 | 12:42:24.63 | 45 12.16 | 120 05.28 | 0.02* | 2.3 | 31/31 | 162 | 0.53 | DC | O0 | |
| 20 | 21:45:33.29 | 46 52.16 | 117 28.06 | 3.20# | 2.2 | 13/14 | 268 | 0.78 | DD | E3 | |
| 25 | 22:08:48.43 | 46 57.80 | 120 24.79 | 2.69 | 2.1 | 29/30 | 46 | 0.34 | CC | E3 | |
| 25 | 23:13:22.72 | 46 05.76 | 122 42.05 | 17.89 | 2.0 | 33/36 | 82 | 0.15 | BA | C3 | |
| 29 | 02:19:49.91 | 46 21.85 | 122 14.35 | 8.59 | 2.6 | 43/53 | 43 | 0.25 | BA | S3 | |
| 29 | 04:52:33.47 | 47 41.28 | 120 12.23 | 0.71 | 2.0 | 19/22 | 128 | 0.19 | BC | N3 | |
| | | | | **December 1987** | | | | | | | |
| 1 | 00:41:09.15 | 48 10.17 | 120 52.98 | 8.66$ | 2.0 | 20/21 | 176 | 0.68 | DD | C3 | |
| 2 | 07:12:57.46 | 46 40.49 | 120 41.03 | 18.20 | 4.1 | 37/40 | 40 | 0.26 | BA | E3 | F |
| 2 | 09:02:24.27 | 46 40.75 | 120 40.39 | 17.80 | 4.3 | 38/39 | 35 | 0.37 | CA | E3 | F |
| 4 | 01:48:02.08 | 46 45.25 | 119 22.78 | 0.03* | 2.2 | 27/32 | 59 | 0.24 | BB | E3 | |
| 11 | 20:50:12.31 | 47 35.55 | 123 03.10 | 44.14 | 2.1 | 25/29 | 64 | 0.22 | BA | P3 | |
| 13 | 05:55:45.85 | 45 59.46 | 118 22.10 | 2.52 | 2.1 | 16/17 | 182 | 0.25 | BD | E3 | |
| 14 | 18:26:52.05 | 46 01.24 | 119 57.77 | 0.03* | 2.0 | 15/15 | 93 | 0.25 | BC | E3 | P |
| 15 | 17:22:21.94 | 45 39.38 | 121 57.83 | 0.03* | 2.0 | 28/28 | 69 | 0.26 | BC | C3 | P |
| 16 | 13:10:58.77 | 46 37.74 | 124 20.38 | 30.97 | 2.3 | 14/16 | 252 | 0.29 | CD | P3 | |
| 19 | 20:30:17.85 | 48 27.67 | 123 22.50 | 23.89 | 2.7 | 27/38 | 51 | 0.26 | BA | P3 | F |
| 20 | 07:38:25.13 | 47 46.56 | 119 22.02 | 0.03* | 2.7 | 19/21 | 84 | 0.31 | CB | N3 | F |
| 21 | 23:23:41.20 | 46 37.05 | 118 52.76 | 1.76 | 2.0 | 28/30 | 197 | 0.23 | BD | E3 | |
| 26 | 16:35:18.36 | 46 44.43 | 119 22.15 | 1.72 | 2.1 | 23/28 | 53 | 0.25 | BB | E3 | |
| 30 | 22:08:24.57 | 46 42.90 | 119 22.48 | 1.38 | 2.2 | 23/26 | 61 | 0.21 | BC | E3 | |
| | | | | **January 1988** | | | | | | | |
| 8 | 07:18:37.94 | 47 03.93 | 122 08.86 | 0.02* | 2.7 | 44/49 | 29 | 0.25 | BB | P3 | F |
| 9 | 02:17:57.34 | 47 04.08 | 122 09.86 | 6.90 | 2.2 | 35/38 | 48 | 0.16 | BB | P3 | |
| 9 | 02:51:54.53 | 47 03.33 | 122 08.23 | 0.90 | 2.0 | 34/38 | 51 | 0.29 | BC | P3 | |
| 9 | 20:29:17.08 | 45 39.33 | 121 56.54 | 4.00 | 2.0 | 33/33 | 49 | 0.23 | BC | C3 | |
| 11 | 05:51:59.93 | 47 04.27 | 122 09.84 | 5.53 | 2.2 | 27/31 | 48 | 0.13 | AB | P3 | |
| 11 | 10:18:13.51 | 47 46.92 | 119 21.70 | 0.65 | 2.3 | 13/18 | 86 | 0.31 | CB | N3 | |
| 14 | 09:37:54.24 | 44 38.28 | 121 20.18 | 20.74 | 2.4 | 10/10 | 210 | 0.36 | CD | O0 | |
| 14 | 23:13:09.60 | 46 37.28 | 118 54.41 | 2.26 | 2.1 | 25/26 | 192 | 0.19 | BD | E3 | |
| 15 | 07:33:47.03 | 46 50.77 | 121 45.04 | 2.70* | 2.7 | 40/45 | 30 | 0.23 | BC | C3 | |
| 15 | 07:47:19.83 | 46 45.14 | 119 21.18 | 0.02* | 2.4 | 22/27 | 61 | 0.17 | BC | E3 | |
| 17 | 22:44:29.64 | 46 44.79 | 119 21.01 | 0.62 | 2.6 | 29/32 | 58 | 0.17 | BB | E3 | |
| 18 | 20:28:25.77 | 46 44.66 | 119 21.09 | 0.04* | 2.0 | 27/31 | 56 | 0.23 | BB | E3 | |
| 22 | 10:41:11.51 | 46 13.31 | 119 53.58 | 12.36 | 2.1 | 26/28 | 83 | 0.20 | BB | E3 | |
| 22 | 22:16:47.22 | 47 09.19 | 118 37.00 | 5.67 | 2.0 | 17/17 | 191 | 0.31 | CD | N3 | P |
| 24 | 20:52:25.34 | 47 43.13 | 120 17.30 | 3.53$ | 2.1 | 31/36 | 57 | 0.39 | CC | N3 | |
| 25 | 21:11:43.44 | 46 13.75 | 119 43.65 | 0.04* | 2.1 | 21/22 | 66 | 0.21 | BA | E3 | |
| 26 | 08:13:38.01 | 47 24.85 | 121 48.94 | 19.69 | 2.9 | 47/53 | 45 | 0.27 | BA | P3 | F |
| 31 | 05:53:33.65 | 49 02.67 | 123 36.83 | 52.40 | 2.0 | 18/26 | 47 | 0.24 | BA | P3 | |
| 31 | 16:17:41.75 | 45 39.05 | 121 57.56 | 0.03* | 2.1 | 26/26 | 64 | 0.23 | BC | C3 | P |
| | | | | **February 1988** | | | | | | | |
| 1 | 15:00:09.08 | 47 50.35 | 121 59.55 | 24.06 | 2.3 | 22/26 | 50 | 0.25 | BA | P3 | |
| 2 | 05:49:56.11 | 46 44.51 | 119 23.77 | 0.51 | 2.9 | 32/35 | 53 | 0.24 | BA | E3 | |
| 2 | 17:27:04.36 | 46 44.44 | 119 23.90 | 0.02* | 2.1 | 25/31 | 53 | 0.26 | BA | E3 | |
| 3 | 19:45:40.43 | 46 44.46 | 119 23.83 | 2.33 | 2.9 | 27/31 | 52 | 0.17 | BA | E3 | |
| 3 | 23:19:39.06 | 46 13.38 | 119 44.04 | 0.02* | 2.5 | 16/18 | 75 | 0.23 | BA | E3 | P |
| 6 | 04:30:39.79 | 46 44.56 | 119 23.78 | 0.03* | 2.1 | 24/29 | 54 | 0.24 | BA | E3 | |
| 6 | 12:51:44.81 | 47 39.98 | 120 01.42 | 7.15 | 3.0 | 32/36 | 32 | 0.26 | BA | N3 | F |
| 6 | 23:05:14.77 | 47 23.22 | 121 46.70 | 18.01 | 2.2 | 38/43 | 72 | 0.13 | AA | P3 | |
| 7 | 22:15:27.61 | 45 21.36 | 119 37.30 | 21.16 | 2.5 | 19/19 | 232 | 0.20 | BD | O0 | P |
| 9 | 15:08:54.99 | 45 50.19 | 120 50.00 | 7.84 | 2.1 | 26/28 | 69 | 0.21 | BB | C3 | |
| 10 | 21:58:42.52 | 46 37.64 | 118 54.26 | 2.38 | 2.3 | 28/29 | 155 | 0.20 | BC | E3 | |

**Table 1.1.** Washington Regional Seismograph Network earthquake catalog *(continued)*

| Day | Time | Latitude (N) | Longitude (W) | Depth | M | NS/NP | Gap | RMS | Q | Model | Type |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **February 1988 cont'd** | | | | | | | |
| 14 | 02:55:23.83 | 45 34.62 | 120 08.96 | 16.58 | 2.5 | 28/28 | 143 | 0.23 | BC | E3 | |
| 20 | 10:18:20.57 | 45 13.02 | 120 07.02 | 2.42$ | 2.1 | 31/33 | 166 | 0.56 | DC | O0 | |
| 20 | 23:55:47.60 | 45 12.98 | 120 06.34 | 14.11* | 2.7 | 52/54 | 143 | 0.44 | CC | O0 | |
| 24 | 12:43:00.64 | 47 02.16 | 119 25.47 | 0.04* | 2.3 | 30/33 | 49 | 0.48 | CC | N3 | |
| 25 | 21:44:02.35 | 46 31.30 | 121 23.43 | 0.02* | 2.2 | 38/41 | 83 | 0.25 | BC | C3 | |
| 26 | 20:13:41.71 | 46 05.32 | 118 46.12 | 0.96 | 2.1 | 18/18 | 122 | 0.19 | BB | E3 | P |
| 26 | 23:53:29.51 | 46 59.31 | 119 14.68 | 2.50* | 2.1 | 23/23 | 61 | 0.14 | AB | E3 | P |
| 27 | 22:12:32.75 | 44 22.01 | 121 02.62 | 1.95* | 2.1 | 8/08 | 120 | 0.13 | AC | O0 | P |
| 28 | 05:55:31.76 | 48 58.05 | 122 56.04 | 7.38$ | 2.2 | 24/36 | 46 | 0.36 | CC | P3 | |
| 28 | 20:47:11.17 | 45 34.27 | 119 53.08 | 0.04* | 2.6 | 21/21 | 144 | 0.18 | BC | E3 | P |
| | | | | **March 1988** | | | | | | | |
| 2 | 11:51:06.43 | 47 11.92 | 122 32.81 | 54.41 | 2.4 | 36/41 | 42 | 0.14 | AA | P3 | |
| 5 | 23:41:09.90 | 46 33.09 | 121 45.87 | 9.65 | 2.3 | 39/47 | 45 | 0.36 | CB | C3 | |
| 8 | 01:28:40.57 | 46 31.17 | 118 35.57 | 5.40 | 2.1 | 29/32 | 150 | 0.37 | CC | E3 | P |
| 10 | 22:27:38.08 | 47 03.13 | 119 54.98 | 0.04* | 2.2 | 25/26 | 62 | 0.39 | CC | N3 | P |
| 11 | 10:01:26.04 | 47 11.44 | 122 19.33 | 64.72 | 3.9 | 41/48 | 35 | 0.16 | BA | P3 | F |
| 12 | 11:53:54.40 | 48 13.94 | 121 39.83 | 3.00$ | 2.5 | 26/34 | 74 | 0.44 | CC | P3 | F |
| 13 | 16:49:14.05 | 47 50.65 | 122 04.37 | 22.70 | 2.0 | 19/23 | 69 | 0.11 | AA | P3 | |
| 15 | 00:59:17.97 | 47 48.42 | 120 50.78 | 10.30 | 2.5 | 21/25 | 87 | 0.39 | CC | C3 | |
| 17 | 20:36:24.54 | 46 07.94 | 119 46.98 | 0.03* | 2.6 | 25/25 | 105 | 0.25 | BC | E3 | P |
| 17 | 20:50:06.74 | 47 03.15 | 119 54.14 | 0.02* | 2.5 | 27/30 | 49 | 0.33 | CC | N3 | P |
| 18 | 07:40:57.54 | 46 21.01 | 119 15.95 | 0.60 | 2.6 | 26/29 | 77 | 0.28 | BB | E3 | |
| 18 | 08:24:43.40 | 46 21.03 | 119 16.09 | 0.05* | 2.5 | 24/26 | 86 | 0.33 | CB | E3 | |
| 18 | 19:55:01.13 | 46 54.10 | 120 44.09 | 9.12 | 2.1 | 23/26 | 40 | 0.43 | CB | C3 | |
| 20 | 23:10:04.85 | 47 41.64 | 122 17.04 | 19.49 | 2.0 | 24/27 | 42 | 0.10 | AA | P3 | |
| 25 | 17:06:46.36 | 48 54.93 | 121 55.29 | 0.03* | 2.0 | 12/14 | 197 | 0.17 | BD | P3 | |
| 25 | 22:46:52.30 | 46 55.04 | 119 05.53 | 1.85* | 2.1 | 27/30 | 120 | 0.18 | BB | E3 | |
| 29 | 22:44:05.90 | 44 49.66 | 118 01.77 | 18.32# | 2.7 | 17/21 | 269 | 0.98 | DD | O0 | |
| | | | | **April 1988** | | | | | | | |
| 1 | 22:05:50.91 | 46 54.95 | 119 06.40 | 3.09 | 2.6 | 30/34 | 118 | 0.19 | BB | E3 | |
| 4 | 02:47:35.78 | 48 29.63 | 122 07.95 | 2.29 | 2.9 | 22/31 | 68 | 0.29 | BB | P3 | F |
| 6 | 23:44:00.08 | 47 23.04 | 118 17.60 | 45.93 | 2.0 | 11/13 | 257 | 0.44 | CD | N3 | |
| 7 | 23:25:18.81 | 47 02.62 | 119 56.34 | 0.03* | 2.6 | 24/24 | 83 | 0.38 | CC | N3 | |
| 8 | 15:31:06.06 | 47 22.77 | 122 39.97 | 21.80 | 2.8 | 39/43 | 53 | 0.20 | BA | P3 | |
| 12 | 02:06:39.55 | 45 57.54 | 122 07.19 | 4.67 | 3.0 | 29/32 | 64 | 0.14 | AC | C3 | |
| 12 | 23:59:17.68 | 47 16.24 | 118 32.62 | 24.10 | 2.4 | 5/05 | 190 | 0.43 | DD | N3 | P |
| 18 | 21:06:41.54 | 45 53.81 | 119 17.40 | 24.08$ | 2.1 | 13/13 | 157 | 0.28 | CC | E3 | P |
| 22 | 09:42:11.12 | 47 51.35 | 119 55.82 | 0.68 | 2.9 | 21/28 | 90 | 0.29 | BC | N3 | |
| | | | | **May 1988** | | | | | | | |
| 2 | 16:21:21.79 | 47 46.80 | 119 21.85 | 0.02* | 2.6 | 21/25 | 85 | 0.30 | BB | N3 | |
| 4 | 22:36:41.79 | 47 50.15 | 121 36.13 | 0.03* | 2.0 | 13/15 | 137 | 0.51 | DC | P3 | P |
| 5 | 00:18:13.45 | 47 39.07 | 120 19.27 | 6.72 | 3.3 | 33/38 | 49 | 0.32 | CA | N3 | F |
| 11 | 18:34:01.97 | 48 35.92 | 121 58.75 | 0.04* | 2.0 | 11/13 | 99 | 0.41 | CC | P3 | |
| 12 | 15:16:57.77 | 46 44.19 | 120 51.09 | 8.15 | 2.4 | 33/36 | 54 | 0.34 | CA | C3 | |
| 13 | 18:19:49.74 | 46 48.35 | 119 25.48 | 0.02* | 2.2 | 22/26 | 62 | 0.37 | CA | E3 | |
| 15 | 04:22:14.84 | 45 22.50 | 121 42.41 | 6.65 | 2.5 | 50/51 | 100 | 0.36 | CB | O0 | |
| 27 | 06:12:58.66 | 47 17.42 | 122 39.34 | 20.99 | 2.5 | 47/56 | 32 | 0.36 | CA | P3 | |
| 27 | 17:04:36.72 | 45 07.73 | 120 03.45 | 21.86 | 2.4 | 21/22 | 232 | 0.58 | DD | O0 | P |
| 28 | 00:34:05.47 | 47 47.59 | 119 41.61 | 19.26 | 2.5 | 21/24 | 74 | 0.44 | CB | N3 | |
| 28 | 09:02:43.96 | 46 48.63 | 119 25.68 | 0.02* | 3.5 | 28/32 | 54 | 0.24 | BA | E3 | |
| 29 | 16:09:35.34 | 47 46.48 | 121 50.13 | 13.85 | 2.2 | 28/33 | 39 | 0.16 | BA | P3 | |
| 31 | 14:09:28.63 | 46 48.62 | 119 25.83 | 0.03* | 2.9 | 29/29 | 52 | 0.26 | BA | E3 | |
| 31 | 14:11:31.34 | 46 48.44 | 119 25.81 | 0.03* | 2.2 | 20/25 | 56 | 0.12 | AA | E3 | |
| 31 | 19:23:57.84 | 46 48.64 | 119 25.89 | 0.02* | 2.4 | 24/27 | 51 | 0.31 | CA | E3 | |
| | | | | **June 1988** | | | | | | | |
| 4 | 01:02:31.04 | 46 37.77 | 123 19.29 | 5.51$ | 2.1 | 20/20 | 119 | 0.12 | AC | P3 | P |
| 5 | 06:20:04.74 | 46 51.54 | 119 20.87 | 12.96 | 2.0 | 15/20 | 145 | 0.17 | BC | E3 | |
| 7 | 01:41:10.61 | 47 26.17 | 122 47.17 | 21.93 | 2.2 | 32/36 | 66 | 0.15 | BA | P3 | |
| 9 | 19:19:02.19 | 45 12.50 | 120 05.93 | 0.05* | 2.0 | 9/10 | 171 | 0.36 | CC | C3 | P |
| 10 | 03:26:54.62 | 46 04.62 | 118 46.23 | 1.25 | 2.0 | 16/17 | 120 | 0.31 | CB | E3 | P |
| 11 | 01:17:38.77 | 46 31.84 | 120 48.84 | 0.68$ | 2.3 | 24/25 | 41 | 0.43 | CC | C3 | |
| 13 | 19:07:21.08 | 46 30.63 | 122 19.83 | 0.05* | 2.2 | 22/23 | 59 | 0.25 | BC | C3 | P |
| 16 | 11:05:04.79 | 47 42.43 | 121 53.84 | 7.51 | 3.1 | 35/47 | 32 | 0.29 | BB | P3 | F |
| 16 | 18:05:51.13 | 46 04.68 | 118 45.82 | 1.58 | 2.1 | 13/15 | 138 | 0.15 | AC | E3 | P |

