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Summary

This is the final technical report for USGS Joint Operating Agreement 14-08-0001-A0266 'Regional Seismic Monitoring in Western Washington' which covers network operation, routine data processing, and preparation of bulletins and reports. The objective of our work under this operating agreement is to gather data for use in evaluation of seismic hazards in western Washington and to support research carried out under contract 14-08-0001-G1390 'Earthquake Hazard Investigations in the Pacific Northwest', as well as other projects. Since 1984, we have issued quarterly bulletins for all of Washington and the northern part of Oregon. These include catalogs of earthquakes and blasts located in Washington and Northern Oregon, providing up-to-date coverage of seismic and volcanic activity. Appendix 1 is composed of quarterly bulletins covering the operating agreement period.

'Earthquake Hypocenters in Washington and Northern Oregon - 1981' and 'Earthquake Hypocenters in Washington and Northern Oregon 1982-1986' have been published by the Washington State Department of Natural Resources, Division of Geology and Earth Resources as Information Circulars 82 and 83. These publications include final event locations for all of Washington and the northern part of Oregon as well as maps showing event locations and station coverage. A separate publication, also to be issued by the Dept. of Natural Resources, will cover technical aspects of data processing procedures, and will include descriptions of recently updated velocity models, and station corrections for each model.

Operations

Twenty-eight stations covering much of western Washington are supported under this operating agreement. Locations of stations supported under this operating agreement are given in Table 1, and shown in Fig. 1. Details of station operation for all stations are included in the Quarterly Reports in Appendix 1.

TABLE 1
Stations supported under USGS Joint Operating Agreement A0266

NAME	LAT	LONG	ELEV	LOCATION
APW	46 39 6.0	122 38 51.0	0.457	Alpha Peak
BHW	47 50 12.6	122 1 55.8	0.198	Bald Hill
BLN	48 0 26.5	122 58 18.6	0.585	Blyn Mt.
BOW	46 28 30.0	123 13 41.0	0.870	Boistfort Mt.
CMW	48 25 25.3	122 7 8.4	1.190	Cultus Mtns.
CPW	46 58 25.8	123 8 10.8	0.792	Capitol Peak
FMW	46 55 54.0	121 40 19.2	1.890	Mt. Fremont
GHW	47 2 30.0	122 16 21.0	0.268	Garrison Hill
GMW	47 32 52.5	122 47 10.8	0.506	Gold Mt.
GSM	47 12 11.4	121 47 40.2	1.305	Grass Mt.
HDW	47 38 54.6	123 3 15.2	1.006	Hoodsport
HTW	47 48 12.5	121 46 8.6	0.829	Haystack Lookout
JCW	48 11 36.6	121 55 46.2	0.616	Jim Creek
LMW	46 40 4.8	122 17 28.8	1.195	Ladd Mt.
MBW	48 47 2.4	121 53 58.8	1.676	Mt. Baker
MCW	48 40 46.8	122 49 56.4	0.693	Mt. Constitution
MEW	47 12 7.0	122 38 45.0	0.097	McNeil Island
NLO	46 5 18.0	123 27 0.	0.900	Nicolai Mt., Oregon
OHW	48 19 24.0	122 31 54.6	0.054	Oak Harbor
OSD	47 49 15.0	123 42 6.0	2.010	Olympics - Snow Dome
PGW	47 49 18.8	122 35 57.7	0.122	Port Gamble
RMW	47 27 35.0	121 48 19.2	1.024	Rattlesnake Mt. (West)
RPW	48 26 54.0	121 30 49.0	0.850	Rockport
RVW	46 8 58.2	122 44 37.2	0.460	Rose Valley
SHW	46 11 33.0	122 14 12.0	1.423	Mt. St. Helens
SMW	47 19 10.2	123 20 30.0	0.840	South Mt.
SPW	47 33 13.3	122 14 45.1	0.008	Seward Park, Seattle
STW	48 9 2.9	123 40 13.1	0.308	Striped Peak

The University of Washington records over 100 seismic channels or stations, including WWSSN stations LON and the Wood-Anderson-response seismometers at station SEA, on the campus of the University of Washington. Earlier this year, the Wood-Anderson seismometers at SEA were replaced by S-13 seismometers electronically modified to give a Wood-Anderson response. We are now recording these stations on the digital system, as SEE (east component) and SEN (north component). The digital system has a larger dynamic range than the drum recorder. A set of Wood-Anderson instruments are also operated at Newport (NEW) in the northeastern part of Washington. While this station is not funded under this operating agreement, it is the longest running (since 1966) station in eastern Washington, and provides critical information for determining earthquake rates and computing consistent Wood-Anderson magnitudes. Data from NEW

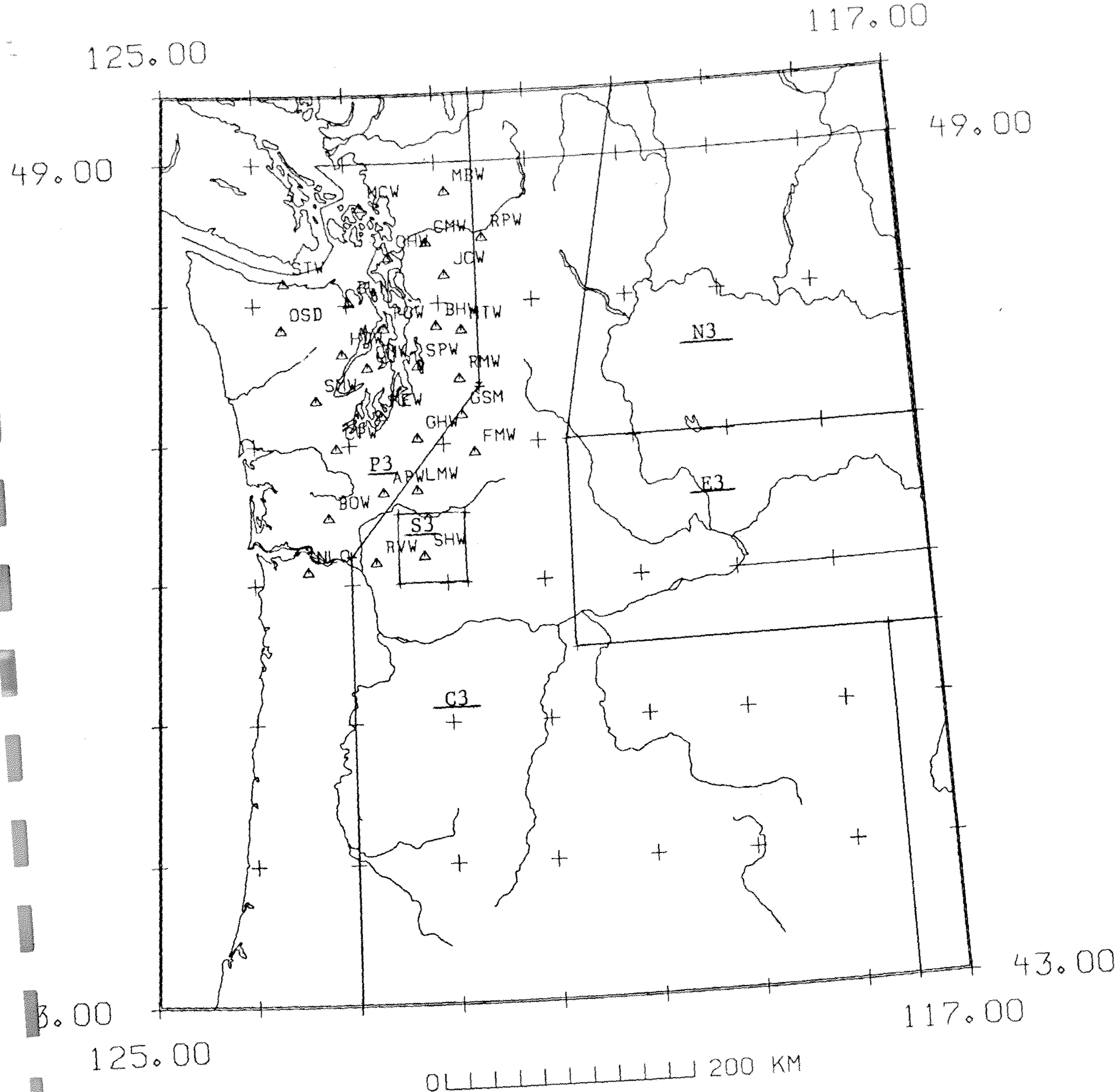

Figure 1. Map view of seismic stations supported under USGS JOA A0266 between Nov. 1, 1986 and Oct. 31, 1987. These twenty-eight stations provide coverage of western Washington. Also shown are the areas of the 5 velocity models used to locate earthquakes. Table 3 gives the velocity models.

were telemetered to the UW on a very long (and expensive) phone line which was discontinued by the USGS in May, 1987. Plans have now been made to install a shorter phone line to the Eastern Control Center (ECC) BPA site, and to use existing BPA microwave circuits from there to the UW.

We recently discovered that several of the station locations which we had been using for many years were inaccurate. These station mislocations are generally not large enough to have any appreciable effect on earthquake locations, but came to light as a result of several research studies which are extremely sensitive to small errors in station locations. We are now beginning a review of all station locations and are evaluating the precision, accuracy, and cost of several methods of location determination. Revised station locations are given in Table 1.

A summary of station installation dates and outages from November 1986 through October 1987 is given in Table 2 for stations operated under this operating agreement. All stations under this operating agreement were operating at the end of the agreement period and no new stations were installed in this period. The telemetry route of one station, RVC, was changed so that the signal now travels through CPW instead of GHW.

During this contract period we installed solar/battery combination power supplies at stations HDW, RVW, FMW and OSD, to provide power for telemetry. Solar power has been successfully used in eastern Washington for several years with advantage of requiring fewer batteries, and an installation that may last longer than a battery-only setup. The disadvantage of solar power it that the battery used is a 12V deep-discharge type, more attractive to thieves than the five 2.5V air-cell batteries used in the battery-only setup. The solar panel also must be mounted high up so that it is exposed to sunlight, often making the installation more visible. Since our stations in western Washington are in well populated areas, this creates a problem, and only the best-protected of our sites can be converted to solar power.

The seismometer at station SHW was replaced in November, 1987. The new seismometer is a calibrated S-13. The seismometer which was replaced had been in place since 1972, and was fatigued, resulting in poor gain. Another long-standing problem at

SHW, low-frequency noise, has now been solved. This persistent problem was discussed in our semi-annual reports in 1986 and 1987. The cause turned out to be a lack of an absolute ground in the equipment circuit. This was corrected in the new installation, and the noise problem is gone. Similar low frequency noise was observed on widely-separated stations in eastern Washington, and we found that the affected stations had lost their absolute circuit grounding in the process of conversion to solar power.

TABLE 2
Western Washington Network
Major station outages and changes, November 1, 1986 - October 31, 1987

Station	Date	Comments
SMW	Nov. 18 - Dec. 3	Struck by Lightning
BHW	June 2 - June 30	Intermittently Noisy
GHW	April 1 - June 30	Intermittent due to RVC
MEW	April 17 - Aug 20	Dead
HDW	April 26 - May 17	Dead
SHW		Intermittly noisy and deteriorating gain

Data Processing

The seismographic network operated by the University of Washington consists of over 110 short-period, vertical component, telemetered seismographic stations. Data is recorded by a DEC PDP 11/34 computer operating in an 'event triggered' mode, recording data (at 100 samples per sec.) only when an event is detected. The digital recording system is closely modeled after the CEDAR system developed at the California Institute of Technology by Carl Johnson. Arrival times, first motion polarities, and signal durations are determined using interactive computer programs on a PDP 11/70 computer. Events are classified into the following categories: teleseisms (epicentral distance greater than 1000 km), regionals (distance less than 1000 km), and local events (epicenter within network). Most local events large enough to be well recorded on at least three stations are analyzed and located. The location program (spong), based on Bob Herrmann's 'FASTHYPO', has been optimized for use with Washington array data. The accuracy of locations determined with this program varies, and depends on the accuracy of the crustal model, the station distribution around the epicenter, station spacing, number of stations used, and quality of arrival time data.