**Table 1.1.** Washington Regional Seismograph Network earthquake catalog *(continued)*

| Day | Time | Latitude (N) | Longitude (W) | Depth | M | NS/NP | Gap | RMS | Q | Model | Type |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **June 1988 cont'd** | | | | | | | |
| 20 | 18:57:54.04 | 47 40.78 | 121 55.88 | 0.15* | 2.2 | 20/22 | 55 | 0.18 | BC | P3 | |
| 24 | 12:17:32.62 | 47 32.09 | 119 21.14 | 0.05* | 2.4 | 24/26 | 52 | 0.49 | CC | N3 | |
| 25 | 11:33:56.03 | 46 55.47 | 120 36.46 | 1.99 | 2.7 | 28/28 | 61 | 0.48 | CA | E3 | |
| 30 | 04:28:02.27 | 47 50.43 | 119 22.48 | 0.71 | 2.3 | 17/21 | 103 | 0.32 | CC | N3 | |
| 30 | 16:58:31.96 | 46 19.69 | 119 52.59 | 0.04* | 2.0 | 18/20 | 109 | 0.32 | CC | E3 | P |
| 30 | 21:51:17.12 | 46 21.76 | 122 31.21 | 1.80 | 2.3 | 23/23 | 125 | 0.18 | BB | C3 | P |
| 30 | 22:49:25.46 | 48 14.11 | 121 39.54 | 3.08$ | 2.2 | 20/25 | 75 | 0.33 | CC | P3 | |
| | | | | **July 1988** | | | | | | | |
| 1 | 03:19:19.15 | 48 14.39 | 121 39.83 | 1.92$ | 2.3 | 13/17 | 89 | 0.38 | CC | P3 | |
| 1 | 10:08:58.80 | 45 15.09 | 120 07.00 | 0.03* | 2.1 | 18/19 | 162 | 0.39 | CC | C3 | |
| 3 | 08:15:00.72 | 45 15.38 | 120 08.10 | 0.02* | 2.4 | 20/21 | 131 | 0.38 | CC | C3 | |
| 3 | 12:01:49.59 | 49 11.81 | 120 00.73 | 0.03* | 2.4 | 13/15 | 231 | 0.19 | BD | P1 | |
| 4 | 18:10:31.04 | 45 14.70 | 120 06.06 | 7.76 | 2.0 | 14/15 | 165 | 0.35 | CC | C3 | |
| 4 | 19:33:42.78 | 47 22.69 | 122 42.88 | 23.62* | 2.1 | 33/38 | 57 | 0.14 | AA | P3 | |
| 6 | 00:51:21.34 | 47 26.03 | 121 49.78 | 18.38 | 2.1 | 26/30 | 74 | 0.18 | BA | P3 | |
| 8 | 04:03:01.52 | 48 05.09 | 121 31.88 | 0.03* | 3.2 | 33/35 | 109 | 0.43 | CC | C3 | F |
| 8 | 22:10:03.43 | 47 31.87 | 119 20.31 | 0.76 | 2.1 | 27/28 | 53 | 0.39 | CC | N3 | P |
| 9 | 01:18:10.90 | 46 50.52 | 119 42.61 | 3.81 | 3.7 | 35/37 | 36 | 0.26 | BC | E3 | |
| 9 | 05:35:14.53 | 46 50.56 | 119 42.97 | 2.43 | 2.6 | 32/36 | 36 | 0.21 | BC | E3 | |
| 9 | 10:37:03.18 | 45 15.03 | 120 06.25 | 2.34$ | 2.4 | 17/18 | 142 | 0.34 | CC | C3 | |
| 10 | 08:46:58.18 | 46 12.47 | 122 12.05 | 0.50 | 2.0 | 10/10 | 86 | 0.05 | AA | S3 | |
| 10 | 08:54:37.24 | 48 53.82 | 123 33.24 | 54.99 | 2.6 | 29/41 | 41 | 0.32 | CA | P3 | |
| 11 | 01:50:19.11 | 45 14.68 | 120 08.53 | 0.03* | 2.9 | 21/22 | 132 | 0.40 | CC | O0 | |
| 11 | 03:17:46.01 | 45 15.21 | 120 07.84 | 0.04* | 2.3 | 14/14 | 160 | 0.26 | BC | C3 | |
| 11 | 08:45:45.89 | 45 15.08 | 120 07.44 | 0.04* | 2.0 | 8/08 | 210 | 0.36 | CD | C3 | |
| 14 | 12:45:33.46 | 46 53.29 | 119 24.80 | 1.79 | 3.3 | 26/26 | 76 | 0.17 | BB | E3 | |
| 14 | 17:02:12.26 | 48 19.09 | 122 05.87 | 12.37 | 3.1 | 25/32 | 55 | 0.23 | BB | P3 | F |
| 15 | 06:13:24.26 | 47 46.27 | 121 56.64 | 25.22 | 2.0 | 21/26 | 51 | 0.17 | BA | P3 | |
| 18 | 22:01:32.87 | 45 16.90 | 119 40.38 | 0.02* | 2.2 | 17/17 | 152 | 0.29 | BD | C3 | |
| 21 | 20:58:47.08 | 47 48.47 | 122 21.68 | 22.01 | 2.3 | 22/29 | 44 | 0.16 | BA | P3 | |
| 23 | 22:51:11.13 | 45 15.61 | 120 07.97 | 0.03* | 2.6 | 25/25 | 131 | 0.35 | CC | C3 | |
| 24 | 06:35:09.28 | 46 51.09 | 121 44.64 | 0.02* | 2.2 | 31/34 | 42 | 0.23 | BC | C3 | |
| 29 | 04:59:47.27 | 46 51.27 | 121 54.82 | 11.83 | 4.1 | 43/43 | 42 | 0.15 | AA | C3 | F |
| 29 | 05:21:35.44 | 46 50.98 | 121 54.25 | 9.69 | 2.0 | 29/37 | 51 | 0.18 | BB | C3 | |
| 29 | 06:00:08.70 | 46 51.04 | 121 55.07 | 10.80 | 3.8 | 46/46 | 41 | 0.16 | BB | C3 | F |
| 30 | 01:08:24.15 | 45 21.38 | 121 39.54 | 0.02* | 2.3 | 7/09 | 102 | 0.28 | BC | C3 | P |
| 30 | 16:13:57.88 | 47 38.98 | 120 04.45 | 0.02* | 3.2 | 33/37 | 30 | 0.37 | CC | N3 | |
| 30 | 19:07:32.20 | 46 21.47 | 122 32.27 | 5.45 | 2.0 | 29/29 | 57 | 0.15 | AB | C3 | P |
| | | | | **August 1988** | | | | | | | |
| 1 | 20:13:26.39 | 46 21.87 | 122 32.58 | 4.55 | 2.0 | 32/32 | 50 | 0.16 | BB | C3 | P |
| 3 | 07:39:43.94 | 47 37.60 | 121 16.99 | 0.60$ | 2.2 | 40/43 | 65 | 0.54 | DC | C3 | |
| 4 | 14:08:09.57 | 46 50.42 | 121 55.94 | 7.34 | 2.1 | 32/39 | 57 | 0.13 | AB | C3 | |
| 4 | 20:48:20.09 | 46 21.99 | 122 32.62 | 3.55 | 2.1 | 29/30 | 50 | 0.15 | BB | C3 | P |
| 6 | 23:43:46.96 | 45 26.10 | 119 52.94 | 0.03* | 2.5 | 29/30 | 129 | 0.33 | CD | C3 | |
| 11 | 20:20:21.04 | 45 12.23 | 121 33.05 | 0.02* | 2.2 | 11/11 | 172 | 0.31 | CC | O0 | P |
| 12 | 12:11:54.32 | 46 50.66 | 121 55.23 | 10.89 | 3.0 | 42/52 | 41 | 0.15 | BB | C3 | |
| 12 | 17:38:23.65 | 46 14.46 | 122 00.00 | 0.13 | 2.0 | 34/42 | 49 | 0.16 | BC | S3 | P |
| 12 | 20:55:39.65 | 47 19.47 | 121 55.99 | 0.04* | 2.1 | 9/09 | 109 | 0.17 | BC | P3 | P |
| 12 | 21:25:21.61 | 44 58.73 | 123 47.22 | 54.24 | 2.0 | 14/17 | 291 | 0.32 | CD | O0 | |
| 15 | 00:04:07.66 | 46 04.59 | 119 55.64 | 0.03* | 2.4 | 29/29 | 49 | 0.27 | BC | E3 | |
| 15 | 13:57:15.02 | 47 42.08 | 122 06.20 | 13.03 | 2.6 | 34/37 | 44 | 0.28 | BB | P3 | |
| 15 | 22:40:27.33 | 46 51.57 | 121 56.03 | 10.69 | 2.4 | 30/39 | 50 | 0.20 | BA | C3 | |
| 16 | 18:32:20.65 | 47 25.68 | 121 51.66 | 19.00 | 2.6 | 40/47 | 37 | 0.32 | CA | P3 | |
| 16 | 20:06:49.24 | 46 21.68 | 122 32.50 | 4.29 | 2.1 | 26/28 | 56 | 0.21 | BB | C3 | P |
| 17 | 16:09:57.29 | 46 02.89 | 122 16.85 | 0.98 | 2.0 | 12/12 | 197 | 0.07 | AD | S3 | P |
| 17 | 17:38:37.18 | 46 45.97 | 123 28.31 | 0.32* | 2.4 | 9/09 | 148 | 0.44 | CC | P3 | P |
| 18 | 08:27:45.71 | 45 13.44 | 120 05.97 | 0.02* | 2.7 | 25/25 | 144 | 0.40 | CC | O0 | |
| 18 | 17:47:37.97 | 47 19.01 | 121 57.61 | 0.04* | 2.1 | 6/06 | 215 | 0.35 | CD | P3 | P |
| 19 | 01:43:10.31 | 46 11.45 | 122 00.04 | 1.39* | 2.3 | 29/32 | 62 | 0.17 | BB | S3 | P |
| 19 | 20:14:24.10 | 45 12.87 | 121 33.17 | 0.03* | 2.5 | 15/15 | 74 | 0.19 | BC | O0 | P |
| 19 | 20:38:59.14 | 47 19.06 | 121 57.13 | 0.12 | 2.1 | 4/04 | 213 | 0.00 | AD | P3 | P |
| 20 | 20:44:10.40 | 46 11.36 | 122 00.22 | 1.81* | 2.7 | 28/29 | 61 | 0.13 | AB | S3 | P |
| 20 | 23:28:21.04 | 47 43.25 | 122 13.77 | 14.32 | 2.3 | 28/31 | 37 | 0.21 | BA | P3 | |
| 24 | 23:18:16.91 | 46 13.57 | 121 31.09 | 0.03* | 2.5 | 33/33 | 42 | 0.33 | CC | C3 | P |
| 24 | 23:57:52.81 | 45 20.72 | 121 40.19 | 3.30 | 2.0 | 5/05 | 103 | 0.32 | CD | O0 | P |
| 26 | 00:50:42.18 | 46 04.23 | 118 46.14 | 3.27 | 2.8 | 21/22 | 119 | 0.17 | BB | E3 | |

**Table 1.1.** Washington Regional Seismograph Network earthquake catalog *(continued)*

| Day | Time | Latitude (N) | Longitude (W) | Depth | M | NS/NP | Gap | RMS | Q | Model | Type |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **August 1988 cont'd** | | | | | | | |
| 26 | 01:18:17.65 | 46 19.34 | 122 27.56 | 1.17 | 2.3 | 23/29 | 78 | 0.12 | AB | S3 | P |
| 30 | 07:02:34.36 | 47 39.76 | 122 11.92 | 0.04* | 2.2 | 22/24 | 72 | 0.17 | BB | P3 | |
| 30 | 11:52:32.64 | 46 56.40 | 120 36.04 | 2.54 | 2.8 | 35/38 | 43 | 0.44 | CA | E3 | |
| 31 | 22:32:57.11 | 48 11.35 | 121 32.55 | 0.02* | 2.2 | 14/16 | 121 | 0.26 | BC | C3 | P |
| | | | | **September 1988** | | | | | | | |
| 1 | 17:55:15.41 | 48 24.71 | 117 42.35 | 5.10$ | 2.1 | 8/08 | 312 | 0.23 | DD | N3 | |
| 7 | 10:50:16.12 | 48 28.46 | 122 51.43 | 27.66 | 2.9 | 36/42 | 29 | 0.38 | CA | P3 | |
| 7 | 15:50:49.04 | 45 28.83 | 122 48.69 | 26.73 | 2.2 | 24/26 | 207 | 0.16 | BD | O0 | |
| 8 | 13:47:13.35 | 48 12.42 | 122 29.94 | 23.12 | 2.8 | 30/40 | 37 | 0.24 | BA | P3 | F |
| 8 | 19:01:46.85 | 46 15.23 | 122 03.10 | 11.43 | 2.1 | 30/38 | 63 | 0.11 | AA | S3 | |
| 8 | 22:56:21.14 | 47 30.48 | 118 50.86 | 2.62 | 2.1 | 16/17 | 110 | 0.27 | BC | N3 | |
| 12 | 10:53:36.97 | 47 41.71 | 120 07.49 | 5.91 | 2.1 | 14/17 | 69 | 0.19 | BC | N3 | |
| 13 | 16:25:03.17 | 47 26.09 | 121 49.04 | 18.40 | 2.4 | 29/40 | 89 | 0.17 | BA | P3 | |
| 14 | 14:44:52.15 | 46 19.42 | 122 24.86 | 1.87 | 2.1 | 32/33 | 65 | 0.20 | BB | S3 | P |
| 15 | 06:18:41.93 | 48 28.00 | 123 28.22 | 16.21 | 2.3 | 32/39 | 42 | 0.40 | CA | P3 | F |
| 15 | 20:28:17.84 | 46 07.33 | 119 46.95 | 0.02* | 2.4 | 26/28 | 72 | 0.30 | BC | E3 | P |
| 15 | 20:41:30.94 | 47 19.35 | 121 55.02 | 0.04* | 2.0 | 15/15 | 78 | 0.42 | CC | P3 | P |
| 16 | 20:37:30.91 | 48 18.52 | 117 25.14 | 0.04* | 2.1 | 7/08 | 322 | 0.71 | DD | N3 | |
| 18 | 18:47:48.49 | 47 32.02 | 123 56.76 | 37.10 | 2.8 | 28/32 | 151 | 0.32 | CC | P3 | |
| 22 | 03:00:51.68 | 45 12.77 | 121 33.10 | 0.03* | 2.6 | 21/22 | 74 | 0.26 | BC | O0 | P |
| 23 | 13:35:06.37 | 47 31.27 | 123 39.28 | 33.84 | 2.0 | 24/28 | 113 | 0.29 | BB | P3 | |
| 24 | 16:46:45.43 | 48 31.29 | 122 32.15 | 17.61 | 2.0 | 20/27 | 38 | 0.17 | BB | P3 | |
| 26 | 00:28:09.88 | 48 31.55 | 122 32.21 | 15.88 | 3.1 | 30/39 | 37 | 0.40 | CB | P3 | F |
| 27 | 22:30:13.57 | 44 39.15 | 121 10.20 | 0.39 | 2.3 | 14/15 | 65 | 0.33 | CC | O0 | P |
| 29 | 08:09:19.55 | 45 50.99 | 120 15.58 | 13.89 | 3.5 | 54/57 | 53 | 0.36 | CC | E3 | |
| 29 | 20:43:44.09 | 45 35.35 | 121 33.46 | 0.05* | 2.2 | 26/26 | 53 | 0.43 | CC | C3 | P |
| | | | | **October 1988** | | | | | | | |
| 1 | 18:17:34.89 | 46 08.41 | 122 10.31 | 2.00 | 2.3 | 29/33 | 52 | 0.14 | AA | S3 | |
| 6 | 19:56:01.10 | 48 16.20 | 117 27.08 | 0.02* | 2.5 | 9/11 | 321 | 0.51 | DD | N3 | |
| 8 | 23:40:08.52 | 46 21.90 | 122 32.42 | 2.96 | 2.0 | 31/31 | 69 | 0.16 | BB | C3 | P |
| 10 | 12:17:47.85 | 47 39.74 | 122 11.15 | 0.02* | 2.1 | 26/30 | 51 | 0.18 | BB | P3 | |
| 10 | 15:12:37.01 | 46 48.54 | 119 25.26 | 0.04* | 2.2 | 21/22 | 62 | 0.26 | BA | E3 | |
| 15 | 17:29:45.00 | 46 11.80 | 122 11.64 | 1.50 | 2.4 | 9/09 | 85 | 0.24 | BA | S3 | |
| 17 | 00:47:28.49 | 47 15.20 | 121 20.92 | 3.17 | 2.1 | 44/46 | 60 | 0.28 | BC | C3 | |
| 19 | 22:54:58.14 | 45 08.38 | 119 08.32 | 19.85 | 2.6 | 29/30 | 199 | 0.45 | CD | O0 | |
| 23 | 00:40:19.97 | 47 49.04 | 122 21.76 | 19.23 | 2.8 | 31/32 | 45 | 0.14 | AA | P3 | |
| 25 | 07:13:02.03 | 48 24.27 | 122 22.70 | 6.55* | 2.8 | 26/32 | 48 | 0.24 | BC | P3 | F |
| 25 | 07:16:11.37 | 48 24.01 | 122 23.15 | 6.67 | 2.3 | 27/32 | 42 | 0.32 | CC | P3 | |
| 26 | 11:36:51.74 | 45 51.68 | 120 15.89 | 13.59 | 2.0 | 26/29 | 139 | 0.32 | CC | E3 | |
| 28 | 06:15:43.44 | 48 06.34 | 122 37.88 | 54.14 | 2.4 | 34/42 | 38 | 0.34 | CA | P3 | |
| 29 | 08:47:04.81 | 47 37.96 | 122 50.09 | 47.12 | 2.9 | 37/41 | 33 | 0.35 | CA | P3 | |
| | | | | **November 1988** | | | | | | | |
| 3 | 17:13:19.95 | 47 26.01 | 121 51.58 | 19.46 | 2.0 | 25/32 | 69 | 0.26 | BA | P3 | |
| 4 | 21:52:11.91 | 45 45.25 | 123 23.20 | 30.06 | 2.0 | 21/23 | 141 | 0.24 | BC | P3 | |
| 5 | 15:17:20.49 | 46 23.48 | 119 16.24 | 0.05* | 2.2 | 21/24 | 78 | 0.21 | BA | E3 | |
| 6 | 23:07:24.43 | 45 06.28 | 122 43.32 | 26.14 | 2.5 | 34/36 | 168 | 0.27 | BC | O0 | |
| 8 | 22:07:04.52 | 46 19.54 | 122 14.00 | 9.87 | 2.2 | 36/46 | 49 | 0.17 | BA | S3 | |
| 19 | 12:11:17.51 | 47 54.97 | 120 02.44 | 0.59 | 2.8 | 21/25 | 120 | 0.29 | BC | N3 | |
| 20 | 06:07:46.89 | 46 28.86 | 119 15.00 | 2.16 | 2.1 | 23/30 | 109 | 0.27 | BB | E3 | |
| 21 | 19:21:30.56 | 45 16.18 | 119 56.65 | 1.73$ | 2.5 | 20/21 | 190 | 0.39 | CD | O0 | |
| 22 | 03:46:12.24 | 49 24.53 | 120 05.26 | 0.04* | 3.0 | 13/22 | 258 | 0.32 | CD | N3 | R |
| 23 | 09:43:04.10 | 47 34.29 | 122 23.71 | 11.84 | 2.3 | 30/32 | 38 | 0.19 | BA | P3 | |
| 25 | 12:35:35.53 | 46 52.80 | 120 49.70 | 1.06$ | 2.2 | 41/48 | 29 | 0.36 | CC | C3 | |
| 28 | 06:31:06.98 | 48 50.81 | 122 34.11 | 16.08$ | 2.2 | 25/39 | 60 | 0.24 | BB | P3 | |
| 29 | 04:13:56.82 | 47 34.27 | 122 24.17 | 10.44 | 2.6 | 36/38 | 37 | 0.17 | BB | P3 | F |
| | | | | **December 1988** | | | | | | | |
| 2 | 19:00:53.19 | 47 19.60 | 121 45.55 | 0.02* | 2.0 | 7/07 | 117 | 1.00 | DC | P3 | P |
| 3 | 23:02:16.96 | 47 32.94 | 122 44.59 | 49.04 | 2.8 | 50/55 | 27 | 0.46 | CA | P3 | |
| 7 | 03:39:41.79 | 46 33.39 | 121 42.85 | 9.28 | 2.1 | 37/48 | 75 | 0.26 | BA | C3 | |
| 10 | 21:10:54.92 | 46 45.82 | 123 26.66 | 0.02* | 2.3 | 9/09 | 144 | 0.19 | BC | P3 | P |
| 11 | 16:38:58.45 | 47 10.38 | 121 52.99 | 15.21 | 2.7 | 44/49 | 52 | 0.14 | AA | P3 | |
| 15 | 21:52:52.84 | 46 27.53 | 119 17.48 | 0.04* | 2.0 | 19/22 | 77 | 0.31 | CA | E3 | |
| 19 | 15:57:55.16 | 45 54.19 | 119 16.97 | 3.06 | 2.2 | 24/25 | 157 | 0.34 | CC | E3 | |
| 19 | 20:11:40.61 | 47 34.27 | 122 23.90 | 8.09* | 2.8 | 37/39 | 38 | 0.16 | BB | P3 | F |