Digital data are saved for all teleseisms, regional events, and all locatable local events. Each trace data file has an associated 'pickfile' which includes arrival times, polarities, and coda lengths for each station read. Near the end of this reporting period, we began recording signal amplitudes from the Seattle station in the phase data files. Using this feature, we can obtain Wood-Anderson type magnitudes directly from the digital traces. P and S amplitudes can also be used to determine a focal mechanism, as a fault plane can be determined by matching a theoretical far-field energy radiation pattern to observed P and S amplitudes. Signal amplitudes also provide a convenient way to check for calibration errors in our calibrated stations; a subset of our stations are calibrated stations from which true ground motion can be recovered. The station response as a function of frequency is determined by multiplying (in the frequency domain) the responses of the station components. As an independent check on the station response, we can use signal amplitudes from a teleseismic arrival to check our calibration. We assume that ground motion will be approximately the same across the array and that large variations of apparent ground motion indicate either a problem in our calibration due to error or aging station components, or true differences in ground response. Significant variations can be investigated to determine the cause.

Our existing PDP 11/34 data acquisition computer has a capacity of only 128 channels. Because of its very limited core memory, it handles data inefficiently, recording to tape in a multiplexed format. The tape must then be dismounted, moved to another computer, (a PDP 11/70) read and demultiplexed before analysis. These two computers will be replaced by a single machine with a far greater capacity, which will reformat the data and write data files directly to disk in near real time. Once on disk, the data will feed directly to automated preliminary analysis programs which will pick arrival times and polarity and rapidly compute a preliminary solution. Automated processing software has been under development here at the U.W., and implementation on the new computer should be smooth. In addition to streamlining data acquisition and processing, the new computer will permit new channels of seismic data to be added.

Since our last report, several minor modifications have been made in the way that teleseisms and regional earthquakes are handled by our analyst. Since mid-1986, a

routine called "teles" has been used to locate teleseisms arriving at our network. Regional events are also being located when possible, using "spong", rather than flagged and not located as in the past. We have implemented a partially automated method of combining Canadian phase picks with our pickfiles. The partial automation removes typographic errors, and merges most of the Canadian data into our pickfiles; but the automatic procedure must be checked for completeness, and results of relocation also checked. Another change to the routine processing is the implementation of "FPFIT", a routine by P. Reasenberg and D. Oppenheimer of the U.S.G.S. (Open-File Report No. 85-739) which automatically determines a focal mechanism. We are now using this program on a routine basis to determine focal mechanisms when possible. Mechanism cards are included in the pickfiles. An ongoing effort is also being made to compile a complete data base of focal mechanisms for past earthquakes, using both hand-done focal mechanisms and the automatically determined mechanisms from FPFIT. These mechanisms will be incorporated into the pickfile data base.

Phase data for eastern Washington events from 1970 - 1975 have been reformatted to the 'pickfile' format used currently, and relocated with the current velocity models used by the Washington Regional Seismic Network (WRSN). Current models are known as the E3, P3, N3, C3, and S3 models. The velocity models are given in Table 3, and the model areas are shown in Fig. 1.

TABLE 3	
Velocity Models for Washington and Oregon	
Cascades Area (C3)	
Depth Range	**Velocity (km/sec)**
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	**Velocity (km/sec)**
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	**Velocity (km/sec)**
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 (P3)	
Depth Range	**Velocity (km/sec)**
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
Mt. Saint Helens Area (S3)	
Depth Range	**Velocity (km/sec)**
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

These pickfiles, and the western Washington pickfiles previously reformatted and relocated have been incorporated into our pickfile data base, and new catalog of summary cards for the relocated events is now in use. This completes our translation of data recorded in Washington into a uniform format.

With the extension this year of the WRSN network into Oregon, we hope to also incorporate phase data from the Oregon Cascade Volcano network which operated from 1980-82 and was recorded in Menlo Park. A quick review of summary cards for this data set and locations determined by the WRSN in the same area indicates that there is considerable overlap between the two data sets, and many of the earthquake locations would benefit from the merger of the data sets. Also, a number of blasts which are unflagged in the USGS data set were identified and flagged in the UW data set and the merged catalog will contain these corrections. Because of the increased interest in Oregon seismicity, both because of the possibility of Cascadia subduction earthquakes, and the necessity of monitoring the Cascade volcanos, the data set should be put into good order, and preserved.

Publications

Publications supported under this operating agreement are listed in Appendix 2. Annual and quarterly catalogs are prepared jointly under this operating agreement and several others.

Acknowledgements

Laurens Engel, who does all field work on the 28 stations supported under this operating agreement, continued to provide an example of perseverance. The mild winter of 1986-1987 allowed almost continuous access to most of our stations, and we had no major problems with vandalism this year. Ruth Ludwin merged Canadian data into the pick files, reformatted and relocated old eastern Washington data, wrote reports, and did miscellaneous administrative tasks. Rick Benson did routine seismic analysis for the entire network. Steve Wyneken and Ivar Mundal assisted with routine processing and data archiving of earthquake data. Tony Qamar spearheaded the effort to publish the catalogs of 1981 and 1982-1986. Chris Jonientz-Trisler helped compile data for quarterly reports, which were written by Linda Noson and Rick Benson.

Articles:

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Ludwin, R. S., S.D. Malone, R.S. Crosson, 1987 (in press), Washington Earthquakes 1984, in United States Earthquakes 1984, U. S. Geological Survey Spec. Pub.

Ludwin, R. S., S.D. Malone, R.S. Crosson, A.I. Qamar 1987 (in press), Washington Earthquakes 1985, in United States Earthquakes 1985, U. S. Geological Survey Spec. Pub.