**Table 1.1.** Washington Regional Seismograph Network earthquake catalog *(continued)*

| Day | Time | Latitude (N) | Longitude (W) | Depth | M | NS/NP | Gap | RMS | Q | Model | Type |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **December 1988 cont'd** | | | | | | | |
| 20 | 22:06:29.96 | 48 38.86 | 122 24.59 | 7.77 | 2.0 | 23/30 | 40 | 0.21 | BC | P3 | |
| 28 | 23:30:01.31 | 47 47.59 | 122 20.81 | 22.42 | 2.4 | 29/32 | 43 | 0.11 | AA | P3 | |
| 30 | 15:13:24.02 | 46 51.03 | 121 57.49 | 9.40 | 2.9 | 46/49 | 47 | 0.26 | BB | C3 | |
| 31 | 17:01:24.53 | 48 18.96 | 119 26.62 | 0.04* | 2.0 | 13/15 | 202 | 0.22 | BD | N3 | |
| | | | | **January 1989** | | | | | | | |
| 11 | 19:51:50.23 | 48 30.78 | 119 54.99 | 0.03* | 2.9 | 20/21 | 197 | 0.40 | CD | N3 | |
| 12 | 03:10:27.30 | 46 23.51 | 119 16.91 | 0.03* | 2.1 | 17/21 | 172 | 0.34 | CC | E3 | |
| 13 | 06:33:27.41 | 47 39.58 | 122 11.71 | 0.04* | 2.1 | 29/33 | 50 | 0.17 | BB | P3 | F |
| 13 | 06:34:44.93 | 47 39.86 | 122 11.60 | 0.04* | 2.2 | 29/32 | 42 | 0.40 | CB | P3 | |
| 13 | 06:39:14.73 | 47 39.77 | 122 11.79 | 0.02* | 2.4 | 28/30 | 50 | 0.22 | BB | P3 | F |
| 14 | 06:47:34.24 | 46 32.82 | 121 48.70 | 3.77 | 3.0 | 49/54 | 61 | 0.15 | BC | C3 | F |
| 14 | 08:26:40.26 | 46 33.16 | 121 48.64 | 3.55 | 2.7 | 44/46 | 38 | 0.21 | BC | C3 | |
| 15 | 21:01:13.92 | 45 27.44 | 122 46.02 | 23.22 | 2.1 | 23/27 | 158 | 0.24 | BC | O0 | |
| 17 | 13:55:28.82 | 47 39.19 | 122 11.43 | 1.53 | 3.3 | 38/42 | 51 | 0.24 | BB | P3 | F |
| 17 | 22:59:39.00 | 48 18.13 | 119 26.45 | 0.28 | 2.2 | 14/15 | 201 | 0.41 | CD | N3 | |
| 19 | 12:21:42.24 | 47 34.11 | 121 54.21 | 2.68 | 2.7 | 40/43 | 50 | 0.15 | BC | P3 | F |
| 19 | 12:34:12.68 | 47 34.16 | 121 53.97 | 2.54 | 2.9 | 41/45 | 43 | 0.30 | BC | P3 | F |
| 20 | 19:33:13.54 | 47 25.66 | 119 18.33 | 11.79 | 2.3 | 22/24 | 72 | 0.19 | BB | N3 | |
| 22 | 19:16:52.38 | 46 24.93 | 121 16.37 | 3.00 | 2.7 | 59/60 | 45 | 0.27 | BC | C3 | |
| 24 | 21:59:40.03 | 47 19.13 | 121 57.08 | 0.02* | 2.2 | 15/15 | 174 | 0.17 | BC | P3 | P |
| 25 | 17:04:12.60 | 46 40.82 | 121 41.13 | 4.34 | 2.7 | 47/50 | 48 | 0.27 | BC | C3 | |
| 26 | 07:19:10.23 | 48 39.31 | 122 11.01 | 14.24 | 2.2 | 24/33 | 59 | 0.25 | BB | P3 | |
| 27 | 12:47:58.59 | 46 02.42 | 118 42.01 | 10.25 | 2.8 | 17/20 | 147 | 0.25 | BC | E3 | |
| 27 | 22:01:01.83 | 47 19.23 | 121 56.38 | 0.02* | 2.0 | 8/08 | 190 | 0.13 | AD | P3 | P |
| 31 | 08:23:44.24 | 47 57.21 | 122 22.52 | 25.84 | 2.1 | 26/29 | 58 | 0.13 | AA | P3 | |
| 31 | 20:30:58.51 | 47 21.71 | 122 21.12 | 15.00 | 2.0 | 35/36 | 34 | 0.12 | AB | P3 | |
| | | | | **February 1989** | | | | | | | |
| 6 | 01:25:52.71 | 48 25.12 | 122 12.78 | 0.05* | 3.2 | 25/30 | 55 | 0.28 | BB | P3 | F |
| 7 | 22:28:54.07 | 46 47.49 | 122 49.98 | 4.75 | 3.1 | 36/36 | 56 | 0.46 | CC | P3 | X |
| 8 | 06:36:27.42 | 48 11.47 | 119 56.72 | 7.07 | 2.3 | 13/15 | 181 | 0.48 | CD | N3 | |
| 9 | 09:43:56.48 | 47 42.23 | 120 00.93 | 3.88 | 2.4 | 20/24 | 104 | 0.27 | BB | N3 | |
| 10 | 18:13:51.13 | 46 06.83 | 120 01.47 | 0.03* | 2.6 | 33/33 | 40 | 0.20 | BC | E3 | |
| 11 | 22:43:31.98 | 46 27.33 | 119 17.93 | 0.04* | 2.2 | 22/25 | 75 | 0.29 | BA | E3 | |
| 13 | 01:36:16.67 | 47 48.99 | 119 26.14 | 0.55 | 2.2 | 16/18 | 139 | 0.38 | CC | N3 | |
| 13 | 23:24:49.26 | 48 21.12 | 119 26.39 | 0.04* | 2.1 | 14/15 | 234 | 0.27 | BD | N3 | |
| 14 | 19:57:00.90 | 48 23.50 | 118 44.74 | 9.56 | 2.9 | 15/17 | 233 | 1.16 | DD | N3 | |
| 14 | 21:41:10.55 | 48 25.62 | 122 13.63 | 0.04* | 4.0 | 25/30 | 56 | 0.22 | BB | P3 | F |
| 15 | 01:11:29.75 | 48 25.01 | 122 13.12 | 0.08 | 2.4 | 24/28 | 54 | 0.38 | CB | P3 | F |
| 15 | 11:52:09.35 | 47 35.06 | 119 15.09 | 0.74 | 2.2 | 22/25 | 108 | 0.22 | BC | N3 | |
| 16 | 13:59:10.14 | 46 29.26 | 119 15.41 | 1.22 | 2.0 | 25/31 | 90 | 0.27 | BB | E3 | |
| 16 | 20:59:30.75 | 48 25.38 | 122 13.22 | 0.03* | 2.3 | 20/25 | 56 | 0.27 | BB | P3 | F |
| 16 | 21:12:11.75 | 48 25.23 | 122 13.65 | 0.02* | 2.8 | 24/28 | 55 | 0.33 | CB | P3 | F |
| 18 | 07:49:41.65 | 47 54.89 | 120 02.31 | 0.51 | 2.2 | 15/19 | 119 | 0.54 | DC | N3 | |
| 19 | 00:42:53.11 | 46 12.31 | 122 11.14 | 4.27 | 2.2 | 31/35 | 59 | 0.13 | AA | S3 | |
| 21 | 06:48:21.66 | 47 19.41 | 122 27.60 | 15.97 | 3.0 | 52/56 | 30 | 0.21 | BB | P3 | F |
| 21 | 19:48:26.68 | 45 44.33 | 120 01.85 | 0.02* | 2.6 | 26/27 | 70 | 0.26 | BC | E3 | |
| 21 | 22:36:37.13 | 46 44.81 | 119 25.94 | 0.03* | 2.9 | 28/30 | 51 | 0.24 | BB | E3 | |
| 22 | 00:12:38.72 | 48 19.41 | 119 26.88 | 0.04* | 2.1 | 15/18 | 203 | 0.30 | BD | N3 | |
| 22 | 06:59:53.37 | 46 44.69 | 119 26.30 | 0.03* | 2.2 | 26/29 | 50 | 0.23 | BB | E3 | |
| 23 | 21:59:31.56 | 47 19.59 | 121 56.02 | 4.05 | 2.1 | 8/08 | 133 | 0.18 | BC | P3 | P |
| 24 | 15:33:21.88 | 46 55.99 | 122 29.99 | 22.87 | 2.4 | 40/45 | 47 | 0.14 | AA | P3 | |
| 28 | 13:56:35.82 | 47 09.67 | 121 49.89 | 13.74 | 2.0 | 34/41 | 58 | 0.19 | BA | C3 | |
| | | | | **March 1989** | | | | | | | |
| 3 | 21:09:45.20 | 47 19.44 | 121 57.49 | 0.05* | 2.1 | 9/09 | 216 | 0.15 | AD | P3 | P |
| 5 | 06:42:00.66 | 47 48.77 | 123 21.41 | 46.17 | 4.5 | 39/40 | 53 | 0.32 | CA | P3 | F |
| 6 | 03:09:53.91 | 48 25.79 | 122 13.91 | 0.06 | 4.2 | 26/30 | 55 | 0.23 | BB | P3 | F |
| 6 | 07:57:06.74 | 48 25.55 | 122 13.50 | 1.12 | 2.0 | 19/24 | 56 | 0.27 | BB | P3 | F |
| 6 | 08:00:01.18 | 48 25.26 | 122 13.62 | 0.03* | 2.4 | 21/24 | 55 | 0.23 | BB | P3 | F |
| 7 | 05:26:48.03 | 46 24.75 | 119 16.77 | 2.37 | 2.2 | 5/05 | 193 | 0.18 | BD | E3 | |
| 7 | 06:40:09.92 | 48 00.15 | 124 23.77 | 30.25 | 3.1 | 21/31 | 175 | 0.50 | DC | P3 | F |
| 12 | 01:33:46.06 | 47 43.15 | 120 00.74 | 6.46 | 2.2 | 19/22 | 64 | 0.35 | CA | N3 | |
| 15 | 11:21:53.96 | 47 40.03 | 120 18.85 | 6.76$ | 2.2 | 25/28 | 51 | 0.25 | BC | N3 | |
| 16 | 00:20:15.68 | 49 01.58 | 118 15.28 | 0.02* | 2.5 | 11/12 | 283 | 0.58 | DD | N3 | |
| 16 | 20:23:39.05 | 47 18.90 | 121 58.52 | 0.02* | 2.0 | 8/08 | 207 | 0.29 | BD | P3 | P |
| 17 | 01:43:49.56 | 47 39.69 | 122 11.52 | 0.04* | 2.1 | 26/29 | 50 | 0.21 | BB | P3 | |

**Table 1.1.** Washington Regional Seismograph Network earthquake catalog *(continued)*

| Day | Time | Latitude (N) | Longitude (W) | Depth | M | NS/NP | Gap | RMS | Q | Model | Type |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **March 1989 cont'd** | | | | | | | |
| 17 | 01:45:46.40 | 47 39.16 | 122 11.90 | 0.04* | 2.0 | 31/34 | 51 | 0.29 | BB | P3 | |
| 17 | 01:53:10.45 | 47 39.37 | 122 11.41 | 0.04* | 2.2 | 33/37 | 51 | 0.16 | BB | P3 | |
| 17 | 01:59:34.50 | 47 39.55 | 122 12.42 | 1.45* | 2.0 | 25/28 | 57 | 0.21 | BB | P3 | |
| 17 | 03:18:27.94 | 46 58.09 | 119 43.28 | 1.54 | 2.7 | 33/35 | 50 | 0.23 | BC | E3 | |
| 17 | 03:29:52.94 | 47 39.30 | 122 12.66 | 0.02* | 2.0 | 26/27 | 50 | 0.20 | BB | P3 | |
| 18 | 12:20:40.66 | 47 54.86 | 120 02.48 | 0.59 | 2.6 | 18/22 | 119 | 0.31 | CC | N3 | |
| 20 | 02:24:05.75 | 46 52.34 | 121 44.61 | 0.02* | 2.1 | 32/41 | 40 | 0.27 | BB | C3 | |
| 20 | 02:34:43.26 | 46 17.17 | 123 21.14 | 22.77 | 2.2 | 36/42 | 135 | 0.22 | BB | P3 | |
| 20 | 16:25:52.70 | 46 27.31 | 119 33.79 | 16.75 | 2.2 | 23/33 | 93 | 0.18 | BB | E3 | |
| 23 | 05:10:01.29 | 46 44.39 | 119 26.20 | 0.02* | 2.1 | 22/26 | 56 | 0.25 | BA | E3 | |
| 24 | 02:57:03.81 | 48 30.69 | 118 48.85 | 0.02# | 2.6 | 9/11 | 260 | 0.30 | BD | N3 | |
| 24 | 08:42:44.03 | 46 29.33 | 119 16.43 | 1.31 | 2.1 | 26/28 | 75 | 0.21 | BB | E3 | |
| 24 | 22:25:28.74 | 46 51.49 | 121 54.35 | 12.09 | 2.5 | 33/40 | 50 | 0.17 | BA | C3 | |
| 24 | 22:37:13.45 | 46 14.06 | 120 41.94 | 3.77 | 2.3 | 34/35 | 32 | 0.35 | CC | E3 | |
| 26 | 06:25:15.85 | 47 40.60 | 120 15.10 | 7.65* | 2.6 | 30/32 | 54 | 0.21 | BC | N3 | F |
| 27 | 20:17:22.28 | 45 48.95 | 120 15.69 | 12.25* | 3.1 | 35/35 | 58 | 0.44 | CC | E3 | |
| 27 | 23:15:30.15 | 46 41.52 | 123 21.18 | 6.32 | 2.4 | 17/17 | 116 | 0.13 | AC | P3 | P |
| 29 | 01:13:38.65 | 49 24.76 | 119 59.95 | 0.03* | 2.2 | 10/12 | 283 | 0.74 | DD | N3 | R |
| | | | | **April 1989** | | | | | | | |
| 1 | 03:01:42.99 | 44 26.55 | 124 13.38 | 55.04$ | 2.8 | 8/11 | 324 | 0.12 | CD | O0 | |
| 1 | 22:32:21.91 | 45 35.55 | 122 28.59 | 9.66 | 2.0 | 27/27 | 90 | 0.24 | BB | C3 | |
| 3 | 16:42:59.89 | 46 29.21 | 119 15.66 | 1.57 | 2.5 | 31/33 | 75 | 0.24 | BB | E3 | |
| 5 | 08:10:22.18 | 47 36.06 | 121 57.22 | 8.41 | 2.2 | 31/35 | 38 | 0.31 | CC | P3 | |
| 5 | 12:01:18.62 | 48 49.06 | 122 04.76 | 3.31 | 2.8 | 23/33 | 110 | 0.41 | CC | P3 | F |
| 6 | 20:22:52.78 | 46 47.50 | 122 50.35 | 6.41# | 2.3 | 11/11 | 123 | 0.12 | AC | P3 | P |
| 11 | 01:26:03.46 | 46 22.41 | 122 15.25 | 11.99 | 2.2 | 33/43 | 56 | 0.19 | BA | S3 | |
| 11 | 07:26:16.08 | 48 36.84 | 121 02.75 | 1.49$ | 2.1 | 11/12 | 199 | 0.84 | DD | C3 | |
| 11 | 11:07:29.48 | 47 48.44 | 119 25.96 | 0.71 | 2.4 | 21/22 | 137 | 0.34 | CC | N3 | |
| 11 | 16:32:59.98 | 47 16.44 | 122 54.40 | 47.06 | 2.8 | 45/48 | 38 | 0.28 | BA | P3 | |
| 14 | 22:49:26.14 | 45 35.61 | 122 27.05 | 8.04 | 2.3 | 16/16 | 92 | 0.15 | AB | C3 | P |
| 16 | 15:35:55.16 | 48 24.98 | 122 13.21 | 0.04* | 2.7 | 22/26 | 53 | 0.23 | BB | P3 | F |
| 17 | 09:52:03.02 | 47 45.39 | 122 33.07 | 21.72 | 2.5 | 30/34 | 45 | 0.17 | BA | P3 | |
| 19 | 02:13:45.05 | 47 37.26 | 122 29.70 | 26.98 | 2.3 | 31/34 | 39 | 0.40 | CA | P3 | |
| 19 | 13:27:13.71 | 48 42.58 | 123 20.57 | 24.48 | 2.9 | 22/32 | 42 | 0.19 | BA | P3 | F |
| 21 | 09:40:43.70 | 47 23.53 | 122 03.37 | 4.50$ | 2.8 | 51/56 | 34 | 0.42 | CC | P3 | F |
| 30 | 22:40:49.40 | 48 09.52 | 122 50.23 | 53.85 | 2.0 | 26/31 | 38 | 0.21 | BA | P3 | |
| | | | | **May 1989** | | | | | | | |
| 1 | 08:14:55.79 | 47 48.55 | 119 26.07 | 0.59 | 2.2 | 21/24 | 137 | 0.40 | CC | N3 | |
| 1 | 10:09:35.72 | 47 46.56 | 119 27.42 | 0.56 | 2.2 | 17/19 | 128 | 0.49 | CB | N3 | |
| 3 | 21:13:46.93 | 47 13.92 | 118 16.73 | 0.59 | 2.0 | 17/18 | 210 | 0.55 | DD | N3 | P |
| 6 | 00:05:01.55 | 46 22.37 | 122 31.27 | 1.61 | 2.1 | 27/27 | 59 | 0.23 | BB | C3 | P |
| 9 | 01:43:10.43 | 46 37.42 | 118 53.91 | 1.45 | 2.2 | 26/28 | 129 | 0.16 | BC | E3 | |
| 9 | 18:28:45.50 | 48 13.83 | 119 51.23 | 15.59 | 4.5 | 22/22 | 175 | 0.48 | CC | N3 | F |
| 10 | 01:24:38.45 | 46 18.29 | 122 22.97 | 2.06 | 2.0 | 21/23 | 142 | 0.11 | AC | S3 | P |
| 13 | 01:54:41.19 | 46 18.30 | 122 22.90 | 1.92 | 2.2 | 22/25 | 101 | 0.14 | AB | S3 | P |
| 20 | 00:54:30.98 | 46 36.63 | 118 50.95 | 0.04* | 2.3 | 25/26 | 191 | 0.22 | BD | E3 | |
| 22 | 13:49:09.69 | 49 10.82 | 122 00.44 | 4.24 | 2.1 | 19/28 | 188 | 0.43 | CD | P3 | F |
| 24 | 01:44:57.11 | 47 07.36 | 118 33.71 | 8.58 | 2.6 | 28/28 | 172 | 0.29 | BC | N3 | P |
| 25 | 01:27:28.92 | 47 22.41 | 122 41.34 | 19.86 | 2.8 | 49/60 | 41 | 0.30 | CA | P3 | |
| 25 | 03:32:11.19 | 47 22.45 | 122 41.91 | 23.70 | 2.5 | 42/48 | 52 | 0.16 | BA | P3 | |
| 25 | 21:25:18.94 | 47 36.10 | 120 13.86 | 10.44 | 2.3 | 25/29 | 40 | 0.34 | CC | N3 | |
| 26 | 18:24:03.80 | 46 17.99 | 118 42.89 | 2.15 | 2.4 | 25/26 | 146 | 0.20 | BC | E3 | |
| 26 | 21:36:20.08 | 46 59.01 | 118 32.68 | 1.50 | 2.1 | 21/21 | 156 | 0.29 | BC | E3 | P |
| 31 | 07:33:18.72 | 48 42.66 | 119 38.70 | 0.02* | 2.0 | 8/08 | 233 | 0.18 | BD | N3 | |
| 31 | 12:46:57.43 | 47 57.13 | 121 53.65 | 17.83 | 2.6 | 31/35 | 55 | 0.29 | BA | P3 | F |
| 31 | 19:17:38.14 | 46 29.79 | 121 50.57 | 9.58* | 2.1 | 34/44 | 78 | 0.11 | AC | C3 | |
| | | | | **June 1989** | | | | | | | |
| 2 | 21:17:58.75 | 45 55.64 | 123 06.77 | 21.75 | 2.6 | 24/24 | 87 | 0.23 | BB | P3 | P |
| 2 | 23:08:30.19 | 46 37.49 | 118 54.35 | 0.02* | 2.2 | 25/27 | 141 | 0.17 | BC | E3 | P |
| 9 | 19:52:42.91 | 46 38.11 | 121 41.28 | 1.15 | 2.1 | 31/35 | 54 | 0.22 | BB | C3 | |
| 11 | 12:00:34.96 | 44 28.80 | 124 48.86 | 42.02 | 3.3 | 11/14 | 313 | 0.34 | CD | O0 | R |
| 11 | 23:02:10.05 | 46 18.63 | 122 19.91 | 0.49 | 2.0 | 25/28 | 44 | 0.11 | AA | S3 | P |
| 13 | 23:18:08.79 | 46 56.90 | 118 32.16 | 11.29$ | 3.0 | 28/31 | 157 | 0.61 | DC | E3 | X |
| 14 | 01:42:20.80 | 47 54.63 | 120 02.61 | 0.53 | 2.0 | 9/14 | 119 | 0.38 | CC | N3 | |
| 15 | 02:39:33.26 | 46 34.79 | 118 51.85 | 0.29# | 2.4 | 23/24 | 210 | 0.34 | CD | E3 | |