Qamar, Anthony, Anne Rathbun, Ruth Ludwin, Robert S. Crosson, and Stephen D. Malone, 1986, Earthquake Hypocenters in Washington and Northern Oregon - 1980; Washington State Department of Natural Resources, Division of Geology and Earth Resources, Information Circular 82

Qamar, Anthony, Anne Rathbun, Ruth Ludwin, Linda L. Noson, Robert S. Crosson, and Stephen D. Malone, 1987, Earthquake Hypocenters in Washington and Northern Oregon - 1981; Washington State Department of Natural Resources, Division of Geology and Earth Resources, Information Circular 83

Qamar, Anthony, Ruth Ludwin, Linda L. Noson, Robert S. Crosson, and Stephen D. Malone, 1987, Earthquake Hypocenters in Washington and Northern Oregon - 1982-1986; Washington State Department of Natural Resources, Division of Geology and Earth Resources, Information Circular 84

Reports:

Quarterly Network Report 86-D on Seismicity of Washington and Northern Oregon, 1987, University of Washington Geophysics Program

Quarterly Network Report 87-A on Seismicity of Washington and Northern Oregon, 1987, University of Washington Geophysics Program

Quarterly Network Report 87-B on Seismicity of Washington and Northern Oregon, 1987, University of Washington Geophysics Program

Quarterly Network Report 87-C on Seismicity of Washington and Northern Oregon, 1987, University of Washington Geophysics Program

Abstracts:

Crosson, R.S. and T.J.Owens, 1987, Slab geometry of the Cascadia Subduction Zone from earthquake hypocenters and teleseismic converted waves, Seismological Research Letters, Vol. 58, No. 1, p. 27.

Lapp, D.B., R.S. Crosson and T.J. Owens, 1987, Subduction Geometry beneath Western Washington from deconvolved teleseismic P waveforms, EOS, Vol. 68, No. 44, p. 1468.

Lees, J.M., 1987, Tomographic Inversion of local earthquake travel time data for lateral velocity variation in western Washington, EOS, Vol. 68, No. 44, p. 1374.

Van Decar, J. C., and R.S. Crosson, 1987, Automated Determination of Teleseismic Relative Phase Arrivals using Multi-channel Cross-correlation and Least Squares, EOS, Vol. 68, No. 44, p. 1359.

QUARTERLY NETWORK REPORT 86-D
on
Seismicity of Washington and Northern Oregon

October 1 through December 31, 1986

Geophysics Program
University of Washington
Seattle, Washington

This report is prepared as a preliminary description of the seismic activity in the state of Washington and northern Oregon. Information contained in this report should be considered preliminary, and not cited for publication. Seismic network operation in Washington and northern Oregon is supported by the following contracts:

U.S. Geological Survey
Contract 14-08-0001-A0266
and
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and
Contract 14-08-0001-21978

and

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INTRODUCTION

This is the fourth quarterly report of 1986 from the University of Washington Geophysics Program covering seismicity of all of Washington and northern Oregon. These comprehensive quarterlies have been produced since the beginning of 1984. Reports covering seismicity in Washington since 1969 are available from the U.W. Geophysics Program. In collaboration with the University of Washington, the State Department of Natural Resources has published catalogs of earthquake activity in western Washington for the period 1970-1980. A catalog for 1981 as well as a five-year catalog covering 1982-1986 are in preparation.

In addition to seismicity, this quarterly report discusses network operations, seismicity of the region, and unusual events or findings. This report is preliminary, and subject to revision. Some earthquake locations may be revised if new data become available, such as P and S arrival times from Canadian seismic stations. Findings mentioned in these quarterly reports should not be cited for publication. Fig. 1 shows major geographical features in the state of Washington and northern Oregon and seismograph stations now in operation.

NETWORK OPERATIONS

Table 1 gives approximate periods of time when stations were inoperable. Data for Table 1 are compiled from weekly plots of network-wide teleseismic arrivals, plus records of maintenance and repair visits. Fig. 1 shows a map view of stations operating during the quarter.

Station LMW in western Washington was vandalized in September, and repaired in October. Station SMW was damaged by lightning and a cable was replaced at SPW. The two horizontal Wood-Anderson instruments at station SEA were intermittent this quarter; difficulties in calibrating these instruments led us to conclude that they should be replaced by Kinemetrics S-13 seismometers modified to give an amplitude response identical to the Wood-Anderson instruments. This will be done in the first quarter of 1987.

TABLE 1
Station Downtime 4th quarter 1986

Station	Outage Dates	Comments
BRV	Whole Period	Switched to BPA microwave link
DIO	Oct. 18 - Dec. 31	Removed during eruption
DPW	Oct. 1 - Nov 20	New Station Installed Nov. 20
EPH	Oct. 1 - Nov. 18	Switched to BPA microwave link
EST	Whole Period	Replaced by TWW
FOX	Oct. 1 - Nov. 22	Switching to BPA microwave link
	Nov. 24 - Dec. 31	Switching to BPA microwave link
GL2	Oct. 1 - Oct. 9	
GRO	Whole Period	Intermittent
HHW	Nov. 24 -	
LMW	Oct. 1 - Oct. 14	Vandalized, Transmitter stolen
NEL	Oct. 1 - Nov. 24	Switched to BPA microwave link
ODS	Oct. 1 - Nov. 6	Switched to BPA microwave link
OSP	Nov. 20 -	
OTH	Oct. 22 -	
PGO	Dec. 16 -	Awaiting antenna alignment at telemetry link
PHO	Oct. 17 -	Replaced by WPO
RPK	Dec. 8 -	
RSW	Oct. 1 - Oct. 31	
RVC	Whole Period	Intermittent
SEA	Whole Period	Intermittent
SMW	Nov. 18 - Dec. 3	Struck by Lightning
SPW	Oct. 22 - Nov. 3	Bad Cable
TDH	Oct. 1 - Oct. 21	
	Nov. 23 - Dec. 13	
TWW	Oct. 1 - Oct 24	New station installed Oct. 24
		Replaces EST
VFP	Dec. 10 -	
VG2	Dec. 16 -	Awaiting antenna alignment at telemetry link
VLM	Dec. 16 -	Awaiting antenna alignment at telemetry link
WEN	Oct. 1 - Dec. 4	Switched to BPA microwave link
WPO	Oct. 1 - Oct. 17	New Station installed Oct. 17
		Replaces PHO
WRD	Oct. 1 - Nov. 20	Switched to BPA microwave link

Major restructuring of the eastern Washington network continued in the fourth quarter. Seismic signals are being rerouted to use the Bonneville Power Administration (BPA) microwave transmitters. Most stations affected by this change have regained function, although a few still need adjustment. Three new stations were installed. Davenport WA (DPW) improved coverage to the east, West Portland OR (WPO) replaced Portland Hills OR (PHO) and Teanaway WA (TWW) replaced Easton WA (EST).

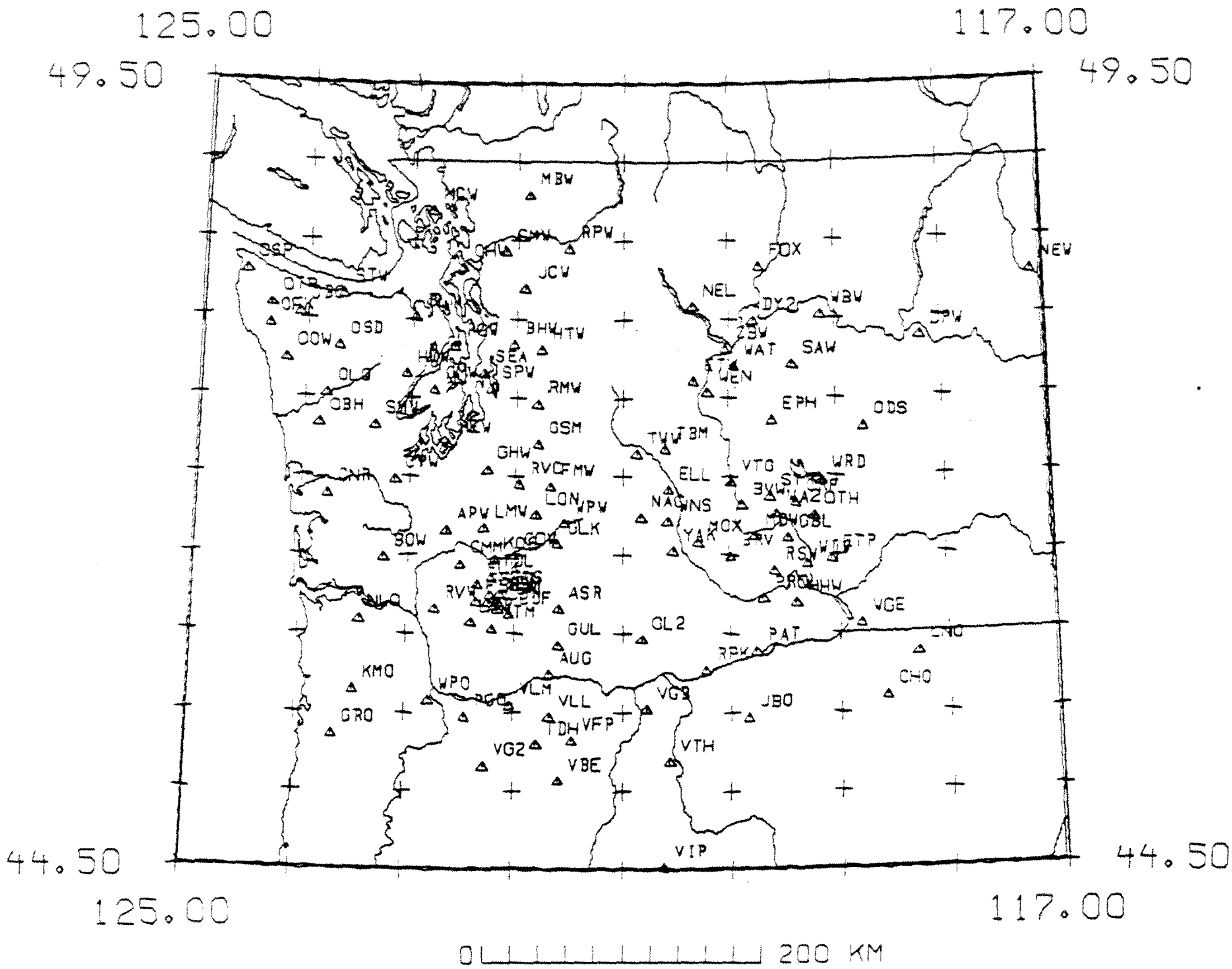

Figure 1. Seismograph stations operating during the 4th quarter 1986.

EARTHQUAKE DATA

There were 822 events processed between October 1 and December 31, 1986 by the University of Washington with data from the digitally recording seismic network. We determined locations for 641 of these in Washington and Northern Oregon; 612 were classified as earthquakes and 29 as known or suspected blasts. The remaining events were teleseisms (78 events), regional events (37) outside the U. W. network, or small unlocated earthquakes within the U. W. network. Sometimes, during eruptive phases of Mount St. Helens, we locate only a representative sample of earthquakes that occur under the volcano. In addition, we do not locate all known blasts. For example, only a few of the frequent mine blasts at Centralia are located. Starting this quarter, we changed the procedure for scanning helicorder records, which is done to check for earthquakes missed by the 11/34 computer. Instead of scanning records every day, we now scan them twice a a week as a check on the operation of the computer. In addition, records are scanned for any period that the computer recording system was down.

Table 3 is the event catalog for this quarter and includes all earthquake locations except those with M_c less than 1.6 under Mt. St. Helens. Of the 612 events classified as earthquakes, 421 occurred at Mt. St. Helens, principally during the October eruption. Eighteen of these volcanic earthquakes had magnitudes from 3.0 to 3.2. The remaining 191 earthquakes were located in western Washington, eastern Washington and northern Oregon (Figures 2, 4, and 5). The largest, a deep (67km) earthquake in southestern Washington on October 12th, had a magnitude of 3.2. Fig. 2 shows all earthquakes located in Washington and Northern Oregon with magnitude greater than or equal to 1.0 ($M \geq 1.0$). Fig. 3 shows blasts and probable blasts ($M \geq 0.$). Fig. 4 shows all earthquakes located in western Washington ($M \geq 0.$). Fig. 5 shows all earthquakes located in eastern Washington ($M \geq 0.$). Fig. 6 shows earthquakes located at Mt. St. Helens ($M \geq 0.$).