**Table 1.1.** Washington Regional Seismograph Network earthquake catalog *(continued)*

| Day | Time | Latitude (N) | Longitude (W) | Depth | M | NS/NP | Gap | RMS | Q | Model | Type |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **June 1989 cont'd** | | | | | | | |
| 15 | 19:23:52.74 | 45 55.69 | 123 05.92 | 15.49* | 2.2 | 26/26 | 80 | 0.19 | BC | P3 | P |
| 18 | 20:38:37.39 | 47 24.58 | 122 46.55 | 44.75 | 4.4 | 52/54 | 25 | 0.31 | CA | P3 | F |
| 19 | 22:05:55.80 | 46 53.23 | 121 58.91 | 8.55 | 2.7 | 41/42 | 49 | 0.26 | BA | C3 | |
| 21 | 02:34:05.49 | 47 38.57 | 122 57.94 | 47.64 | 2.1 | 28/32 | 42 | 0.24 | BA | P3 | |
| 25 | 05:08:18.57 | 48 16.04 | 121 45.78 | 2.59$ | 2.0 | 13/17 | 69 | 0.36 | CC | P3 | |
| 26 | 13:41:57.24 | 48 16.31 | 121 46.39 | 3.43$ | 2.2 | 18/23 | 61 | 0.36 | CC | P3 | |
| 27 | 04:44:07.57 | 47 37.36 | 122 01.96 | 15.65 | 2.0 | 30/34 | 70 | 0.13 | AB | P3 | |
| 29 | 22:36:30.20 | 46 11.81 | 122 11.89 | 0.03* | 2.3 | 5/05 | 122 | 0.06 | AD | S3 | |
| | | | | **July 1989** | | | | | | | |
| 2 | 04:40:17.66 | 48 30.02 | 122 07.37 | 1.73 | 2.0 | 13/14 | 129 | 0.31 | CB | P3 | |
| 3 | 18:46:21.47 | 46 52.10 | 120 49.98 | 1.26$ | 2.8 | 47/51 | 44 | 0.32 | CC | C3 | |
| 6 | 21:13:54.47 | 45 04.83 | 121 19.14 | 0.04* | 2.3 | 17/18 | 72 | 0.26 | BC | O0 | P |
| 11 | 20:36:02.94 | 46 01.52 | 118 39.01 | 6.78 | 2.0 | 22/23 | 141 | 0.19 | BC | E3 | |
| 11 | 22:20:24.29 | 47 02.21 | 119 56.91 | 0.45 | 2.1 | 23/23 | 48 | 0.51 | DB | N3 | |
| 13 | 07:03:59.27 | 49 16.73 | 120 26.96 | 0.05* | 2.7 | 16/16 | 244 | 0.50 | CD | C3 | |
| 13 | 20:19:00.55 | 46 00.55 | 121 58.17 | 1.91 | 2.1 | 22/23 | 89 | 0.09 | AC | S3 | P |
| 17 | 13:02:01.63 | 49 09.20 | 120 32.42 | 5.80 | 2.6 | 15/16 | 236 | 0.68 | DD | C3 | |
| 17 | 19:28:09.08 | 48 51.60 | 118 31.02 | 0.03* | 2.2 | 9/10 | 290 | 0.29 | BD | N3 | |
| 18 | 21:43:46.13 | 49 10.89 | 122 07.68 | 0.02* | 2.0 | 6/07 | 294 | 0.26 | BD | P3 | |
| 20 | 04:46:07.86 | 46 18.34 | 122 20.09 | 1.07 | 2.1 | 31/32 | 43 | 0.19 | BA | S3 | P |
| 20 | 17:10:02.50 | 49 23.83 | 122 25.02 | 7.83 | 2.0 | 10/10 | 294 | 0.23 | DD | P3 | |
| 20 | 22:10:07.08 | 45 04.21 | 121 19.47 | 0.04* | 2.1 | 13/13 | 88 | 0.39 | CC | O0 | P |
| 21 | 11:14:10.82 | 46 32.72 | 121 48.58 | 3.46* | 2.9 | 46/54 | 62 | 0.14 | AC | C3 | F |
| 21 | 11:38:00.99 | 49 11.25 | 120 30.42 | 2.96$ | 2.6 | 21/24 | 239 | 0.68 | DD | C3 | |
| 21 | 16:27:43.19 | 47 55.26 | 120 02.16 | 0.63 | 2.4 | 15/21 | 122 | 0.37 | CC | N3 | |
| 22 | 19:21:29.74 | 45 24.08 | 119 25.89 | 0.02* | 2.3 | 25/27 | 163 | 0.76 | DC | O0 | |
| 24 | 01:00:23.77 | 49 18.12 | 123 47.19 | 0.04* | 2.3 | 13/13 | 265 | 0.28 | BD | P3 | |
| 24 | 22:19:58.29 | 46 45.82 | 123 26.64 | 7.28 | 2.6 | 14/14 | 144 | 0.19 | BC | P3 | P |
| 25 | 05:07:40.25 | 46 46.01 | 120 48.22 | 0.69$ | 2.2 | 29/32 | 58 | 0.45 | CC | C3 | |
| 25 | 20:59:39.38 | 45 56.48 | 119 56.23 | 18.44 | 2.2 | 23/25 | 64 | 0.15 | BA | E3 | |
| 25 | 23:02:43.93 | 49 22.24 | 120 35.26 | 0.05* | 2.1 | 8/11 | 282 | 0.42 | CD | C3 | |
| 26 | 19:51:49.59 | 48 51.83 | 118 30.64 | 0.03* | 2.2 | 6/07 | 291 | 0.28 | BD | N3 | P |
| 28 | 02:31:56.50 | 48 24.10 | 122 33.71 | 7.18 | 2.0 | 14/15 | 81 | 0.26 | BB | P3 | |
| 28 | 03:05:49.73 | 48 24.00 | 122 33.53 | 7.43* | 2.2 | 15/16 | 81 | 0.20 | BB | P3 | |
| 29 | 19:41:11.95 | 47 35.10 | 121 44.75 | 5.38$ | 2.1 | 32/36 | 53 | 0.32 | CC | P3 | |
| 30 | 01:02:09.49 | 46 18.48 | 122 20.10 | 1.13 | 2.4 | 34/38 | 43 | 0.26 | BA | S3 | P |
| | | | | **August 1989** | | | | | | | |
| 1 | 08:25:01.82 | 46 57.24 | 121 04.17 | 6.20 | 2.4 | 48/54 | 48 | 0.42 | CC | C3 | |
| 1 | 11:15:36.67 | 48 13.88 | 121 42.27 | 3.74$ | 2.5 | 26/30 | 69 | 0.33 | CC | P3 | |
| 1 | 23:25:17.58 | 45 36.54 | 122 27.42 | 14.36 | 3.7 | 42/43 | 74 | 0.21 | BB | C3 | F |
| 2 | 02:10:02.62 | 45 08.92 | 122 30.25 | 15.21 | 2.1 | 14/15 | 266 | 0.48 | DD | O0 | P |
| 2 | 21:46:11.36 | 47 03.59 | 119 54.41 | 0.04* | 2.0 | 21/21 | 81 | 0.36 | CC | N3 | |
| 4 | 00:53:06.30 | 46 18.46 | 122 22.97 | 1.08 | 2.0 | 34/37 | 53 | 0.17 | BA | S3 | P |
| 8 | 01:08:59.87 | 47 38.30 | 120 11.61 | 8.75 | 2.7 | 32/37 | 44 | 0.30 | BB | N3 | |
| 8 | 21:13:49.00 | 44 35.90 | 120 17.90 | 0.02* | 2.8 | 14/14 | 193 | 0.46 | CD | O0 | P |
| 11 | 02:33:52.66 | 45 32.96 | 117 51.82 | 53.28$ | 2.6 | 5/05 | 309 | 0.11 | DD | E3 | |
| 11 | 21:52:22.53 | 46 18.47 | 122 19.91 | 1.09 | 2.4 | 27/28 | 67 | 0.24 | BA | S3 | P |
| 11 | 21:56:12.56 | 48 43.89 | 118 35.13 | 0.02* | 2.1 | 7/08 | 282 | 0.17 | BD | N3 | |
| 13 | 00:27:22.34 | 45 50.63 | 122 39.29 | 16.68 | 2.3 | 32/34 | 90 | 0.18 | BB | C3 | |
| 13 | 10:41:46.27 | 46 12.08 | 122 11.48 | 1.45 | 2.3 | 21/21 | 77 | 0.10 | AA | S3 | |
| 14 | 10:12:11.00 | 45 59.39 | 118 18.87 | 71.35 | 2.2 | 8/08 | 273 | 0.19 | CD | E3 | |
| 16 | 17:14:19.18 | 46 51.77 | 121 45.27 | 1.12* | 2.1 | 14/14 | 57 | 0.19 | BA | C3 | |
| 16 | 21:28:59.32 | 46 43.07 | 123 26.50 | 10.45 | 2.1 | 12/12 | 156 | 0.28 | CC | P3 | |
| 18 | 02:47:59.94 | 45 16.47 | 119 58.96 | 6.25 | 2.7 | 23/26 | 164 | 0.39 | CC | O0 | |
| 19 | 01:15:21.99 | 46 18.47 | 122 23.01 | 1.84 | 2.0 | 32/34 | 53 | 0.23 | BA | S3 | P |
| 24 | 15:46:33.72 | 45 18.15 | 121 44.61 | 1.47$ | 2.0 | 7/08 | 93 | 0.38 | CB | O0 | P |
| 25 | 05:27:56.56 | 46 12.06 | 122 11.47 | 0.02* | 2.7 | 15/15 | 55 | 0.15 | BA | S3 | |
| 28 | 10:06:55.98 | 48 44.64 | 121 48.49 | 19.37 | 2.0 | 7/07 | 203 | 0.19 | CD | P3 | |
| 28 | 18:02:30.09 | 45 51.31 | 122 34.77 | 13.78* | 2.6 | 43/49 | 40 | 0.16 | BB | C3 | |
| 28 | 21:19:24.80 | 48 53.68 | 118 30.81 | 0.03* | 2.1 | 6/07 | 292 | 0.27 | BD | N3 | |
| 30 | 10:10:13.98 | 47 14.18 | 123 44.24 | 11.51$ | 2.3 | 33/34 | 144 | 0.60 | DC | P3 | |
| 31 | 00:24:05.74 | 48 26.48 | 122 32.65 | 24.45 | 2.0 | 15/18 | 90 | 0.29 | BA | P3 | |

**Table 1.1.** Washington Regional Seismograph Network earthquake catalog *(continued)*

| Day | Time | Latitude (N) | Longitude (W) | Depth | M | NS/NP | Gap | RMS | Q | Model | Type |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **September 1989** | | | | | | | |
| 2 | 14:07:37.58 | 48 44.38 | 122 13.76 | 0.04* | 2.3 | 13/13 | 216 | 0.50 | CD | P3 | |
| 3 | 10:22:42.94 | 46 09.80 | 122 52.07 | 21.56 | 2.0 | 35/39 | 80 | 0.11 | AA | C3 | |
| 4 | 06:34:54.44 | 47 53.86 | 122 38.38 | 17.51 | 2.7 | 21/25 | 122 | 0.19 | BB | P3 | F |
| 5 | 00:07:30.67 | 45 36.49 | 122 26.33 | 0.02* | 2.1 | 15/15 | 102 | 0.08 | AC | C3 | P |
| 7 | 22:30:08.19 | 46 52.05 | 121 44.78 | 0.02* | 2.5 | 42/47 | 40 | 0.30 | CA | C3 | |
| 7 | 22:34:22.43 | 46 52.05 | 121 44.92 | 0.02* | 2.1 | 31/38 | 40 | 0.23 | BA | C3 | |
| 12 | 00:18:48.80 | 46 18.35 | 122 22.38 | 2.17 | 2.0 | 29/31 | 52 | 0.12 | AA | S3 | P |
| 12 | 17:43:25.60 | 45 04.37 | 121 18.72 | 0.02* | 2.3 | 9/09 | 73 | 0.16 | BC | O0 | P |
| 14 | 17:11:00.52 | 46 55.17 | 122 28.15 | 21.43 | 2.0 | 37/42 | 47 | 0.14 | AB | P3 | |
| 14 | 23:25:48.07 | 46 18.44 | 122 22.79 | 1.86 | 2.1 | 23/24 | 53 | 0.08 | AA | S3 | P |
| 15 | 03:04:44.44 | 45 16.02 | 121 44.70 | 0.08 | 2.8 | 30/30 | 77 | 0.28 | BA | O0 | P |
| 15 | 10:15:06.41 | 45 22.08 | 121 42.79 | 4.58 | 2.2 | 34/39 | 59 | 0.31 | CC | O0 | |
| 15 | 10:22:25.52 | 45 22.09 | 121 42.17 | 5.51 | 2.1 | 23/25 | 96 | 0.29 | BB | O0 | |
| 15 | 10:28:00.84 | 45 22.36 | 121 42.41 | 5.22 | 3.5 | 39/41 | 38 | 0.29 | BB | O0 | F |
| 15 | 10:39:37.18 | 45 21.66 | 121 42.13 | 5.70 | 2.0 | 30/33 | 58 | 0.35 | CB | O0 | |
| 15 | 11:43:48.83 | 46 20.90 | 122 14.67 | 9.57 | 2.0 | 35/47 | 40 | 0.12 | AA | S3 | |
| 21 | 02:50:24.28 | 46 15.13 | 122 05.68 | 7.35 | 2.1 | 37/46 | 59 | 0.18 | BA | S3 | |
| 21 | 18:18:02.25 | 48 18.93 | 122 06.27 | 10.97 | 2.3 | 15/18 | 55 | 0.22 | BB | P3 | |
| 22 | 06:20:49.59 | 48 18.95 | 122 06.29 | 12.18* | 2.2 | 13/19 | 55 | 0.16 | BA | P3 | |
| 22 | 23:38:10.74 | 46 23.02 | 123 46.89 | 23.22 | 2.5 | 31/34 | 188 | 0.52 | DD | P3 | |
| 25 | 06:29:42.24 | 48 29.02 | 120 30.08 | 0.48$ | 2.2 | 18/19 | 204 | 0.30 | CD | N3 | |
| 25 | 12:54:18.54 | 46 47.32 | 124 11.15 | 26.39 | 2.4 | 17/17 | 214 | 0.41 | CD | P3 | |
| 27 | 23:31:04.01 | 46 18.71 | 122 22.42 | 2.04 | 2.3 | 34/36 | 45 | 0.26 | BA | S3 | P |
| 28 | 00:38:52.63 | 46 18.36 | 122 20.07 | 1.08 | 2.1 | 30/30 | 54 | 0.20 | BA | S3 | P |
| 29 | 21:06:08.92 | 46 07.99 | 119 43.31 | 0.02* | 2.1 | 15/16 | 81 | 0.40 | CB | E3 | P |
| 30 | 01:38:49.95 | 48 27.22 | 124 41.20 | 0.02# | 2.1 | 8/08 | 280 | 1.03 | DD | P3 | |
| | | | | **October 1989** | | | | | | | |
| 2 | 22:57:26.06 | 44 53.46 | 122 44.62 | 24.84 | 2.1 | 26/27 | 252 | 0.31 | CD | O0 | |
| 3 | 10:36:26.85 | 47 40.37 | 120 06.85 | 6.70 | 2.7 | 36/37 | 40 | 0.32 | CB | N3 | |
| 6 | 00:56:23.25 | 46 18.70 | 122 22.82 | 1.62 | 2.4 | 31/35 | 44 | 0.17 | BA | S3 | P |
| 6 | 10:43:40.00 | 46 51.40 | 121 45.84 | 0.03* | 2.5 | 7/07 | 78 | 0.43 | CB | C3 | L |
| 13 | 16:24:21.45 | 46 47.91 | 122 48.72 | 0.03* | 2.2 | 22/24 | 55 | 0.22 | BC | P3 | P |
| 14 | 17:09:02.89 | 48 27.59 | 123 16.25 | 24.01 | 2.9 | 31/41 | 34 | 0.26 | BA | P3 | F |
| 16 | 00:43:30.81 | 49 17.22 | 123 57.85 | 62.38 | 2.8 | 20/30 | 60 | 0.36 | CA | P3 | |
| 16 | 07:57:05.94 | 47 20.00 | 122 21.82 | 8.99$ | 2.0 | 45/49 | 33 | 0.48 | CC | P3 | |
| 17 | 00:06:59.74 | 45 35.21 | 121 36.23 | 2.61 | 2.3 | 33/33 | 53 | 0.27 | BC | C3 | P |
| 20 | 05:08:41.45 | 47 41.29 | 120 03.16 | 7.64 | 2.1 | 23/29 | 48 | 0.29 | BA | N3 | |
| 21 | 07:29:20.11 | 47 42.22 | 120 13.00 | 0.13 | 2.0 | 29/33 | 90 | 0.41 | CC | N3 | |
| 25 | 21:59:27.29 | 46 15.95 | 122 02.91 | 10.94 | 2.3 | 39/44 | 64 | 0.11 | AA | S3 | |
| 29 | 01:43:24.40 | 46 18.60 | 122 22.59 | 1.99 | 2.0 | 28/30 | 52 | 0.11 | AA | S3 | P |
| 29 | 12:08:36.69 | 47 38.37 | 122 26.54 | 25.18 | 2.4 | 33/38 | 53 | 0.12 | AA | P3 | |
| | | | | **November 1989** | | | | | | | |
| 1 | 08:49:44.19 | 45 12.35 | 122 38.52 | 20.52 | 2.4 | 35/36 | 152 | 0.27 | BC | O0 | |
| 1 | 19:19:00.04 | 48 36.78 | 119 35.00 | 0.38$ | 2.5 | 16/20 | 226 | 0.44 | CD | N3 | |
| 2 | 01:56:32.17 | 46 53.90 | 123 20.75 | 0.04* | 2.3 | 22/22 | 80 | 0.21 | BC | P3 | P |
| 2 | 23:24:41.70 | 47 05.49 | 118 09.97 | 0.02* | 2.3 | 19/19 | 279 | 0.19 | BD | N3 | |
| 8 | 00:42:35.09 | 47 38.62 | 122 11.72 | 25.69* | 2.2 | 34/36 | 52 | 0.14 | AA | P3 | |
| 8 | 23:44:08.48 | 48 29.92 | 124 56.49 | 0.03* | 2.3 | 7/07 | 296 | 0.61 | DD | P3 | |
| 10 | 18:18:38.74 | 45 43.43 | 120 15.90 | 0.02* | 2.2 | 21/22 | 69 | 0.27 | BC | E3 | |
| 12 | 18:17:19.07 | 46 12.13 | 122 11.25 | 0.04* | 2.7 | 6/06 | 101 | 0.24 | BC | S3 | |
| 14 | 18:21:40.48 | 47 39.88 | 122 10.20 | 21.46 | 2.4 | 29/31 | 34 | 0.16 | BA | P3 | |
| 15 | 00:17:20.45 | 46 08.07 | 122 10.50 | 1.60 | 2.1 | 15/16 | 91 | 0.10 | AB | S3 | P |
| 17 | 00:49:27.64 | 46 18.41 | 122 20.16 | 1.21 | 2.2 | 28/28 | 49 | 0.08 | AA | S3 | P |
| 18 | 22:19:08.67 | 46 12.55 | 122 12.10 | 0.03* | 2.3 | 12/12 | 71 | 0.14 | AA | S3 | L |
| 21 | 21:05:24.86 | 45 46.59 | 123 18.16 | 11.93* | 2.3 | 27/27 | 118 | 0.25 | BB | P3 | P |
| 22 | 02:51:29.81 | 46 18.29 | 122 23.16 | 0.58 | 2.1 | 29/31 | 48 | 0.15 | BA | S3 | P |
| 24 | 23:25:34.70 | 48 03.53 | 124 37.49 | 32.99 | 2.1 | 17/22 | 216 | 0.24 | BD | P3 | |
| 29 | 00:24:04.09 | 46 18.48 | 122 22.74 | 1.89 | 2.0 | 32/36 | 53 | 0.14 | AA | S3 | P |
| 30 | 03:00:41.53 | 47 27.63 | 121 42.42 | 12.91 | 2.2 | 43/47 | 48 | 0.28 | BA | P3 | F |
| 30 | 06:29:04.79 | 48 34.76 | 122 20.44 | 7.46* | 2.0 | 19/28 | 67 | 0.17 | BC | P3 | |

**Table 1.1.** Washington Regional Seismograph Network earthquake catalog *(continued)*

| Day | Time | Latitude (N) | Longitude (W) | Depth | M | NS/NP | Gap | RMS | Q | Model | Type |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **December 1989** | | | | | | | |
| 5 | 20:16:00.88 | 45 29.35 | 119 31.31 | 0.03* | 2.3 | 20/20 | 152 | 0.24 | CC | O0 | P |
| 5 | 23:17:43.86 | 46 10.43 | 122 10.24 | 0.02* | 2.0 | 6/06 | 173 | 0.31 | CC | S3 | |
| 6 | 12:25:04.75 | 47 12.45 | 123 45.75 | 31.57 | 2.1 | 22/24 | 150 | 0.15 | AC | P3 | |
| 8 | 00:11:17.83 | 46 12.29 | 122 12.04 | 0.98 | 2.6 | 10/10 | 108 | 0.22 | BB | S3 | |
| 10 | 16:36:24.88 | 46 55.73 | 121 57.77 | 12.66 | 2.0 | 28/34 | 52 | 0.15 | AA | C3 | |
| 12 | 22:13:50.21 | 46 54.50 | 118 42.18 | 0.02* | 2.1 | 23/23 | 184 | 0.25 | BD | E3 | P |
| 16 | 15:52:38.14 | 46 53.53 | 121 56.95 | 4.16 | 2.1 | 39/44 | 67 | 0.29 | BB | C3 | |
| 20 | 10:19:06.17 | 48 03.18 | 120 39.32 | 0.02* | 2.3 | 22/22 | 138 | 0.67 | DC | C3 | |
| 22 | 16:40:11.26 | 46 51.85 | 121 54.83 | 12.31 | 2.3 | 40/44 | 41 | 0.11 | AA | C3 | |
| 22 | 20:15:30.48 | 48 50.67 | 122 28.91 | 15.58 | 2.0 | 21/27 | 107 | 0.24 | BC | P3 | |
| 24 | 08:45:58.90 | 46 39.00 | 122 06.97 | 18.45 | 4.9 | 53/53 | 40 | 0.19 | BA | C3 | F |
| 26 | 11:28:45.39 | 49 19.88 | 120 05.58 | 16.76$ | 2.0 | 15/18 | 206 | 0.58 | DD | C3 | |
| 28 | 20:42:41.12 | 45 28.90 | 119 29.35 | 0.02* | 2.5 | 24/25 | 154 | 0.31 | CC | O0 | P |

**Table 1.2.** Stations recorded digitally by the Washington Regional Seismograph Network from 1987 to 1989 (see Figs. 1.1 and 1.2), plus station SEA (not digital). Stations are in Washington State unless otherwise noted in the **Station location** column. The **Years** column shows years during which the station was being recorded: 7__ means 1987 only; 78_ means 1987 and 1988; 789 means 1987, 1988, and 1989. The **Changes** column indicates changes in station operation as a type of change and the month/year of change; types of changes are: I, installed; R, removed; B, began recording at the WRSN (station not operated by WRSN); and E, ended recording at the WRSN (station not operated by WRSN).

In the **Station location** column: OR indicates an Oregon station; USGS indicates a station operated by the U.S. Geological Survey; **Westinghouse/Hanford** or **West/Han** indicates a station operated by Westinghouse Hanford Co.; **WWSSN** indicates a World Wide Standardized Seismograph Network station operated by the U.S. Geological Survey; **MSH** indicates Mount St. Helens; **WA** indicates a Wood-Anderson seismograph; **psuedo-WA** indicates an instrument that electronically simulates a Wood-Anderson seismograph; **Z**, **N**, or **E** indicate instruments recording vertical, horizontal north-south, or horizontal east-west ground motion, respectively

| Station name | Years | Latitude (N) (degrees | minutes | seconds) | Longitude (W) (degrees | minutes | seconds) | Elevation (km) | Changes | Station location |
|---|---|---|---|---|---|---|---|---|---|---|
| APW | 789 | 46 | 39 | 06.0 | 122 | 38 | 51.0 | 0.457 | | Alpha Peak |
| ASR | 789 | 46 | 09 | 02.4 | 121 | 35 | 33.6 | 1.280 | | Mount Adams–Stagman Ridge |
| AUG | 789 | 45 | 44 | 10.0 | 121 | 40 | 50.0 | 0.865 | | Augspurger Mountain |
| BHW | 789 | 47 | 50 | 12.6 | 122 | 01 | 55.8 | 0.198 | | Bald Hill |
| BLN | 789 | 48 | 00 | 26.5 | 122 | 58 | 18.6 | 0.585 | | Blyn Mountain |
| BOW | 789 | 46 | 28 | 30.0 | 123 | 13 | 41.0 | 0.870 | | Boistfort Mountain |
| BPO | 789 | 44 | 39 | 06.9 | 121 | 41 | 19.2 | 1.957 | I 9/87 | Bald Peter, OR |
| BRV | 789 | 46 | 29 | 07.2 | 119 | 59 | 29.4 | 0.925 | | Black Rock Valley |
| BVW | 789 | 46 | 48 | 30.6 | 119 | 52 | 48.0 | 0.707 | | Beverly |
| CBS | 789 | 47 | 48 | 16.7 | 120 | 02 | 27.6 | 1.073 | I 12/87 | Chelan Butte (south) |
| CBW | 7__ | 47 | 48 | 25.5 | 120 | 01 | 57.6 | 1.160 | R 12/87 | Chelan Butte |
| CDF | 789 | 46 | 06 | 58.2 | 122 | 02 | 51.0 | 0.780 | | Cedar Flats |
| CHO | 78_ | 45 | 35 | 27.0 | 118 | 34 | 45.0 | 1.076 | R 8/88 | Cabbage Hill, OR |
| CMM | 789 | 46 | 26 | 07.0 | 122 | 30 | 21.0 | 0.620 | | Crazy Man Mountain |
| CMW | 789 | 48 | 25 | 25.3 | 122 | 07 | 08.4 | 1.190 | | Cultus Mountains |
| COW | 789 | 46 | 29 | 27.6 | 122 | 00 | 43.6 | 0.305 | R 4/89 | Cowlitz River |
| CPW | 789 | 46 | 58 | 25.8 | 123 | 08 | 10.8 | 0.792 | | Capitol Peak |
| CRF | 789 | 46 | 49 | 30.6 | 119 | 23 | 18.0 | 0.260 | | Corfu |
| DPW | 789 | 47 | 52 | 14.3 | 118 | 12 | 10.2 | 0.892 | | Davenport |
| DY2 | 789 | 47 | 59 | 06.9 | 119 | 46 | 13.3 | 0.884 | | Dyer Hill 2 |
| EDM | 789 | 46 | 11 | 50.4 | 122 | 09 | 00.0 | 1.609 | | East Dome |
| ELK | 789 | 46 | 18 | 20.0 | 122 | 20 | 27.0 | 1.270 | | Elk Rock |
| ELL | 789 | 46 | 54 | 34.8 | 120 | 33 | 58.8 | 0.789 | | Ellensburg |
| EPH | 789 | 47 | 21 | 12.8 | 119 | 35 | 46.2 | 0.628 | | Ephrata |
| ET2 | __9 | 46 | 32 | 06.0 | 118 | 57 | 01.2 | 0.330 | I 4/89 | Eltopia |
| ETP | 789 | 46 | 27 | 53.4 | 119 | 03 | 32.4 | 0.250 | R 4/89 | Eltopia |
| ETW | 789 | 47 | 36 | 16.2 | 120 | 19 | 51.6 | 1.475 | | Entiat |
| FL2 | 789 | 46 | 11 | 47.0 | 122 | 21 | 01.0 | 1.378 | | Flat Top 2 |
| FMW | 789 | 46 | 56 | 29.6 | 121 | 40 | 11.3 | 1.859 | | Mount Fremont |
| FOX | 7__ | 48 | 19 | 50.0 | 119 | 42 | 29.0 | 0.896 | R 4/87 | Fox Mountain |
| GBL | 789 | 46 | 35 | 51.6 | 119 | 27 | 35.4 | 0.330 | | Gable Mountain |
| GHW | 789 | 47 | 02 | 30.0 | 122 | 16 | 21.0 | 0.268 | | Garrison Hill |
| GL2 | 789 | 45 | 57 | 35.0 | 120 | 49 | 22.5 | 1.000 | | New Goldendale |
| GLK | 789 | 46 | 33 | 50.2 | 121 | 36 | 30.7 | 1.320 | | Glacier Lake |

**Table 1.2.** Stations recorded digitally by the Washington Regional Seismograph Network from 1987 to 1989 *(continued)*

| Station name | Years | Latitude (N) (degrees | minutes | seconds) | Longitude (W) (degrees | minutes | seconds) | Elevation (km) | Changes | Station location |
|---|---|---|---|---|---|---|---|---|---|---|
| GMO | 789 | 44 | 26 | 02.8 | 120 | 57 | 22.3 | 1.689 | I 8/87 | Grizzly Mountain, OR |
| GMW | 789 | 47 | 32 | 52.5 | 122 | 47 | 10.8 | 0.506 | | Gold Mountain |
| GRO | 789 | 45 | 21 | 04.5 | 123 | 39 | 43.0 | 0.945 | | Grindstone Mountain, OR |
| GSM | 789 | 47 | 12 | 11.4 | 121 | 47 | 40.2 | 1.305 | | Grass Mountain |
| GUL | 789 | 45 | 55 | 27.0 | 121 | 35 | 44.0 | 1.189 | | Guler Mountain |
| HDW | 789 | 47 | 38 | 54.6 | 123 | 03 | 15.2 | 1.006 | | Hoodsport |
| HH2 | _8_ | 46 | 10 | 18.0 | 119 | 23 | 01.0 | 0.490 | I 8/87 R 8/88 | Horse Heaven Hills |
| HHW | 7__ | 46 | 10 | 59.0 | 119 | 22 | 59.0 | 0.415 | R 3/87 | Horse Heaven Hills |
| HSR | 789 | 46 | 10 | 22.2 | 122 | 10 | 58.2 | 1.774 | | South Ridge (MSH) |
| HTW | 789 | 47 | 48 | 12.5 | 121 | 46 | 08.6 | 0.829 | | Haystack Lookout |
| JBO | 789 | 45 | 27 | 41.7 | 119 | 50 | 13.3 | 0.645 | | Jordan Butte, OR |
| JCW | 789 | 48 | 11 | 42.7 | 121 | 55 | 31.1 | 0.792 | | Jim Creek |
| JUN | 789 | 46 | 08 | 48.0 | 122 | 09 | 10.8 | 1.049 | | June Lake |
| KMO | 789 | 45 | 38 | 07.8 | 123 | 29 | 22.2 | 0.975 | | Kings Mountain, OR |
| KOS | 789 | 46 | 27 | 40.8 | 122 | 11 | 25.8 | 0.828 | | Kosmos |
| LMW | 789 | 46 | 40 | 04.8 | 122 | 17 | 28.8 | 1.195 | | Ladd Mountain |
| LNO | 789 | 45 | 52 | 15.8 | 118 | 17 | 06.0 | 0.768 | | Lincton Mountain, OR |
| LOC | __9 | 46 | 43 | 04.8 | 119 | 25 | 54.6 | 0.201 | B 8/89 | Westinghouse/Hanford |
| LON | 789 | 46 | 45 | 00.0 | 121 | 48 | 36.0 | 0.853 | | Longmire (WWSSN) |
| LO2 | _89 | 46 | 45 | 00.0 | 121 | 48 | 36.0 | 0.853 | I 3/88 | Longmire |
| LVP | 789 | 46 | 04 | 06.0 | 122 | 24 | 30.0 | 1.170 | | Lakeview Peak |
| MBW | 789 | 48 | 47 | 02.4 | 121 | 53 | 58.8 | 1.676 | | Mount Baker |
| MCW | 789 | 48 | 40 | 46.8 | 122 | 49 | 56.4 | 0.693 | | Mount Constitution |
| MDW | 789 | 46 | 36 | 48.0 | 119 | 45 | 39.0 | 0.330 | | Midway |
| MEW | 789 | 47 | 12 | 07.0 | 122 | 38 | 45.0 | 0.098 | | McNeil Island |
| MJ2 | __9 | 46 | 33 | 28.0 | 119 | 21 | 50.0 | 0.150 | B 3/89 | Westinghouse/Hanford |
| MOX | 789 | 46 | 34 | 38.0 | 120 | 17 | 35.0 | 0.540 | | Moxee City |
| MTM | 789 | 46 | 01 | 31.8 | 122 | 12 | 42.0 | 1.121 | | Mount Mitchell |
| NAC | 789 | 46 | 43 | 59.4 | 120 | 49 | 25.2 | 0.728 | | Naches |
| NCO | 789 | 43 | 42 | 14.4 | 121 | 08 | 18.0 | 1.908 | I 9/87 | Newberry Crater, OR |
| NEL | 789 | 48 | 04 | 41.8 | 120 | 20 | 17.7 | 1.490 | | Nelson Butte |
| NEW | 7__ | 48 | 15 | 50.0 | 117 | 07 | 13.0 | 0.760 | E 3/87 | Newport (USGS) |
| NLO | 789 | 46 | 05 | 18.0 | 123 | 27 | 00.0 | 0.900 | | Nicolai Mountain, OR |
| OBC | 789 | 48 | 02 | 07.1 | 124 | 04 | 39.0 | 0.938 | | Olympics–Bonidu Creek |
| OBH | 789 | 47 | 19 | 34.5 | 123 | 51 | 57.0 | 0.383 | | Olympics–Burnt Hill |
| OD2 | __9 | 47 | 23 | 27.6 | 118 | 42 | 38.4 | 0.590 | I 9/89 | Odessa site #2 |
| ODS | 789 | 47 | 18 | 24.0 | 118 | 44 | 42.0 | 0.523 | R 6/89 | Odessa |
| OFK | 789 | 47 | 57 | 00.0 | 124 | 21 | 28.1 | 0.134 | | Olympics–Forks |
| OHW | 789 | 48 | 19 | 24.0 | 122 | 31 | 54.6 | 0.054 | | Oak Harbor |
| OLQ | 789 | 47 | 30 | 58.1 | 123 | 48 | 31.5 | 0.121 | R 6/89 | Olympics–Lake Quinault |
| ONR | 789 | 46 | 52 | 37.5 | 123 | 46 | 16.5 | 0.257 | | Olympics–North River |
| OOW | 789 | 47 | 44 | 12.0 | 124 | 11 | 22.0 | 0.743 | | Olympics–Octopus West |
| OSD | 789 | 47 | 49 | 15.0 | 123 | 42 | 06.0 | 2.010 | | Olympics–Snow Dome |
| OSP | 789 | 48 | 17 | 05.5 | 124 | 35 | 23.3 | 0.585 | | Olympics–Sooes Peak |
| OSR | __9 | 47 | 30 | 02.3 | 123 | 57 | 42.0 | 0.815 | I 9/89 | Olympics–Salmon Ridge |
| OTH | 78_ | 46 | 44 | 20.4 | 119 | 12 | 59.4 | 0.260 | R 12/88 | Othello |
| OT2 | _89 | 46 | 43 | 17.0 | 119 | 14 | 05.0 | 0.355 | I 12/88 | New Othello |
| OTR | 789 | 48 | 05 | 08.0 | 124 | 02 | 39.0 | 0.712 | | Olympics–Tyee Ridge |
| PAT | 789 | 45 | 52 | 50.1 | 119 | 45 | 40.1 | 0.300 | | Paterson |
| PGO | 789 | 45 | 28 | 00.0 | 122 | 27 | 10.0 | 0.237 | | Gresham, OR |
| PGW | 789 | 47 | 49 | 18.8 | 122 | 35 | 57.7 | 0.122 | | Port Gamble |
| PRO | 789 | 46 | 12 | 45.6 | 119 | 41 | 09.0 | 0.552 | | Prosser |
| RC1 | _89 | 46 | 56 | 36.0 | 119 | 26 | 00.0 | 0.500 | B 5/88 | Royal City (West/Han) |
| RCS | __9 | 46 | 52 | 15.6 | 121 | 43 | 52.0 | 2.877 | I 6/89 | Rainier–Camp Schurman |
| REM | 789 | 46 | 11 | 57.0 | 122 | 11 | 03.0 | 2.102 | B 1/87 | Rembrandt (USGS) |
| RER | __9 | 46 | 49 | 09.2 | 121 | 50 | 27.3 | 1.756 | I 7/89 | Rainier-Emerald Ridge |
| RMW | 789 | 47 | 27 | 35.0 | 121 | 48 | 19.2 | 1.024 | | Rattlesnake Mountain (west) |
| RPK | 78_ | 45 | 45 | 42.0 | 120 | 13 | 50.0 | 0.330 | R 8/88 | Roosevelt Peak |
| RPW | 789 | 48 | 26 | 54.0 | 121 | 30 | 49.0 | 0.850 | | Rockport |
| RSW | 789 | 46 | 23 | 28.2 | 119 | 35 | 19.2 | 1.037 | | Rattlesnake Mountain (east) |
| RVC | 789 | 46 | 56 | 34.5 | 121 | 58 | 17.3 | 1.000 | | Rainier–Voight Creek |
| RVW | 789 | 46 | 08 | 58.2 | 122 | 44 | 37.2 | 0.460 | | Rose Valley |
| SAW | 789 | 47 | 42 | 06.0 | 119 | 24 | 03.6 | 0.690 | | St. Andrews |
| SEA | 789 | 47 | 39 | 18.0 | 122 | 18 | 30.0 | 0.030 | | Seattle (WA) |
| SEE | 789 | 47 | 39 | 18.0 | 122 | 18 | 30.0 | 0.030 | I 1/87 | Seattle (pseudo-WA; E) |
| SEN | 789 | 47 | 39 | 18.0 | 122 | 18 | 30.0 | 0.030 | I 1/87 | Seattle (pseudo-WA; N) |
| SEV | 789 | 47 | 39 | 18.0 | 122 | 18 | 30.0 | 0.030 | I 1/87 | Seattle (Z) |
| SHW | 789 | 46 | 11 | 50.6 | 122 | 14 | 08.4 | 1.399 | | Mount St. Helens |
| SIG | 7__ | 46 | 12 | 45.0 | 122 | 11 | 09.0 | 1.800 | S 12/87 | Microphone (MSH) |
| SMW | 789 | 47 | 19 | 10.2 | 123 | 20 | 30.0 | 0.840 | | South Mountain |

**Table 1.2.** Stations recorded digitally by the Washington Regional Seismograph Network from 1987 to 1989 *(continued)*

| Station name | Years | Latitude (N) (degrees | minutes | seconds) | Longitude (W) (degrees | minutes | seconds) | Elevation (km) | Changes | Station location |
|---|---|---|---|---|---|---|---|---|---|---|
| SND | 78_ | 46 | 12 | 45.0 | 122 | 11 | 09.0 | 1.800 | R 7/88 | Microphone (MSH) |
| SOS | 789 | 46 | 14 | 38.5 | 122 | 08 | 12.0 | 1.270 | | Source of Smith Creek |
| SPW | 789 | 47 | 33 | 13.3 | 122 | 14 | 45.1 | 0.008 | | Seattle–Seward Park |
| STD | 789 | 46 | 14 | 16.0 | 122 | 13 | 21.9 | 1.268 | | Studebaker Ridge |
| STW | 789 | 48 | 09 | 02.9 | 123 | 40 | 13.1 | 0.308 | | Striped Peak |
| SYR | 78_ | 46 | 51 | 46.8 | 119 | 37 | 04.2 | 0.267 | R 5/88 | Smyrna |
| TBM | 789 | 47 | 10 | 10.1 | 120 | 35 | 54.0 | 1.064 | | Table Mountain |
| TCO | 789 | 44 | 06 | 21.0 | 121 | 36 | 01.0 | 1.975 | I 8/87 | Three Creek Meadows, OR |
| TDH | 789 | 45 | 17 | 23.4 | 121 | 47 | 25.2 | 1.541 | | Tom, Dick and Harry Mtn., OR |
| TDL | 789 | 46 | 21 | 03.0 | 122 | 12 | 57.0 | 1.400 | | Tradedollar Lake |
| TWW | 789 | 47 | 08 | 17.2 | 120 | 52 | 04.5 | 1.046 | | Teanaway |
| VBE | 789 | 45 | 03 | 37.2 | 121 | 35 | 12.6 | 1.544 | | Beaver Butte, OR |
| VCR | 789 | 44 | 58 | 58.2 | 120 | 59 | 17.3 | 1.015 | I 8/87 | Criterion Ridge, OR |
| VFP | 789 | 45 | 19 | 05.0 | 121 | 27 | 54.3 | 1.716 | | Flag Point, OR |
| VG2 | 789 | 45 | 09 | 20.0 | 122 | 16 | 15.0 | 0.823 | | Goat Mountain, OR |
| VGB | 789 | 45 | 30 | 56.4 | 120 | 46 | 39.0 | 0.729 | | Gordon Butte, OR |
| VIP | 789 | 44 | 30 | 29.4 | 120 | 37 | 07.8 | 1.731 | | Ingram Point, OR |
| VLL | 789 | 45 | 27 | 48.0 | 121 | 40 | 45.0 | 1.195 | | Laurance Lake, OR |
| VLM | 789 | 45 | 32 | 18.6 | 122 | 02 | 21.0 | 1.150 | | Little Larch, OR |
| VTG | 789 | 46 | 57 | 28.8 | 119 | 59 | 14.4 | 0.208 | | Vantage |
| VTH | 789 | 45 | 10 | 52.2 | 120 | 33 | 40.8 | 0.773 | | The Trough, OR |
| WA2 | 789 | 46 | 45 | 24.2 | 119 | 33 | 45.5 | 0.230 | | Wahluke Slope |
| WAT | 789 | 47 | 41 | 55.0 | 119 | 57 | 15.0 | 0.900 | | Waterville |
| WBW | 78_ | 48 | 01 | 04.2 | 119 | 08 | 13.8 | 0.825 | R 8/88 | Wilson Butte |
| WEN | 78_ | 47 | 31 | 46.2 | 120 | 11 | 39.0 | 1.061 | R 6/88 | Wenatchee |
| WG2 | 789 | 46 | 01 | 50.2 | 118 | 51 | 20.0 | 0.511 | I 4/87 | Wallula Gap |
| WGE | 7__ | 46 | 03 | 09.0 | 118 | 48 | 08.0 | 0.262 | R 4/87 | Wallula Gap (east) |
| WIW | 789 | 46 | 25 | 48.8 | 119 | 17 | 13.4 | 0.130 | | Wooded Island |
| WNS | 78_ | 46 | 42 | 37.0 | 120 | 34 | 30.0 | 1.000 | R 8/88 | Wenas |
| WP2 | _89 | 45 | 33 | 57.2 | 122 | 47 | 06.9 | 0.341 | I 12/88 | West Portland, OR |
| WPO | 78_ | 45 | 34 | 24.0 | 122 | 47 | 22.4 | 0.334 | R 12/88 | West Portland, OR |
| WPW | 789 | 46 | 41 | 53.4 | 121 | 32 | 48.0 | 1.250 | | White Pass |
| WRD | 789 | 46 | 58 | 11.4 | 119 | 08 | 36.0 | 0.378 | | Warden |
| YAK | 789 | 46 | 31 | 43.8 | 120 | 31 | 14.4 | 0.629 | | Yakima |
| YEL | 789 | 46 | 12 | 35.0 | 122 | 11 | 16.0 | 1.750 | | Yellow Rock |

**Table 1.4.** Felt earthquakes, 1987–1989. **Day** gives year, month, and day of earthquake. **Time** is hour and minute in Coordinated Universal Time (subtract 8 hours for Pacific Standard Time or 7 hours for Pacific Daylight Time). **Latitude** is degrees and minutes north. **Longitude** is degrees and minutes west. **H** is earthquake depth in kilometers, **M** is coda-duration magnitude of the earthquake, and **Intensity** is an estimate of the maximum Modified Mercalli Intensity (see p. 29) from earthquake felt reports. Intensities in parentheses are estimated from reports received by the University of Washington. Other intensities are from the National Earthquake Information Center, U.S. Geological Survey (Carl W. Stover, written commun., 1991). **Location** is in Washington except where noted as OR or BC