Western Washington and Oregon

560 earthquakes were located between 44.5° and 49.5° north latitude and between 121° and 125° west longitude during the fourth quarter of 1986. There were no earthquakes reported felt in

western Washington this quarter. Excluding Mt. St. Helens, 139 earthquakes occurred in western Washington. As usual, a number of these were deep earthquakes located within the Puget Sound lowland including a 67 km deep, magnitude 3.2 earthquake that occurred on Oct. 12th in southwest Washington.

Shallow Washington earthquakes continued to be more numerous than deep events and occurred widely over western Washington. Small clusters of shallow earthquakes were located in some areas. Of note, are several clusters northeast of Lake Washington in an area where shallow clusters have been relatively common in the past. Figures 2 and 4 show a cluster of seven earthquakes greater than magnitude 1.0 located in northwestern Washington, about 30 km to the northeast of Darrington, Wa. More active clusters (i.e. having more earthquakes) occurred near Darrington in July/ August of 1985 and March/April 1986 and near Day Creek to the northwest of Darrington in February 1986.

Eastern Washington and Oregon

During the fourth quarter of 1986, 52 earthquakes were located in eastern Washington. There were no earthquakes reported felt in eastern Washington this quarter. The largest earthquake in eastern Washington was a shallow earthquake of magnitude 2.9 on November 8 located directly north of Yakima (Fig. 5).

Of other interest was the activity that occurred near the town of Beverly, north of Vantage in the Saddle Mountains. This activity began in September, and the last event occurred on October 24. There were 18 earthquakes in October in addition to the 20 that occurred in September. A new station, BVW, was installed in this area on September 30 to better monitor this activity.

Two areas that have often been active in the past, south of the Grand Coulee dam and in the Entiat area south of Lake Chelan, were again active. Normally 15-20 earthquakes are located in the Entiat area each quarter. Outside of the three areas of clustered activity described above, Eastern Washington earthquakes occurred as isolated events rather than in clusters.

Mount St. Helens Area

The fourth quarter of 1986 was highlighted by an eruption at Mount St. Helens during the month of October. There were 496 earthquakes located near Mt. St. Helens during the fourth quarter. Of these, 421 located under the mountain (Fig. 6). All but four of these earthquakes occurred during October. This was the second dome-building eruption this year, the other having occurred in May. Seismicity started to rise above background levels by the weekend of October 4-5, but returned to background by October 7. During the weekend of October 11-12 the seismicity began to pick up again, and by October 19, seismicity was at a high level. During the afternoon of October 21 seismicity decreased and tremor began which continued for several hours. At first, tremor amplitude increased and then decreased until, shortly after midnight, only large low-frequency earthquakes were occurring. The U.S. Geological Survey confirmed the extrusion of a new lobe of lava at the top of the lava dome early the morning of October 22. Seismicity returned to background levels by October 27.

QUARTERLY NETWORK REPORT 87-A
on
Seismicity of Washington and Northern Oregon

January 1 through March 31, 1987

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Joint Operating Agreement 14-08-0001-A0266
and
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and
Grant 14-08-0001-G1390
and
Contract 14-08-0001-21978

and

U.S. Department of Energy
Contract DE-AM06-76RL02225
Task Agreement 39

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INTRODUCTION

This is the first quarterly report of 1987 from the University of Washington Geophysics Program covering seismicity of all of Washington and northern Oregon. These comprehensive quarterlies have been produced since the beginning of 1984. Prior to that we published quarterlies for western Washington in 1983 and for eastern Washington from 1975 to 1983. Annual reports covering seismicity in Washington since 1969 are available from the U.W. Geophysics Program. In collaboration with the University of Washington, the State Department of Natural Resources has published catalogs of earthquake activity in western Washington for the period 1970-1980. Earthquake catalogs for the whole state are in preparation for 1981 and 1982-1986.

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NETWORK OPERATIONS

Table 1 gives approximate periods of time when stations were inoperable. Data for Table 1 are compiled from weekly plots of network-wide teleseismic arrivals, plus records of maintenance and repair visits. Fig. 1 shows a map view of stations operating during the quarter.

The changeover of telemetry to BPA microwave links was continued from last quarter. This quarter saw the completion of this changeover from the more expensive phone lines used in the past. Stations in the vicinity of Mt. St. Helens were switched to BPA telemetry on January 21 and 22, minimizing down time. Stations affected were FL2, HSR, ELK, CMM, EDM, SHW, STD, SOS, and YEL. In addition, stations in the northwest corner of Oregon were transferred to the BPA microwave network between Feb. 6 and April 7. These included GRO, KMO, VG2, TDH, VLM. Station PGO