| Day | Time | Latitude (N) | | Longitude (W) | | H (km) | M | Intensity | Location |
|---|---|---|---|---|---|---|---|---|---|
| 87/02/28 | 14:55 | 47 | 49.99 | 120 | 02.89 | 1 | 2.6 | (felt) | Chelan |
| 87/03/17 | 16:34 | 48 | 15.36 | 121 | 45.66 | 3 | 2.8 | IV | Darrington |
| 87/03/17 | 16:39 | 48 | 15.89 | 121 | 45.95 | 3 | 1.1 | (felt) | Darrington |
| 87/03/19 | 18:40 | 48 | 15.18 | 121 | 45.13 | 4 | 2.1 | III | Darrington |
| 87/04/05 | 01:06 | 48 | 15.36 | 121 | 44.74 | 2 | 2.8 | IV | Darrington |
| 87/04/28 | 06:42 | 47 | 36.61 | 122 | 45.80 | 20 | 2.8 | IV | Belfair, Kitsap Peninsula |
| 87/05/16 | 09:08 | 45 | 44.00 | 122 | 35.17 | 21 | 2.3 | (felt) | felt by one person in Vancouver, WA |
| 87/06/18 | 10:15 | 47 | 32.29 | 122 | 49.57 | 19 | 2.4 | III | Maple Valley |
| 87/06/19 | 05:47 | 46 | 47.65 | 124 | 21.04 | 38 | 3.9 | IV | Tokeland, South Bay, and Raymond |
| 87/08/06 | 21:12 | 48 | 07.80 | 122 | 45.83 | 22 | 2.7 | (felt) | Whidbey Island |
| 87/08/09 | 03:32 | 45 | 08.67 | 120 | 51.62 | 28 | 2.4 | (felt) | Deschutes Valley, OR |
| 87/09/08 | 05:02 | 45 | 11.47 | 120 | 04.32 | 13 | 3.1 | (felt) | Condon, OR |
| 87/09/16 | 20:10 | 49 | 05.72 | 122 | 42.00 | 12 | 3.3 | (felt) | Blaine |
| 87/09/20 | 06:55 | 48 | 08.37 | 122 | 45.27 | 21 | 2.8 | (felt) | felt by two people in Port Townsend |
| 87/09/29 | 16:20 | 45 | 10.57 | 120 | 03.67 | 20 | 2.7 | (felt) | Condon, OR |
| 87/10/02 | 02:32 | 45 | 44.06 | 122 | 34.86 | 19 | 2.6 | (felt) | Vancouver, WA |
| 87/12/02 | 07:12 | 46 | 40.49 | 120 | 41.03 | 18 | 4.1 | V | Naches, Goose Prairie |
| 87/12/02 | 09:02 | 46 | 40.75 | 120 | 40.39 | 18 | 4.3 | IV | Goose Prairie, Hanford, Wenatchee |
| 87/12/19 | 20:30 | 48 | 27.67 | 123 | 22.50 | 24 | 2.7 | (felt) | Victoria, BC |
| 87/12/20 | 07:14 | 47 | 46.09 | 119 | 21.67 | 1 | 1.2 | (felt) | Sims Corner |
| 87/12/20 | 07:28 | 47 | 44.44 | 119 | 21.18 | 17 | 1.1 | (felt) | Sims Corner |
| 87/12/20 | 07:38 | 47 | 46.56 | 119 | 22.02 | 0 | 2.7 | (felt) | Sims Corner |
| 88/01/08 | 07:18 | 47 | 03.93 | 122 | 08.86 | 0 | 2.7 | III | Enumclaw, Orting |
| 88/01/26 | 08:13 | 47 | 24.85 | 121 | 48.94 | 20 | 2.9 | (felt) | North Bend |
| 88/02/06 | 12:51 | 47 | 39.98 | 120 | 01.42 | 7 | 3.0 | (felt) | Chelan |
| 88/03/11 | 10:01 | 47 | 11.44 | 122 | 19.33 | 65 | 3.9 | III | Federal Way, Puyallup, Olympia |
| 88/03/12 | 11:53 | 48 | 13.94 | 121 | 39.83 | 3 | 2.5 | II | Darrington (White Horse) |
| 88/04/04 | 02:47 | 48 | 29.63 | 122 | 07.95 | 2 | 2.9 | IV | Sedro Woolley, Clear Lake |
| 88/05/05 | 00:18 | 47 | 39.07 | 120 | 19.27 | 7 | 3.3 | (felt) | Wenatchee |
| 88/06/16 | 11:04 | 47 | 42.43 | 121 | 53.84 | 8 | 3.1 | III | Carnation |
| 88/07/08 | 04:02 | 48 | 05.09 | 121 | 31.88 | 0 | 3.2 | IV | Verlot |
| 88/07/14 | 17:01 | 48 | 19.09 | 122 | 05.87 | 12 | 3.1 | (felt) | Arlington |
| 88/07/29 | 04:59 | 46 | 51.27 | 121 | 54.82 | 12 | 4.1 | V | Carbonado, Randle, Eatonville, Orting, Kapowsin |
| 88/07/29 | 05:59 | 46 | 51.04 | 121 | 55.07 | 11 | 3.8 | (III) | Carbonado, Randle, Eatonville, Orting, Kapowsin |
| 88/09/08 | 13:47 | 48 | 12.42 | 122 | 29.94 | 23 | 2.8 | (felt) | Oak Harbor |
| 88/09/15 | 06:18 | 48 | 28.00 | 123 | 28.22 | 16 | 2.3 | (III) | Victoria, BC |
| 88/09/26 | 00:27 | 48 | 31.55 | 122 | 32.21 | 16 | 3.1 | (felt) | Goldstream, BC |
| 88/10/25 | 07:12 | 48 | 24.27 | 122 | 22.70 | 7 | 2.8 | felt | Skagit County |
| 88/11/29 | 04:13 | 47 | 34.27 | 122 | 24.17 | 10 | 2.6 | III | Seattle |
| 88/12/13 | 13:14 | 48 | 24.73 | 123 | 23.89 | 13 | 1.9 | (felt) | Victoria, BC |
| 88/12/19 | 20:11 | 47 | 34.27 | 122 | 23.90 | 8 | 2.8 | III | Seattle |
| 89/01/13 | 06:33 | 47 | 39.58 | 122 | 11.71 | 0 | 2.1 | III | Mercer Island, Bellevue, Redmond |
| 89/01/13 | 06:39 | 47 | 39.77 | 122 | 11.79 | 0 | 2.4 | (III) | Mercer Island, Bellevue, Redmond |
| 89/01/14 | 06:47 | 46 | 32.82 | 121 | 48.70 | 4 | 3.0 | (felt) | Packwood, Randle |
| 89/01/17 | 13:55 | 47 | 39.19 | 122 | 11.43 | 2 | 3.3 | IV | Seattle |
| 89/01/19 | 12:21 | 47 | 34.11 | 121 | 54.21 | 3 | 2.7 | III | Preston, Fall City, Issaquah |
| 89/01/19 | 12:34 | 47 | 34.16 | 121 | 53.97 | 3 | 2.9 | IV | Preston, Fall City, Issaquah |
| 89/01/29 | 13:45 | 47 | 39.41 | 122 | 12.32 | 0 | 1.4 | (felt) | Kirkland |
| 89/02/06 | 01:25 | 48 | 25.12 | 122 | 12.78 | 0 | 3.2 | V | Mt. Vernon, Burlington |
| 89/02/06 | 09:18 | 48 | 24.80 | 122 | 13.21 | 0 | 1.8 | II | Skagit County |
| 89/02/14 | 21:40 | 48 | 25.62 | 122 | 13.63 | 0 | 4.0 | V | Mt. Vernon, Big Lake |
| 89/02/15 | 01:11 | 48 | 25.01 | 122 | 13.12 | 0 | 2.4 | (felt) | Mt. Vernon |
| 89/02/16 | 20:59 | 48 | 25.38 | 122 | 13.22 | 0 | 2.3 | (felt) | Big Lake |
| 89/02/16 | 21:11 | 48 | 25.23 | 122 | 13.65 | 0 | 2.8 | V | Big Lake |
| 89/02/21 | 06:48 | 47 | 19.41 | 122 | 27.60 | 16 | 3.0 | IV | Federal Way, Enumclaw, Vashon Island, Tacoma, Port Orchard, Fife |
| 89/03/05 | 06:41 | 47 | 48.77 | 123 | 21.41 | 46 | 4.5 | V | Victoria, BC, to Olympia; Port Angeles to Seattle |
| 89/03/06 | 03:09 | 48 | 25.79 | 122 | 13.91 | 0 | 4.2 | V | Mt. Vernon |
| 89/03/06 | 07:56 | 48 | 25.55 | 122 | 13.50 | 1 | 2.0 | (felt) | Mt. Vernon |
| 89/03/06 | 07:59 | 48 | 25.26 | 122 | 13.62 | 0 | 2.4 | (felt) | Mt. Vernon |
| 89/03/07 | 06:40 | 48 | 00.15 | 124 | 23.77 | 30 | 3.1 | IV | Forks |
| 89/03/26 | 06:25 | 47 | 40.60 | 120 | 15.10 | 8 | 2.6 | (felt) | Wenatchee |
| 89/04/05 | 12:01 | 48 | 49.06 | 122 | 04.76 | 3 | 2.8 | II | Deming |
| 89/04/12 | 12:12 | 48 | 25.16 | 122 | 13.80 | 1 | 1.5 | (felt) | Mt. Vernon |
| 89/04/14 | 11:11 | 47 | 39.28 | 122 | 12.00 | 0 | 1.5 | (felt) | Kirkland |
| 89/04/16 | 15:35 | 48 | 24.98 | 122 | 13.21 | 0 | 2.7 | III | Mt. Vernon |

**Table 1.4.** Felt earthquakes, 1987–1989 *(continued)*

| Day | Time | Latitude (N) | | Longitude (W) | | H (km) | M | Intensity | Location |
|---|---|---|---|---|---|---|---|---|---|
| 89/04/19 | 13:27 | 48 | 42.58 | 123 | 20.57 | 24 | 2.9 | (felt) | Sidney to Victoria, BC; and Saltspring Island, BC |
| 89/04/21 | 09:40 | 47 | 23.53 | 122 | 03.37 | 4 | 2.8 | III | Kent |
| 89/05/09 | 18:28 | 48 | 13.83 | 119 | 51.23 | 16 | 4.5 | VI | Chelan, Wenatchee, Manson, Brewster |
| 89/05/22 | 13:4 | 49 | 10.82 | 122 | 00.44 | 4 | 2.1 | (felt) | Chilliwack, BC |
| 89/05/31 | 12:46 | 47 | 57.13 | 121 | 53.65 | 18 | 2.6 | III | Granite Falls |
| 89/06/18 | 20:38 | 47 | 24.58 | 122 | 46.55 | 45 | 4.4 | V | Seattle to Victoria, BC; North Bend to Seattle |
| 89/07/21 | 11:13 | 46 | 32.72 | 121 | 48.58 | 3 | 2.9 | IV | T12N R8E, section 22 |
| 89/08/01 | 23:25 | 45 | 36.54 | 122 | 27.42 | 14 | 3.7 | V | Portland, OR; Kelso; Longview |
| 89/09/04 | 06:34 | 47 | 53.86 | 122 | 38.38 | 18 | 2.7 | III+ | Port Ludlow, Port Gamble |
| 89/09/15 | 10:27 | 45 | 22.36 | 121 | 42.41 | 5 | 3.5 | IV | Mt. Hood |
| 89/10/14 | 17:08 | 48 | 27.59 | 123 | 16.25 | 24 | 2.9 | (felt) | Victoria, BC |
| 89/10/24 | 10:54 | 48 | 55.90 | 125 | 09.34 | 39 | 3.7 | (felt) | Barkley Sound, BC |
| 89/11/30 | 03:00 | 47 | 27.63 | 121 | 42.42 | 13 | 2.2 | (felt) | North Bend |
| 89/12/24 | 08:45 | 46 | 39.00 | 122 | 06.97 | 18 | 4.9 | V | Vancouver, WA, to Seattle; Buckley, Enumclaw, Eatonville, Kent, Port Orchard, Auburn |

**Explanation of the Modified Mercalli Intensity Scale**
(modified from a pamphlet "The severity of an earthquake" prepared by the U.S. Geological Survey in 1986)

I. *Not felt except by a very few under especially favorable circumstances.*

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.

IV. Felt indoors by many, outdoors by few during the day. At night, some awakened, especially light sleepers. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably.

V. Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.

VI. Felt by all; many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.

VII. Damage negligible in buildings of good construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures. Some chimneys broken. Noticed by persons driving automobiles.

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.

X. Few, if any, (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.

XI. Damage total. Lines of sight and level distorted. Objects thrown into the air.

**Table 1.5.** Fault-plane solutions for earthquakes $M_c \geq 3.5$, 1987–1989. The event numbers in the first column are also shown next to the pictorial 'beach ball' representation of each fault-plane solution in Figure 1.7. The next six columns give the origin time (Universal Coordinated Time), location, magnitude, and depth of each earthquake. From each solution, we obtain the specifications for two perpendicular planes (here labeled A and B), one of which represents the true fault plane. P-wave first motions, from which the fault-plane solutions are derived, are not sufficient by themselves to determine whether A or B is the true fault plane. The strike (azimuth measured clockwise from north) and dip (angle from horizontal) of each plane are given in degrees. The general type of the earthquake focal mechanism represented by each fault-plane solution is given in the last column. **Nrml**, normal fault; **Rvrs**, reverse or thrust fault; **Strk**, strike-slip fault. In instances (for example, event 2) where the data are consistent with more than one fault-plane solution, all are tabulated

| Event no. | Year | Month/ Day | Hour: Min | Latitude | Longitude | Magnitude | Depth (km) | Plane A (Strike | Dip) | Plane B (Strike | Dip) | Type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1987 | 6/19 | 05:47 | 46.79 | 124.35 | 3.9 | 38 | 350 | 45E | 209 | 52NW | Nrml |
| 2 | 1987 | 12/02 | 07:12 | 46.67 | 120.68 | 4.1 | 18 | 100 | 50S | 280 | 40N | Rvrs |
| | | | | | | | | 255 | 55N | 131 | 51SW | Rvrs |
| | | | | | | | | 240 | 80NW | 148 | 80SW | Strk |
| 3 | 1987 | 12/02 | 09:02 | 46.68 | 120.67 | 4.3 | 18 | 100 | 55S | 263 | 36N | Rvrs |
| 4 | 1988 | 3/11 | 10:01 | 47.19 | 122.32 | 3.9 | 65 | 0 | 70E | 133 | 28SW | Nrml |
| 5 | 1988 | 5/28 | 09:02 | 46.81 | 119.43 | 3.5 | 0 | 15 | 50E | 248 | 54N | Nrml |
| | | | | | | | | 40 | 40SE | 245 | 53NW | Nrml |
| 6 | 1988 | 7/09 | 01:17 | 46.84 | 119.71 | 3.7 | 4 | 100 | 35S | 280 | 55N | Rvrs |
| 7 | 1988 | 7/29 | 04:59 | 46.85 | 121.91 | 4.1 | 12 | 100 | 25S | 237 | 71NW | Rvrs |
| | | | | | | | | 40 | 45SE | 279 | 63N | Rvrs |
| 8 | 1988 | 7/29 | 05:59 | 46.85 | 121.92 | 3.8 | 11 | 95 | 35S | 240 | 60NW | Rvrs |
| 9 | 1988 | 9/29 | 08:09 | 45.85 | 120.26 | 3.5 | 14 | 145 | 30SW | 271 | 71N | Rvrs |
| 10 | 1989 | 2/14 | 21:40 | 48.43 | 122.23 | 4.0 | 0 | 25 | 50SE | 247 | 48NW | Rvrs |
| | | | | | | | | 270 | 70N | 11 | 62E | Strk |
| 11 | 1989 | 3/05 | 06:41 | 47.81 | 123.36 | 4.5 | 46 | 10 | 50E | 175 | 41W | Nrml |
| 12 | 1989 | 3/06 | 03:09 | 48.43 | 122.23 | 4.2 | 0 | 40 | 45SE | 247 | 48NW | Rvrs |
| | | | | | | | | 275 | 70N | 16 | 62E | Strk |
| 13 | 1989 | 5/09 | 18:28 | 48.23 | 119.85 | 4.5 | 16 | 135 | 55SW | 11 | 51E | Nrml |
| 14 | 1989 | 6/18 | 20:38 | 47.41 | 122.78 | 4.4 | 45 | 180 | 70W | 270 | 90N | Strk |
| 15 | 1989 | 8/01 | 23:25 | 45.61 | 122.46 | 3.7 | 14 | 65 | 60SE | 319 | 64NE | Strk |
| 16 | 1989 | 9/15 | 10:27 | 45.37 | 121.71 | 3.5 | 5 | 105 | 50S | 208 | 75NW | Strk |
| 17 | 1989 | 12/24 | 08:45 | 46.65 | 122.12 | 4.9 | 18 | 15 | 55E | 267 | 66N | Strk |

**Table 1.6.** Number of Mount St. Helens earthquakes by month, 1987–1989. Area used is 46.15°–46.25°N latitude, 122.1°–122.27°W longitude (same area used in table 4 of Qamar and others, 1987b). Magnitude range includes earthquakes equal to or greater than the smaller magnitude, and less than the larger magnitude: Range 0. to 1., for example, includes earthquakes having $0.0 \leq Mc < 1.0$. The smallest earthquakes located in this time period had magnitude -0.5

| Year | Month | Total number of events | Number of events in selected magnitude ranges -1. to 0. | 0. to 1. | 1. to 2. | 2. to 3. | Maximum magnitude for month |
|---|---|---|---|---|---|---|---|
| 1987 | Jan. | 7 | 1 | 5 | 1 | 0 | 1.0 |
| | Feb. | 4 | 2 | 2 | 0 | 0 | 0.6 |
| | Mar. | 2 | 2 | 0 | 0 | 0 | -0.4 |
| | Apr. | 1 | 0 | 1 | 0 | 0 | 0.7 |
| | May | 2 | 0 | 1 | 1 | 0 | 1.2 |
| | June | 10 | 0 | 8 | 1 | 1 | 2.1 |
| | July | 5 | 1 | 3 | 1 | 0 | 1.4 |
| | Aug | 11 | 0 | 7 | 4 | 0 | 1.6 |
| | Sept. | 3 | 0 | 3 | 0 | 0 | 0.6 |
| | Oct. | 12 | 0 | 12 | 0 | 0 | 0.8 |
| | Nov. | 12 | 1 | 6 | 4 | 1 | 2.1 |
| | Dec. | 14 | 0 | 14 | 0 | 0 | 0.7 |
| 1988 | Jan. | 4 | 0 | 4 | 0 | 0 | 0.4 |
| | Feb. | 14 | 1 | 12 | 1 | 0 | 1.0 |
| | Mar. | 22 | 2 | 20 | 0 | 0 | 0.6 |
| | Apr. | 15 | 0 | 11 | 4 | 0 | 1.9 |
| | May | 8 | 0 | 6 | 2 | 0 | 1.6 |
| | June | 7 | 0 | 6 | 1 | 0 | 1.4 |
| | July | 8 | 0 | 6 | 1 | 1 | 2.0 |
| | Aug. | 23 | 0 | 20 | 3 | 0 | 1.6 |
| | Sept. | 10 | 0 | 9 | 1 | 0 | 1.2 |
| | Oct. | 18 | 3 | 10 | 4 | 1 | 2.4 |
| | Nov. | 11 | 0 | 10 | 1 | 0 | 1.9 |
| | Dec. | 26 | 0 | 22 | 4 | 0 | 1.5 |
| 1989 | Jan. | 45 | 8 | 31 | 6 | 0 | 1.7 |
| | Feb. | 56 | 1 | 48 | 6 | 1 | 2.2 |
| | Mar. | 26 | 1 | 17 | 8 | 0 | 1.6 |
| | Apr. | 77 | 5 | 64 | 8 | 0 | 1.9 |
| | May | 56 | 5 | 47 | 4 | 0 | 1.8 |
| | June | 31 | 1 | 26 | 3 | 1 | 2.3 |
| | July | 36 | 2 | 29 | 5 | 0 | 1.8 |
| | Aug. | 86 | 1 | 54 | 29 | 2 | 2.7 |
| | Sept. | 50 | 4 | 33 | 13 | 0 | 1.9 |
| | Oct. | 182 | 15 | 140 | 27 | 0 | 1.7 |
| | Nov. | 58 | 2 | 42 | 12 | 2 | 2.7 |
| | Dec. | 53 | 4 | 38 | 9 | 2 | 2.6 |

# Part 2: Operation of the Washington Regional Seismograph Network

## INTRODUCTION

The Washington Regional Seismograph Network (WRSN), operated by the Geophysics Program of the University of Washington (UW), has been in operation since late 1969. It has grown from an initial seven-station network in the Puget Sound area to more than 100 stations that cover all of Washington and large parts of northern and western Oregon. In 1990, the network had 119 short-period vertical component stations. Significant expansions of the network took place in 1975 to cover eastern Washington, in 1980 for detailed coverage of Mount St. Helens and the Olympic Peninsula, and in 1981 and 1987 to cover northern Oregon.

The WRSN began real-time event-triggered digital recording in 1980. 'Real time' means that the system processes incoming data immediately and on an ongoing basis, and 'event triggered' means that digitally sampled data are permanently recorded only when seismic signals (or other signals that resemble seismic ones) are detected by a computer algorithm. Before 1980, analog seismic signals from all stations were continuously recorded on photographic Develocorders. Photographic recording ended in late 1984 after the computer system had proven to be reliable. The current system, called *HAWK*, runs on a Concurrent 5600 computer and began operation in 1988. It is based on our previous Digital Equipment Corporation PDP-11/34 *TURKEY* system. We also have continuous 'Helicorder' paper recordings of 20 stations to provide quality control, a backup to the computer system, and continuous monitoring of the Cascade volcanoes, where volcanic earthquakes too small to trigger the recording system may possibly occur.

If signal amplitudes increase at several stations in the same part of the state at about the same time, a computer algorithm causes the system to 'trigger', and digital data are recorded for all stations. Two time channels (the WWVB radio signal and an IRIG-H time code from a time-code generator that is kept synchronized to WWVB) are also recorded to ensure that seismic signals can be precisely timed. A preliminary occurrence time, location, and magnitude are immediately computed for each event by using the individual station trigger times (each accurate to a precision of about 2 seconds). In the event of a large local earthquake, the automatic processing sets off an alarm system to alert a seismologist. The alarms include an audible signal, electronic mail, telephone calls, and a radio pager. (The alarm system also provides notification in the event of power or computer failure, lack of disk space, and some types of software failures.)

Final origin time, location, and magnitude for each earthquake are determined within a few days, when the seismic data have been reviewed by an analyst. The analyst determines the times of seismic-wave arrivals (precision about .01–.1 second) and the durations of the seismic signals (for magnitude determination) and identifies P-wave polarities (up or down first motion) for determination of a focal mechanism.

The Geophysics Program staff maintains a public computer bulletin board that gives the locations of significant Pacific Northwest earthquakes during the previous several days and the locations of significant recent earthquakes anywhere in the world (received from the National Earthquake Information Center). This service is available via modem by dialing a computer (206-685-0889) and logging in as 'quake' with password 'quake'.

Since 1986 (when eruptive activity at Mount St. Helens ceased), an average of 2,800 events per year has been recorded and processed by the WRSN. Of these, approximately 2,000 are earthquakes within the WRSN network for which hypocentral locations, magnitudes, and occurrence times can be determined. About 300 events per year are local or regional events too small to locate accurately; the remaining (500) events are teleseisms (distant earthquakes) or regional earthquakes outside the network, for which we determine approximate locations only.

## SEISMOGRAPH STATIONS AND INSTRUMENTATION

### Equipment

The standard University of Washington seismic telemetry station is similar to those used by the U.S. Geological Survey in central California. Each station consists of (1) a single-component, short-period vertical seismometer, (2) a pre-amplifier/voltage-controlled oscillator (VCO) component, (3) either a phone-line connection or radio for signal transmission, and (4) either non-rechargeable batteries to power the equipment for at least 18 months or a solar panel and rechargeable battery. The seismometers currently used are either Mark Products L-4C or Geotech S-13 1.0-Hz short-period seismometers. Before installation, they are adjusted to a damping of 0.7 critical, and their velocity sensitivity (usually a few hundred volts/m/sec) is checked. The seismometer output voltage is amplified and encoded into an FM signal using a unit that combines an amplifier and a voltage-controlled oscillator (VCO). Several kinds of amplifier/VCO units are presently in use, including Emtel model 6202 and 6242 units, the USGS J302 and J402, and the Interface Technology VCO based on the design of Sean Morrissey.