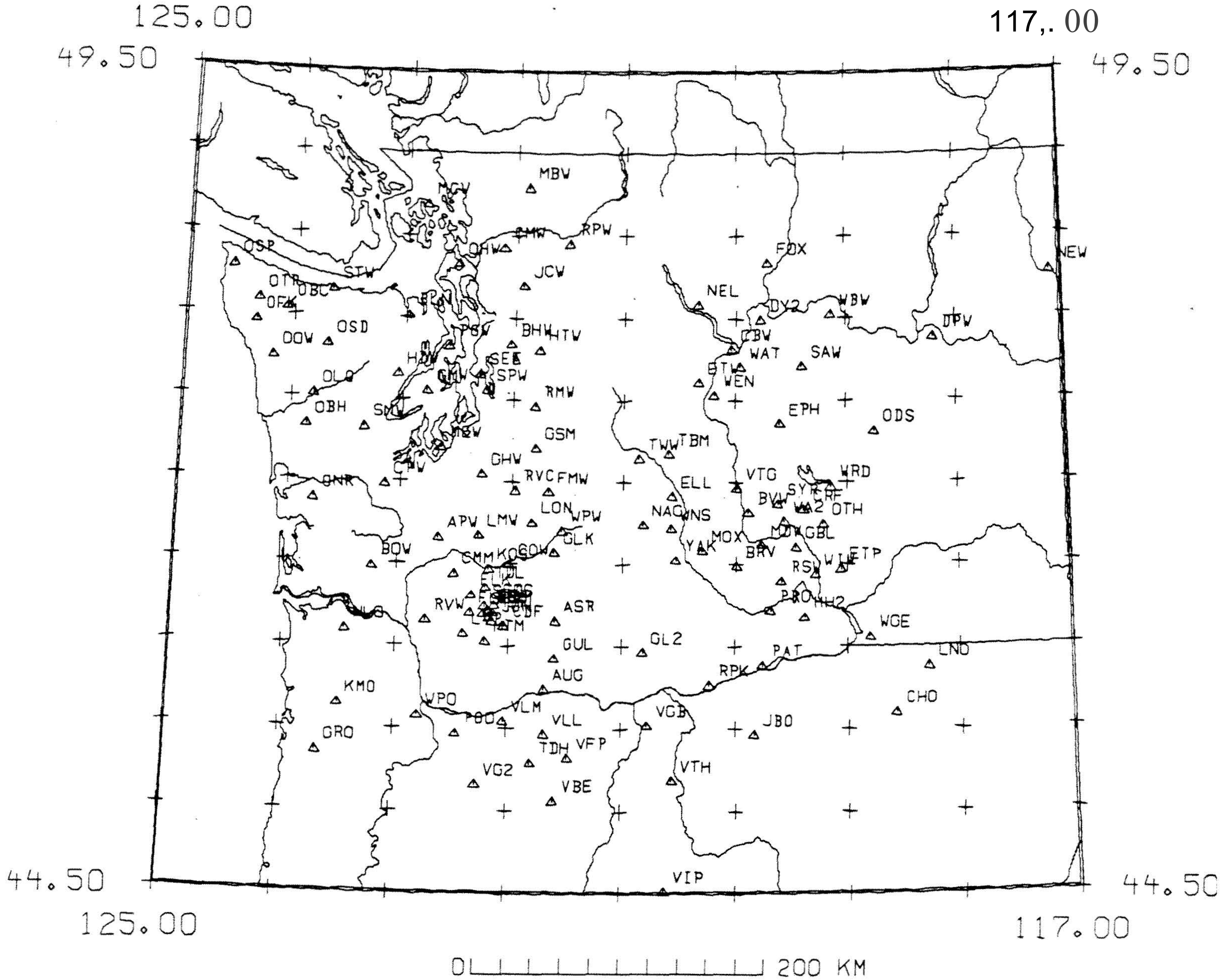

Figure 1. Seismograph stations operating during the 1st quarter 1987.

TABLE 1
Station Outages 1st quarter 1987

Station	Outage Dates	Comments
FOX	Whole Period	Transmitter problems
CBW	January 1-March 31	Intermittent
HHW	March 10-March 24	Replaced by HH2
HH2	March 24-March 31	Replaced HHW
PRO	January 21-March 31	Intermittently noisy
CHO	Whole Period	
RSW	February 10-March 31	Intermittently noisy
ETP	February 10-March 23	Dead batteries
JUN	Whole Period	Intermittently noisy
NAC	January 14-March 6	
WNS	January 1-March 25	Broken seismometer cable
BRV	January 1-February 19	Broken cable
YAK	January 1-February 9	Low power supply
OSP	January 1-January 5	Dead batteries
ONR	January 1-February 5	Transmitter dead
OBC	January 1-January 5,March 4-March 31	Intermittent
CMM	February 4-March 31	Rerouting telemetry
OTR	January 14-March 25	Seis cable chewed; telemetry problem
OOW	March 6-March 31	Intermittently noisy
VG2	January 1-February 5	Switchover to BPA
VFP	Whole Period	
PGO	Whole Period	Switchover to BPA; renamed WPO on Feb. 4
WPO	January 1-February 5	New PGO station
VLM	January 1-February 5	Switchover to BPA
TDH	February 5	Switch to BPA
KMO	February 5	Switch to BPA
GRO	February 5-March 31	Switch to BPA then intermittently noisy
RPK	January 1-January 23;March 6-March 31	Disconnected solar panel
JBO	March 15-March 31	Dead batteries

was moved to a new site and renamed WPO on Feb. 4. During this time, these stations were intermittent. In eastern Washington, the station HHW was moved and renamed HH2 on March 24.

One horizontal Wood-Anderson instrument was replaced with a Kinemetrics S-13 seismometer and brought online January 9. The new seismometer will allow for a more accurate calibration. The station was named SEE and is the east-west component. The replacement for the second, north-south component, to be named SEN, will be brought online during the second quarter of 1987.

QUARTERLY NETWORK REPORT 87-B
on
Seismicity of Washington and Northern Oregon

April 1 through June 30, 1987

Geophysics Program
University of Washington
Seattle, Washington

This report is prepared as a preliminary description of the seismic activity in the state of Washington and northern Oregon. Information contained in this report should be considered preliminary, and not cited for publication. Seismic network operations in Washington and northern Oregon is supported by the following contracts:

U.S. Geological Survey
Joint Operating Agreement 14-08-0001-A0266
and
Grant 14-08-0001-G1390
and
Contract 14-08-0001-21978

and

U.S. Department of Energy
Contract DE-AM06-76RL02225
Task Agreement 39

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NETWORK OPERATIONS

Table 1 gives approximate periods of time when stations were inoperable. Data for Table 1 are compiled from weekly plots of network-wide teleseismic arrivals, plus records of maintenance and repair visits. Fig. 1 shows a map view of stations operating during the quarter.