The output of the VCO is transmitted to the University of Washington by low-power FM radio, voice-grade phone lines, or microwave circuits provided by the Bonneville Power Administration or Puget Power and Light Co., or by some combination of these. Up to eight band-limited FM signals can be combined on one standard phone line. Although about 70 stations use VHF FM radio transmission, only 24 transmit di-

rectly to the UW. The 70 VHF radio links transmit over a combined distance of nearly 5,000 km, the 17 microwave channels a combined distance of nearly 5,000 km, and four long-haul phone lines a total distance of about 600 km.

After the FM signal has reached the UW, the seismometer output voltage is recovered from the FM radio signal by a discriminator, which reverses the action of the VCO. Discriminator models currently in use include Develco 6203 and 6212, Emtel 6203 and 6243, USGS J101, J110, and J120, and Sprengnether and SLU models.

Two sites have non-standard instrumentation. Seattle (SEA) has two Wood-Anderson horizontal seismometers whose signals are recorded on a Helicorder by means of a photo-tube amplifier. SEA also includes two horizontal Geotech S-13 seismometers, which are filtered to provide the same frequency response as standard Wood-Andersons and then recorded digitally. Longmire (LON) is a World-Wide Standardized Network (WWSSN) station, which is now recorded digitally as part of the U.S. Geological Survey Digital WWSSN (DWWSSN). Analog signals from the long-period vertical WWSSN seismometer and from a 1.0 Hz Geotech S-13 vertical seismometer installed by the WRSN at Longmire are telemetered from Longmire to the University of Washington.

### Maintenance

Although many of the Cascade Range and Olympic Mountain stations are inaccessible most of the year because of snow (making maintenance difficult or impossible except during the summer months) overall up-time for the entire WRSN network was 91 percent over the 2-year period 1989–1990 and ranged from 88 percent, at worst, to 96 percent following several months of good field-work conditions. Most seismic stations are visited at least once a year for maintenance and calibration. In addition to regular checks on solar panels and (or) battery power supplies, visits are made in response to problems noticed at the UW. These problems are detected during periodic checks of telemetry channels and discriminators, from the output of an automatic maintenance log made by the recording computer, or from routine analysis of seismic data. The technical staff makes several checks of the discriminators each week to ascertain that each station is functioning normally. In addition, recorded signals from teleseisms and the stronger local events are routinely examined in detail to verify correct operation of all components and to check whether the signal recorded at the UW properly records the polarity (up or down) of ground motion.

## RECORDING AND AUTOMATIC PRELIMINARY DATA ANALYSIS

### *HAWK* Real-Time System

*HAWK* is a reliable and efficient integrated data acquisition and processing system that is modeled after our previous system (*TURKEY*), which, in turn, was closely modeled after the CEDAR system conceived and implemented at CalTech by Carl Johnson (1979). The real-time file system in *HAWK* uses a special separate (not accessible through UNIX) first-in-first-out 'fifo' file system derived from *RAVEN*, a system written by NEWT INC. for Los Alamos National Lab's hot dry rock experiment and licensed to the University of Washington by NEWT INC. Within the *RAVEN* file system, multiplexed digital data are continuously tested for the presence of earthquake-like signals. When such a signal is detected, the multiplexed data are recorded in the RAVEN file system, and the near-real-time processing is then initiated.

Figure 2.1 is a schematic representing the real-time data acquisition system. All channels of incoming seismic data are digitized by the real-time part of *HAWK* at 100 samples per second per channel and briefly (nominally about 20 seconds) stored on a circular 'ring buffer' disk file while the data are examined to see if a seismic 'event' is under way. The ring buffer provides a delay so that the computer can make a decision about whether an event of possible interest is occurring without losing the beginning of the signal. If the signals in the ring buffer do not meet the criteria for an event trigger, they are overwritten by new data. If the triggering criteria are met, the multiplexed data are saved on the *RAVEN* file system.

*HAWK* data recording consists of several concurrently running tasks that are coordinated and monitored by the MAIN task using a block of shared memory.

A decision-making process, called TRIG, monitors the ring buffer and decides when to record data. This involves two separate steps, one to evaluate whether data from individual seismometers show an increase in amplitude, and the other to determine whether several stations that are close together show nearly simultaneous individual triggers (as would be the case for an earthquake signal).

For each individual data channel, long- and short-term average amplitudes are computed (for both rectified and unrectified signals). A change in signal amplitude can be determined by comparing short- and long- term averages. When the fluctuation is large enough, a trigger is declared for that channel.

Because earthquakes or blasts will cause increases in amplitude at a number of nearby stations, TRIG considers groups of stations that are close together as 'subnets'. Stations in Washington and Oregon are grouped into about 20 overlapping subnets with an average of 12 stations in each. When enough channels (usually three or four) within a given subnet have active individual triggers, an 'event' is declared, and DEMON is informed that it should start saving data. Data are saved until all subnet triggers have turned off, so that a large event that sequentially triggers many subnets will continue to record for as long as several minutes. After each seismic event has been detected and recorded, the LOGGER task enters basic information about the event in a log-file and queues the event for further processing.

The DEMON task manages the ring buffer and, when directed by TRIG, stores the event data in the *RAVEN* 'fifo' file system. It also produces a hardware 'heartbeat' pulse used by an external 'watchdog' device, which produces an alarm if the heartbeat stops.

### *HAWK* INTERFACE Task

To maximize the recovery of useful data and minimize the recording of non-seismic data, a number of parameters can be adjusted interactively within the INTERFACE task, which can be initiated by the analyst at any time. Possible adjustments include the identity of stations composing each subnet,

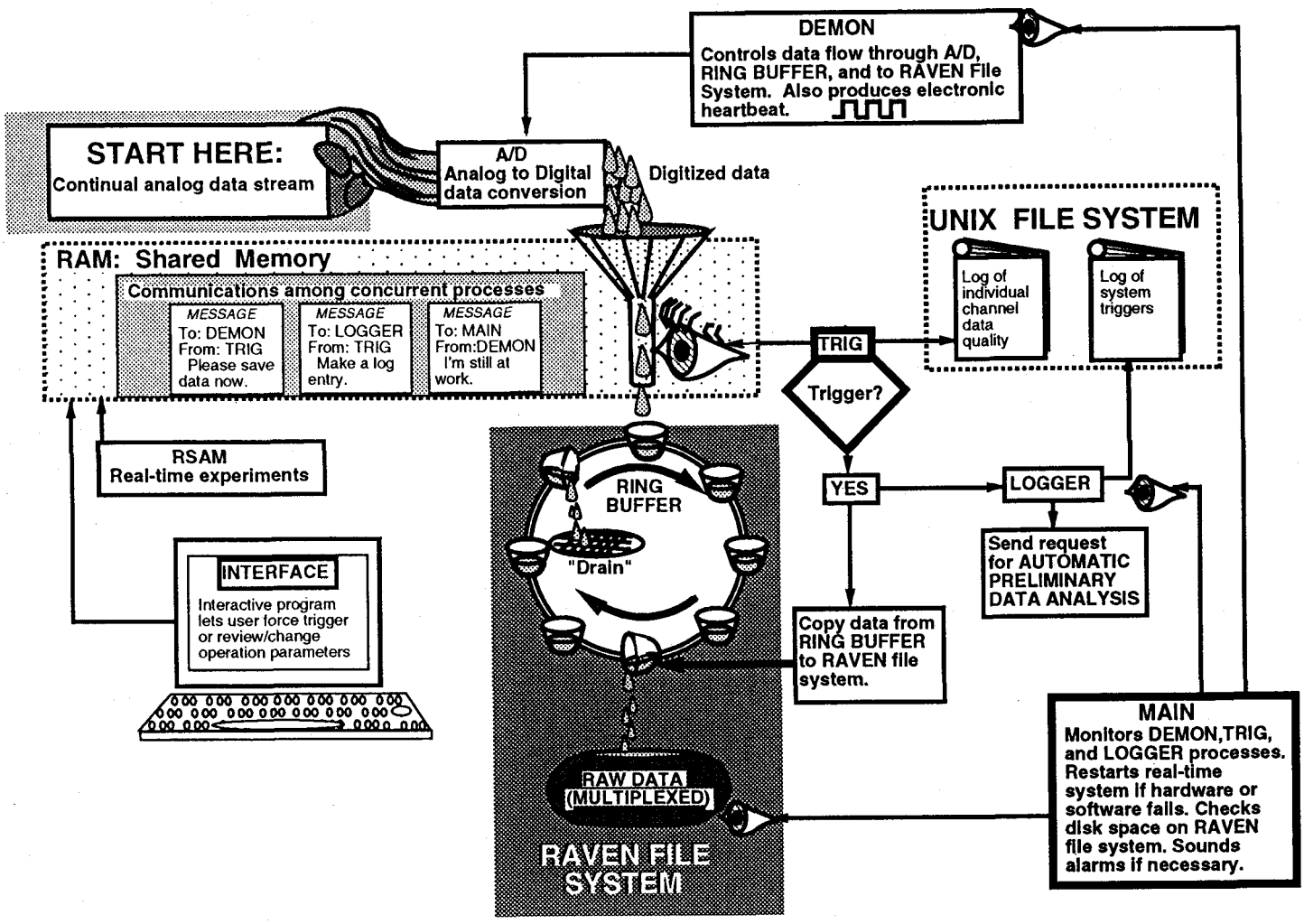


**Figure 2.1. *Real-time data recording.*** Our real-time data analysis system, *HAWK*, consists of four tasks that run simultaneously: MAIN, DEMON, TRIG, and LOGGER. Shared random access memory (RAM) is used for communications among the tasks. Arrows indicate how each task interacts with the data stream and file systems.

**Deciding to record data.** The incoming data 'stream' is digitized at 100 samples per second per channel and stored in a circular 'ring buffer' file, which provides a brief delay, allowing TRIG, the decision-making process, to decide whether the data should be recorded. This process is indicated in the figure by the large 'hairy eyeball', which scrutinizes the data in two steps: one to evaluate whether signals from individual seismometers show increased amplitude and another to determine whether several close-together seismic stations show nearly simultaneous increases in amplitude. If the triggering criteria are met, multiplexed data are written to the *RAVEN* file system, otherwise the ring-buffer data are over-written. TRIG also compiles a data-quality log on the UNIX file system.

After each seismic event has been detected and recorded, the LOGGER task enters basic information about the event in a log file on the UNIX file system and queues the event for further processing. MAIN monitors and coordinates the other tasks, as suggested by the small 'eyes'. The DEMON task manages the ring buffer, stores event data in the *RAVEN* file system, and produces a hardware 'heartbeat' pulse.

**Other features.** Also available in real time are the INTERFACE task, which allows adjustment of parameters such as trigger thresholds for individual stations, the identity or number of stations required for a system trigger to be declared, or the minimum length of an event trigger; and RSAM (Real-time Signal Amplitude Measurement), an optional triggering system based on average signal amplitude (useful for volcanic monitoring).

the number of stations in each subnet required to trigger individually for a system trigger to be declared, station trigger thresholds for the individual stations, the minimum length of time a station remains in a triggered state, and the minimum time period of an event trigger. Currently most single station triggers remain active for at least 15 seconds, and the event trigger stays active for an additional 25 seconds so that the minimum recording time for even a small event is about 40 seconds. INTERFACE can also display one or more station traces in real time on a graphics console.

## *HAWK* Automatic Preliminary Data Analysis

Figure 2.2 is a flow chart showing the automatically initiated procedures of our preliminary data analysis. Preliminary estimates of occurrence time, event location, and magnitude are automatically made for each recorded event using two slightly different automatic processing routines. The first, called QUICKLOC, is usually completed within about 30 seconds of event termination, and it runs only on larger events for which many individual station triggers occurred. QUICKLOC uses trigger times at each station as arrival times in a location routine, and it estimates event magnitude by integrating the rec-

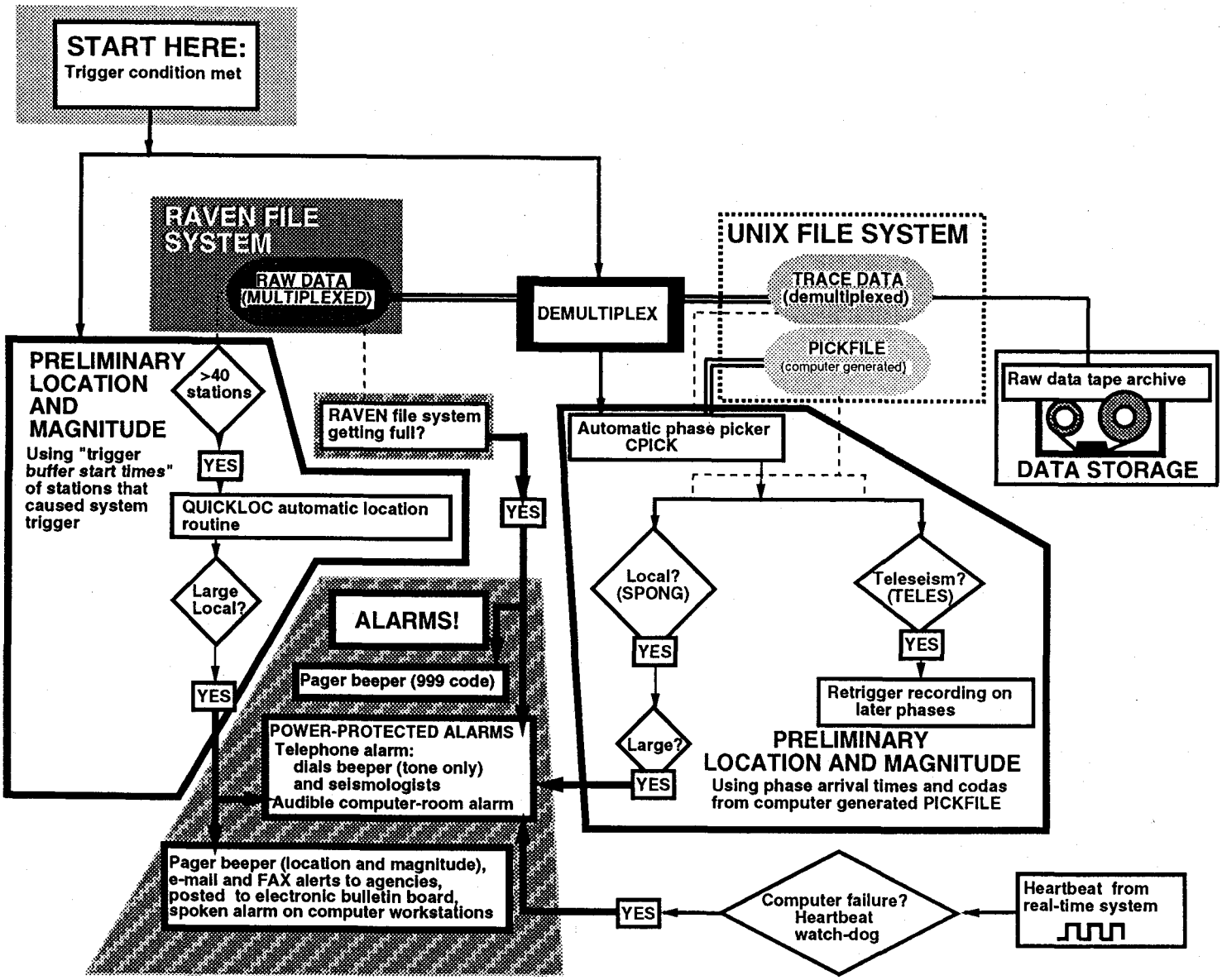


**Figure 2.2. Automatic preliminary data analysis.** Automatic preliminary estimates of occurrence time, event location, and magnitude are made using two slightly different automatic processing routines. Arrows indicate logic flow, dashed lines show which data files are accessed, and double lines indicate modification or creation of data files. In many instances, certain criteria must be met for automatic processing to continue; otherwise the processing stops.

**Preliminary location and magnitude estimates.** The first location and magnitude estimator, QUICKLOC, completes its task very rapidly (usually within about 30 seconds of event termination) and runs only for larger events for which 40 or more individual stations satisfied the trigger criteria. QUICKLOC uses the trigger-buffer start time at each station that triggered as an arrival time in a location routine.

The second automatic processing routine is more precise but slower. For every system trigger, data are demultiplexed from the *RAVEN* file system to the UNIX file system. A phase-picking routine, CPICK, then selects arrival times and coda durations. Standard UW hypocenter determination routines, TELES and SPONG, are used to estimate the event location and magnitude. If the event appears to be large and local (within Washington or Oregon), alarms are initiated. All events are automatically queued to be stored on magnetic tape.

**Alarms and automatic notification.** If either of the preliminary location routines determines that the event is a large local earthquake, seismologists are notified via an assortment of alarms, including an audible alarm, electronic mail, telephone calls, Faxes to emergency agencies and the NEIC, and a digital radio page to a beeper, which is carried by a seismologist at all times. Alarms are also initiated if the real-time 'heartbeat' ceases, or if the *RAVEN* file system begins to fill up.

tified signal over the length of the trigger. QUICKLOC can usually discriminate between a large local earthquake and a teleseism. If it determines that the event is a large local earthquake, it has *HAWK* notify seismologists via an audible alarm, electronic mail, telephone calls, and a digital radio pager (carried by a seismologist at all times) that displays the QUICKLOC event location and magnitude.

The second automatic processing routine is more detailed and time consuming and is activated for all events. Data are demultiplexed from the *RAVEN* file system to the UNIX file system and stored in the standard WRSN University of Washington digital data format, in use since 1980. An automatic P- and S-wave detection and timing routine, CPICK, is run on all the triggered traces and creates a standard-format data 'pick-

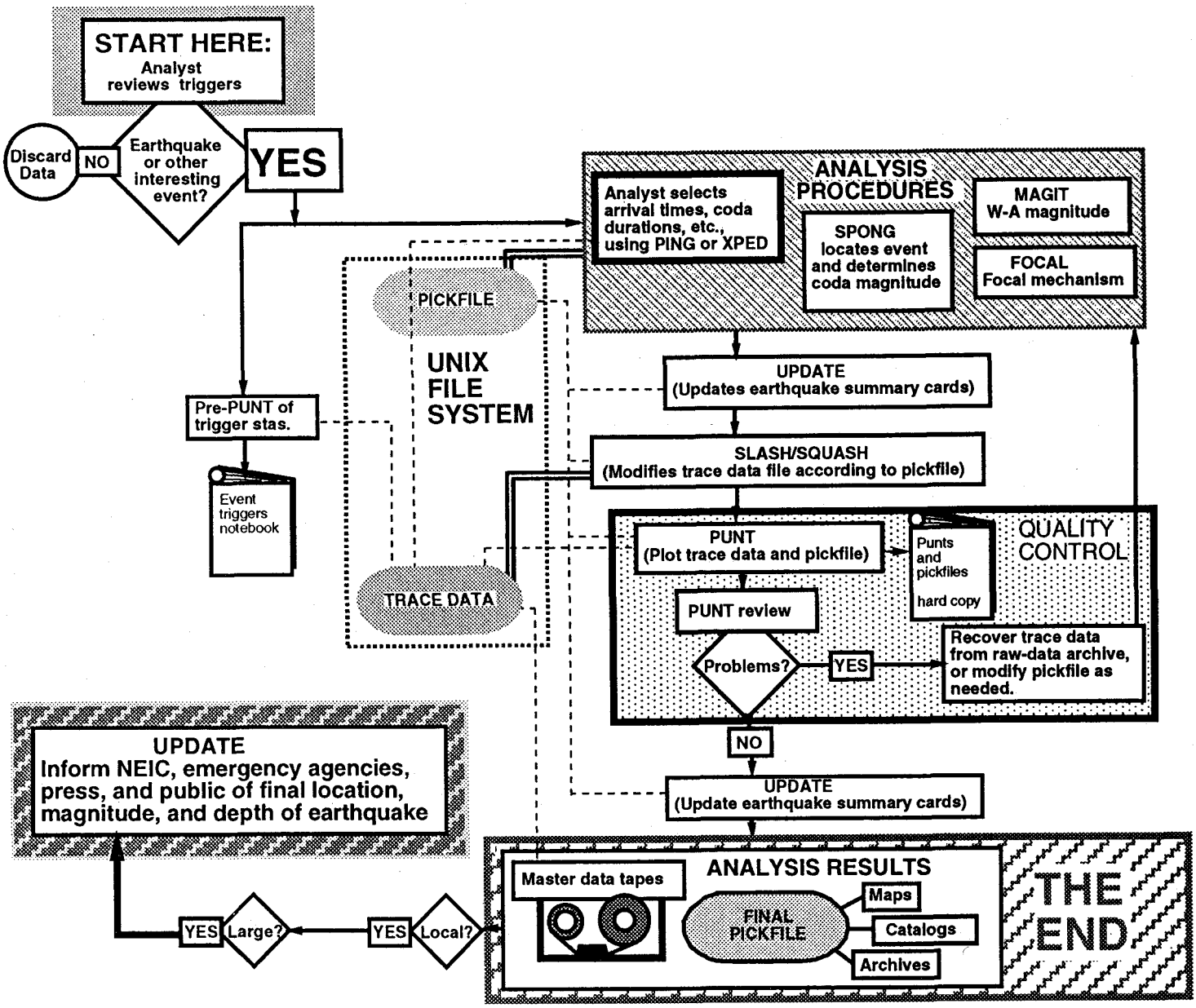


**Figure 2.3.** ***Final data analysis.*** If a sizable event occurs, a seismologist reviews the event as soon as possible—usually within an hour. Otherwise, routine processing is done every day or so. Arrows indicate logic flow, dashed lines show which data files are accessed, and double lines indicate modification or creation of data files.

***Analysis procedures.*** The analysis procedure begins with a review, where non-seismic data (e.g., triggers due to wind noise or electronic glitch) are discarded.

The analyst then invokes an interactive program (XPED or PING) that allows P- and S-wave arrival times to be determined, and signal durations, trace polarities, and signal amplitudes to be specified. For each seismic event, this information is stored on disk in a 'pickfile'. The location program (SPONG) uses the data in the pickfile to determine a location and magnitude for the earthquake, and produces a one-line summary, which is also stored in the pickfile. If information allows, MAGIT allows determination of Richter-type (i.e., Wood-Anderson or W-A) magnitudes, and FOCAL (adapted from the USGS program FPFIT; Reasenberg and Oppenheimer, 1985) can automatically determine a focal mechanism.

**Quality Control.** A plot (PUNT) of the pickfile and the trace data showing phase arrival 'picks' is made and reviewed.

***Analysis results.*** Trace data (edited to include only data of interest) are archived on 'Master Data' magnetic tapes. The final pickfile is permanently saved on disk, where it is used for maps, catalogs, and research. If the event is large or known to have been felt, the National Earthquake Information Center (NEIC), and state- and federal-level emergency agencies receive the updated location and magnitude information, either by fax, e-mail, or phone. Press and public can learn the final location through our voice mail 'current events' option, via modem, or telephone calls.

file' of 'phase' data (arrival times, signal durations or polarity, etc., related to P- or S-waves). Arrival times determined by CPICK are more precise than the trigger times used by QUICKLOC. Our standard hypocenter determination routines, TELES (best for distant earthquakes) and SPONG (best for local earthquakes), are run on the CPICK arrival times.

If this procedure determines an event to be large and local (within Washington or Oregon), the alarm system is activated independently of alarms that may have been initiated by QUICKLOC. Additional alarm conditions exist to alert a seismologist if the computer disk fills with data or if hardware fails.

All demultiplexed digital trace data are automatically stored in a compressed form on 8-mm magnetic tape as a backup procedure.

## FINAL DATA ANALYSIS

Figure 2.3 is a schematic diagram detailing our final data analysis, archiving, and quality-control procedures. A seismic analyst reviews the triggers every day or so, discards data not caused by earthquakes, blasts, or other seismic sources, and then processes the seismic events. Processing begins with an interactive trace picking program (PING or XPED), which allows P- and S-wave arrival times to be determined and signal durations, trace polarities, and signal amplitudes to be specified. For each seismic event, this information is stored on disk in a pickfile. The location program (SPONG) uses the data in the pickfile to determine a location and magnitude for the earthquake and produces a one-line summary, which is stored both in the pickfile itself and in a separate event catalog. A PUNT plot of the earthquake trace data, pickfile, and focal mechanism (if one can be determined) is made; trace data (edited to include only data of interest) are stored on magnetic tape; and the pickfile is archived on the computer.

### Interactive Trace Picking (PING or XPED)

An interactive picking program, PING, is used to conveniently obtain arrival times, coda durations, signal polarities, and selected signal amplitudes from the trace data. PING normally displays all trace data sorted by distance from the station that has the earliest arrival, and it allows the operator to choose which channels are to be examined more closely. These channels are then displayed one at a time and may be scaled in either time or amplitude and band-pass filtered to bring out subtle features. P- and S-wave arrival times are 'picked' and assigned reading uncertainties. The analyst determines signal durations (used to calculate magnitude) and P-wave first motions (used to determine fault-plane solutions). Signal duration is defined as the time from the P-wave arrival until the signal amplitude decreases to twice the amplitude of the background 'noise' that preceded the P-wave arrival. The pickfile produced by PING includes one line of information per station and may include coda duration, P- and S-wave arrival times and amplitudes, and P-wave polarity. PING can also read the pickfile of an event already processed by the location routine (SPONG) and show both the observed phase arrival selected by the analyst and the time difference (or 'travel-time residual') between the observed arrival and the calculated arrival time (computed using the location of the event and a model of velocities in the region). XPED is another interactive phase picking program that uses X-windows (available for a wide variety of computer hardware).

### Earthquake Locations

#### Station locations and velocity models

The earthquake location is initially assigned the location of the seismometer that first recorded a P-wave arrival. A crustal velocity model is then used to compute travel times from that location to all seismic stations that recorded the event. The location is then adjusted until the overall difference between the observed and computed P- and S-wave arrival times is minimized.

We currently use seven different layered crustal velocity models, with a constant velocity assigned to each layer. Each model is used in a specific geographic area and is identified by a two-character code; the first letter corresponds to the geographic region for which the model is appropriate, and the second character is a number identifying the version of the model. For example 'S0' was our initial model for the Mount St. Helens area and has no station corrections. The 'S1' model is a revised St. Helens model with station corrections, and the 'S2' and 'S3' models are further revisions. Table 2.1 shows the velocity models in current use, and Table 2.2 defines the velocity model areas.

Each velocity model includes the velocity within each layer, the depth to each layer, and (optionally) a station list. The station list includes a time correction and quality factor (used for weighting) for each station included in the list. The time correction (in seconds) is added to all readings for the station and represents an adjustment for soil or geologic conditions near the station.

A separate file contains the locations of all stations that are associated with phase readings in our pickfile database. Each station is identified by a three letter station code, with a fourth character available for identifying individual components of a triaxial station.

#### Earthquake Location Algorithm SPONG

**The SPONG Program.** Like most earthquake location programs, the fundamental design of SPONG is based on mathematics originally described by Geiger (1910). The program SPONG is an adaptation of FASTHYPO by Herrmann (1979). The routine that calculates the travel times and partial derivatives is a slight modification to TRVDRV, a well-tested and reliable routine used in HYPO71 and described thoroughly in Lee and Lahr (1975).

The mathematical solution to the problem of using arrival time information to determine the best-fitting source time and location is called 'least-squares inversion'. The problem is non-linear but is linearized by using a trial solution (the location of the nearest station) and making small adjustments, while comparing predicted with observed travel times to compute the next round of adjustments. The adjustment vector is determined by solving a (usually over-determined) linear system of equations. The residuals between predicted and observed travel times for the previous location and the derivative of the travel time with respect to the trial location and time are used to compute the coefficients for these equations. Since the solution of these equations can be unstable, the actual matrix inversion is done by the *QR* or single value decomposition technique (Buland, 1976). Various weighting and damping functions are used to speed convergence to a solution and guarantee convergence to a global minimum. This program has been thoroughly tested on synthetic data, benchmarked against other location routines such as HYPO71 and HYPOELLIPSE, and run on real data from quarry blasts with known locations. These tests indicate that SPONG works well on a variety of data.

**Location iteration logic in SPONG.** The main iteration loop in SPONG contains many tests, and the actions taken de-

**Table 2.1.** Washington Regional Seismograph Network (WRSN) velocity models. See inset map in Figure 1.1 for area boundaries

| Cascades Area (C3) | |
|---|---|
| *Depth range (km)* | *Velocity (km/s)* |
| 0.0–1.0 | 5.1 |
| 1.0–10.0 | 6.0 |
| 10.0–18.0 | 6.6 |
| 18.0–34.0 | 6.8 |
| 34.0–43.0 | 7.1 |
| 43.0–∞ | 7.8 |
| **Southeastern Washington and eastern Oregon (E3)** | |
| *Depth range (km)* | *Velocity (km/s)* |
| 0.0–0.4 | 3.70 |
| 0.4–8.5 | 5.15 |
| 8.5–13.0 | 6.10 |
| 13.0–23.0 | 6.40 |
| 23.0–38.0 | 7.10 |
| 38.0–∞ | 7.90 |
| **Northeastern Washington (N3)** | |
| *Depth range (km)* | *Velocity (km/s)* |
| 0.0–0.5 | 5.1 |
| 0.5–14.0 | 6.1 |
| 14.0–24.0 | 6.4 |
| 24.0–38.0 | 7.1 |
| 38.0–∞ | 7.9 |
| **Western Washington and Oregon (P3)** | |
| *Depth range (km)* | *Velocity (km/s)* |
| 0.0–4.0 | 5.40 |
| 4.0–9.0 | 6.38 |
| 9.0–16.0 | 6.59 |
| 16.0–20.0 | 6.73 |
| 20.0–25.0 | 6.86 |
| 25.0–41.0 | 6.95 |
| 41.0–∞ | 7.80 |
| **Mount St. Helens Area (S3)** | |
| *Depth range (km)* | *Velocity (km/s)* |
| 0.0–2.2 | 4.6 |
| 2.2–3.4 | 5.1 |
| 3.4–6.0 | 6.0 |
| 6.0–10.0 | 6.2 |
| 10.0–18.0 | 6.6 |
| 18.0–34.0 | 6.8 |
| 34.0–43.0 | 7.1 |
| 43.0–∞ | 7.8 |
| **Oregon (O0)** | |
| *Depth range (km)* | *Velocity (km/s)* |
| 0.0–1.3 | 2.9 |
| 1.3–3.4 | 4.7 |
| 3.4–8.0 | 6.0 |
| 8.0–30.0 | 6.4 |
| 30.0–42.0 | 6.8 |
| 42.0–∞ | 7.7 |
| **Offshore oceanic crust (J1)** | |
| *Depth range (km)* | *Velocity (km/s)* |
| 0.0–5.0 | 6.5 |
| 6.5–∞ | 8.0 |

**Table 2.2.** Washington Regional Seismograph Network (WRSN) velocity model areas. See inset map in Figure 1.1 for area boundaries. Coordinates given in table are corner points of area polygons

| Cascades area (C) | |
|---|---|
| *N. Latitude* | *W. Longitude* |
| 45.5 | 123.0 |
| 46.2 | 123.0 |
| 47.4 | 121.6 |
| 49.5 | 121.6 |
| 49.5 | 120.0 |
| 47.0 | 120.7 |
| 45.5 | 120.7 |
| 45.5 | 123.0 |
| **Southeastern Washington and eastern Oregon area (E)** | |
| *N. Latitude* | *W. Longitude* |
| 45.5 | 120.7 |
| 47.0 | 120.7 |
| 47.0 | 117.0 |
| 45.5 | 117.0 |
| 45.5 | 120.7 |
| **Northeastern Washington area (N)** | |
| *N. Latitude* | *W. Longitude* |
| 49.5 | 120.0 |
| 49.5 | 117.0 |
| 47.0 | 117.0 |
| 47.0 | 120.7 |
| 49.5 | 120.0 |
| **Western Washington and Oregon area (P)** | |
| *N. Latitude* | *W. Longitude* |
| 49.5 | 121.6 |
| 47.4 | 121.6 |
| 46.2 | 123.0 |
| 45.5 | 123.0 |
| 45.5 | 126.0 |
| 49.5 | 126.0 |
| 49.5 | 121.6 |
| **Mount St. Helens area (S)** | |
| *N. Latitude* | *W. Longitude* |
| 46.0 | 121.8 |
| 46.0 | 122.5 |
| 46.5 | 122.5 |
| 46.5 | 121.8 |
| 46.0 | 121.8 |
| **Oregon area (O)** | |
| *N. Latitude* | *W. Longitude* |
| 42.5 | 126.0 |
| 45.5 | 126.0 |
| 45.5 | 117.0 |
| 42.5 | 117.0 |
| 42.5 | 126.0 |

pend on fixed constants in some instances and on dynamically changing variables in others. SPONG has been modified to improve on the standard iterative location technique, with the goal of maximizing the confidence in the final hypocenter solution. Enhancements in SPONG can be divided into the following categories: weighting algorithms, adjustment damping algorithms, and termination decisions.

1. *Phase Weighting.* Before it is used in a hypocenter calculation, each arrival-time residual is multiplied by a weight, which is itself the product of five weight values based on reading quality, station, distance of station from epicenter, travel-time residual, and phase type (P or S). The final weight is a number that ranges from 1.0 (full weight) to 0.0 (phase not used at all).

(a) *Reading quality.* Each phase reading has a 'quality' designator that is normally determined by the estimated reading uncertainty in seconds, although the analyst can override this to change the weight of a reading if desired. The relation between quality, timing uncertainty, and SPONG weight is given in Table 2.3a.

(b) *Station weight.* An optional quality factor may be applied to arrivals read on certain stations. Quality factors range from 0 to 4 and translate to weights as described in Table 2.3b. The station quality factor is used to prevent distant stations in other geomorphic provinces from participating in the event location. Each velocity model may include a list of station quality factors, and stations not assigned quality factors receive full weight.

(c) *Distance weight.* A distance weight is applied after the third iteration, when the solution is close to the correct location. Its application depends on two parameters, *xnear* and *xfar*. A weight of 1.0 (full weight) is applied to stations out to a distance of *xnear* km (default is 50 km from the closest seismographic station) and then linearly decreases to a weight of 0.0 at *xfar* (default 150 km). A weight of 1.0 (full weight) is applied to stations within a circle of radius *xnear* + *xmin*, where *xmin* is the distance in kilometers from the epicenter to the nearest station. Stations are downweighted linearly between that radius and a radius equal to *xfar* + *xmin*, beyond which they have zero weight. Normally, *xnear* = 50 km and *xfar* = 100 km.

(d) *Residual weight.* Once the iterative loop has neared convergence (correction vector is less than 100 m), a residual weight is applied to remove the effect of obviously poor data. This weight is either 1.0 (full weight) or 0.0 (no weight) depending on the current residual of a particular phase. If this residual is larger than 2.5 times the average of the absolute value of all residuals during the previous iteration, this phase is given a zero weight. There must be more than six phases and more than five stations before any residual weighting is applied. This weighting routine is only applied once to prevent it from continuously trimming off arrivals during subsequent iterations.

(e) *S-Wave weighting.* By default, S-waves are treated no differently than P-waves, although the reading uncertainty is usually greater than for P-waves. Because S-waves travel more slowly than P-waves by about a factor of 1.78, they have a greater effect on a solution than P-

**Table 2.3.** Phase reading and station weights used in SPONG

| (a) Phase reading quality factors, uncertainties, and weights | | | (b) Station quality factors and weights | |
|---|---|---|---|---|
| Quality | Uncertainty (sec) | SPONG weight | Quality | SPONG weight |
| 0 | <0.03 | 1.00 | 0 | 1.00 |
| 1 | <0.06 | 0.75 | 1 | 0.75 |
| 2 | <0.15 | 0.50 | 2 | 0.50 |
| 3 | <0.30 | 0.25 | 3 | 0.25 |
| 4 | >0.30 | 0.00 | 4 | 0.00 |

waves. For example, shifting the earthquake location by 1 km will result in a larger change to the S-wave travel time than to the P-wave travel time. To compensate for this effect, the default S-wave weighting factor is 0.5618 (.5618 * 1.78 = 1.0), so that S-waves have the same effective weight as P-waves.

If the final weight for a phase (product of all the individual weights) is less than 0.05, then the weight is assigned a value of 0.00 and the phase is not used nor counted as contributing to the solution. If the phase is not used in the solution, a letter code is placed just after the reading quality on the output indicating the reason this phase is being excluded. Table 2.4 gives the key to codes for excluded phases.

**Table 2.4.** Key to codes for excluded phases

| Code | Reason |
|---|---|
| X | Pick quality of 4 |
| S | Station weight of 4 |
| D | Distance > *xfar* |
| R | Residual too large |
| N | S-wave not used |

2. *Adjustment Damping.* Several damping techniques are used to both speed convergence and stabilize an otherwise oscillating approach to a solution. Some of our damping applications have been developed in an ad-hoc manner to solve specific problems characteristic of our data. In particular, shallow events at Mount St. Helens and in eastern Washington benefit from our approach to damping the depth coordinate. Damping algorithms can be characterized as follows:

(a) *Matrix inversion.* The fundamental single value decomposition matrix inversion technique that we use has a damping factor that prevents those coordinates that have the least control from being adjusted too much. This is similar to the F-test in HYPO71 (Herrmann, 1979) but is applied as a damping factor rather than just shutting off any adjustment.

(b) *Divergent solution.* After the third iteration, the current RMS (root mean square of the arrival time residuals) is compared to that of the previous iteration. If the RMS is increasing (1.2 times the previous one), then the adjustments are divided by 4 and applied without incrementing the iteration counter. This compensates for the situation where the adjustment overshoots the correct solution so far that the solution actually gets worse. In practice, this only seems to occur at low iterations when the event is near the edge of an array and the computed adjustments are large.

(c) *Large depth adjustment.* The depth of the earthquake is normally less well constrained by the data than origin time, latitude, and longitude. Because it may not be possible to determine the depth with the same accuracy as the other parameters, adjustments need to be constrained to reasonable values. Following the idea of Klein (1978) in HYPOINVERSE, the depth adjustment is checked to see if it is larger than a damping factor. If the depth adjustment exceeds the damping factor, then the entire correction vector is reduced to values proportional to the computed depth. This means that shallow events that are getting shallower with each iteration will approach the surface slowly, and a solution with a depth above the surface is not allowed.

(d) *Damp everything.* If after ten iterations a solution has not been reached, the correction vector is halved. This situation normally occurs because an instability has developed in the solution, and it is bouncing back and forth around the correct solution. By halving the correction vector, convergence is slowed down, but it is more likely that a convergent solution will be found. In practice, this seems to occur most commonly when the solution is near a layer boundary in the crustal velocity model.

3. *Iteration Termination.* The location process is forced to go at least four iterations so that all weighting functions will have been properly applied and is terminated under only two conditions:

(a) *Convergence.* When the correction vector is small (epicenter adjustment less than 1 meter, depth adjustment less than 10 meters).

(b) *Maximum iterations (24) exceeded without convergence.* If termination is caused by exceeding the maximum number of iterations (24), then the solution should be examined carefully. In test cases when this happened, the solution was always not far from the correct location, but an instability had developed, causing the solution to bounce back and forth around the correct location.

In addition to the application of damping (discussed above), other adjustments are made to attempt to stabilize the solution. If the computed depth becomes very shallow (less than 0.05 km), then it is fixed at .05 km and only the epicenter and origin time are adjusted further. Also, if after 20 iterations the depth adjustment is small (less than 0.2 km) but not getting smaller, then the depth is fixed and only epicenter and origin time are adjusted further. Again, this normally occurs when the event depth is near a layer boundary in the velocity model, when the calculated depth jumps back and forth across the boundary.

## Earthquake Magnitudes and Focal Mechanisms

### Magnitude determination (MAGIT)

A coda-duration magnitude, $M_c$, is produced for every local earthquake from the durations picked at the same time as the phases. The coda-duration magnitude (Crosson, 1972) is given in the summary line. For earthquakes large enough to record on the simulated-Wood-Anderson response traces at the UW, a local magnitude, $M_L$, is also determined. The amplitudes of the digitized Wood-Anderson response traces are measured and used with the epicentral distance to determine a local Richter-type magnitude. This magnitude is recorded on a magnitude line in the pickfile.

### Focal mechanism (FOCAL)

For any event that has ten or more first-motion P-wave polarities picked that are reasonably well distributed over the focal sphere, the program FOCAL is used to determine a focal mechanism, which, if reasonably well constrained, is added to the pickfile. FOCAL uses the USGS program FPFIT (Reasenberg and Oppenheimer, 1985), adapted to work with the WRSN pickfile format. We have computed and reviewed focal mechanisms for all events with ten or more first motions.

## Quality Control and Final Data and Analysis Products

### Digital data compression (SQUASH, SLASH)

Digital trace data for our network are quite voluminous and would be cumbersome to try to keep in their entirety. For most earthquakes (that is, small events) only a part of the seismic network will be close enough to detect the event. The data for stations that do not detect an event need not be kept. The program SQUASH reduces the number of traces kept by rewriting the data file. Trace data for each event is kept for all stations with phase readings and for additional stations as listed in the pickfile.

A companion routine, SLASH, will cut off the beginning and (or) end of the trace data if there is no interesting information there. It is also used to reduce the sampling rate for data from regional earthquakes and teleseisms, for which a high sampling rate is not needed.

Using SLASH and SQUASH typically reduces the volume of data to be archived by a factor between 5 and 10.

### Hard-copy trace data plot (PUNT)

After an event has been picked and located, a hard-copy plot or PUNT is made on a laser printer. The PUNT includes phase and location information, along with plots of trace data from each picked station with a cross-hair marking each pick. This plot is our permanent visual record of the event and is reviewed as part of our quality-control checking.

### Trace data archiving

Digital trace data are archived in UNIX 'tar' (tape archive) format on 8-mm Exabyte tapes. One tape (2.3 gigabytes) normally contains all the events for a year. Each tape is duplicated, and a copy is stored in another building to protect against loss.

### Adding phase data from other networks

For earthquakes at the edges of our network, we request phase readings from other network operators, such as Boise State University, the University of Montana, the USGS, and the Pacific Geoscience Center (PGC) in Sidney, BC. Due to the frequency of earthquakes in northwestern Washington and southwestern British Columbia, we exchange extensive lists of phase and polarity readings with the PGC twice a year. For earthquakes located by our network near the Canadian border, we merge phase readings from Canadian stations with our pickfiles and relocate the earthquakes. The relocations are checked for errors and problems, and the focal mechanisms are redone if necessary.

### Archiving phase data pickfiles

Phase data in our pickfile format are kept on computer disk and backed up on tape daily. The phase data are archived in 1-month blocks, one file per month, in UNIX 'ar' (archive) format. Each archive is accompanied by two files: an index to the files in the pickfile archive and a 'loc' file of summary lines, one per archived event, which give the location, origin time, coda-duration magnitude, and depth of the event.

### Catalogs and Maps

The occurrence time, location, depth, magnitude, and location quality of each earthquake are summarized in a one-line 'summary card'. Catalogs and maps of seismicity are produced from our collection of summary cards, using computer programs to plot maps or cross-section views of seismicity and to select earthquakes that meet certain criteria of size, depth, location, etc.

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