Only 4 station changes occurred this quarter. In western Washington, a north-south component simulated Wood-Anderson instrument, station SEN, was installed on April 6 alongside a similar east-west component instrument station SEE, that was installed last quarter. Both stations are located in the basement of Johnson Hall at the University of Washington and utilize a standard 1 Hz, Geotech S13 seismometer and an integrating amplifier that simulates a Wood-Anderson frequency response. In eastern Washington, the station WGE was removed on April 23, and replaced by WG2 on April 31. The station FOX was permanently removed on April 22 due to land use permission problems with the State Department of Natural Resources. The Newport station, NEW was disconnected from the telephone telemetry link by the USGS during the first week of March. We have been informed that the USGS plans to permanently close this important station within a few months for budgetary reasons.

Telemetry changes to BPA sites were completed last quarter. The BPA receiver site in Portland, WPB, was down all of May 17. All stations received through the WPB receiver site are subject to periodic noise bursts resulting from interference with Coast Guard radios using the same frequency. There will be an attempt to resolve this interference during the third quarter. In the third quarter we will begin to add new seismograph stations in Oregon.

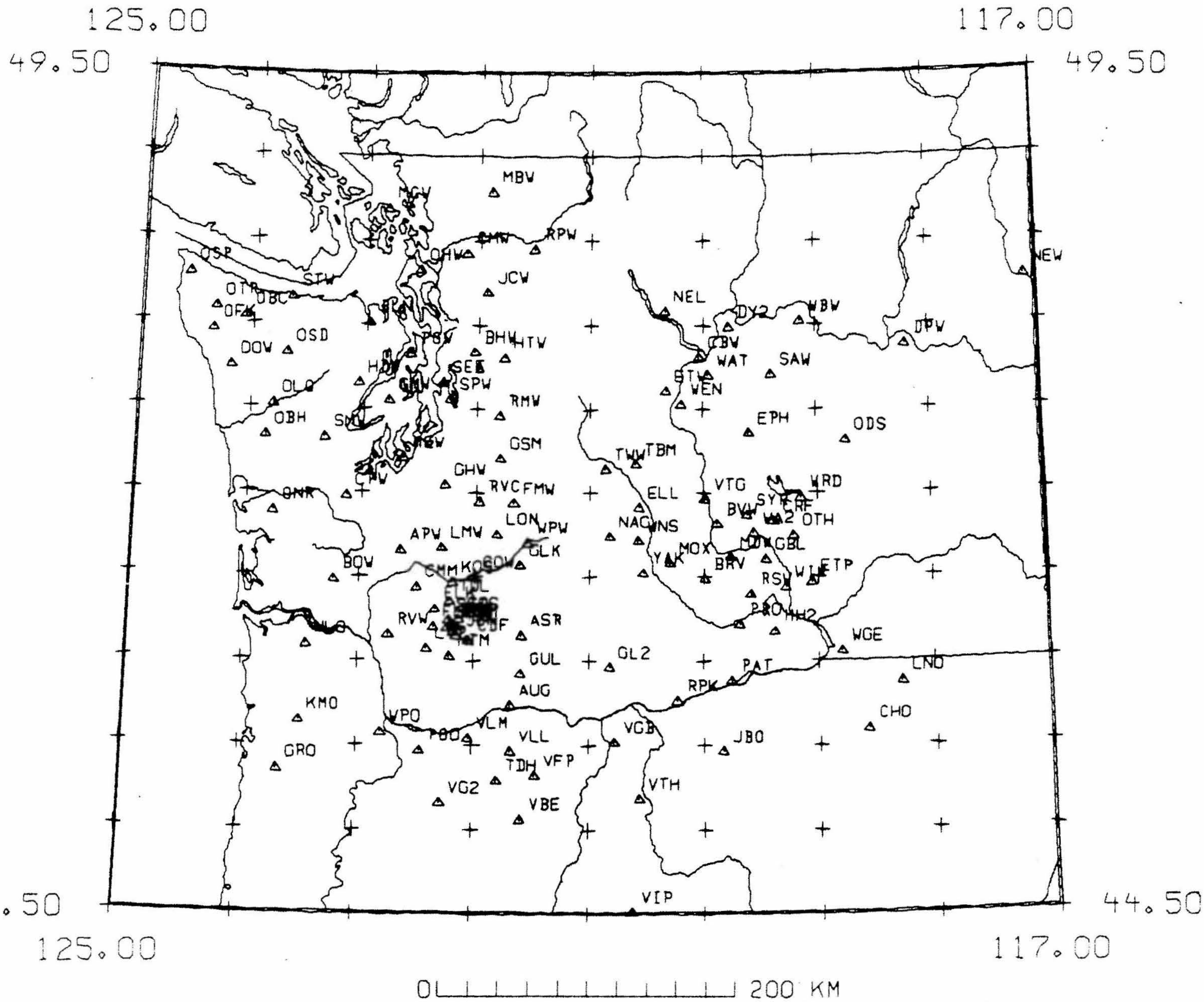

Figure 1. Seismograph stations operating during the 2nd quarter 1987.

TABLE 1
Station Outages 2nd quarter 1987

Station	Outage Dates	Comments
BHW	June 2-June 30	Intermittently noisy
GHW	April 1-June 30	Intermittent
MEW	April 17-June 30	Dead
RVW	Whole Period	Intermittent
HDW	April 26-May 17	Dead
NEL	Whole Period	Intermittently noisy
WBW	April 26-June 30	Telemetry problems
SAW	April 26-June 30	Telemetry problems
WAT	April 26-June 30	Telemetry problems
FOX	Whole Period	Transmitter problems; removed April 22
CBW	April 26-May 31	Intermittent
DY2	April 26-June 30	Intermittently noisy
PRO	Whole Period	Intermittently noisy
DPW	May 9-June 30	Intermittently noisy
CHO	Whole Period	Intermittently noisy
EPH	April 26-May 21	Damaged VCO
ODS	May 17-June 30	Intermittently noisy
RSW	April 1-May 17	Intermittently noisy
WGE		Removed April 23; replaced by WG2
WG2	April 31-June 30	Intermittent; replaced WGE
JUN	Whole Period	Intermittently noisy
BVW	April 14-May 17	Intermittently noisy
TWW	May 9-June 30	Dead; vandalized
LVP	April 14-June 9	Dead; vandalized
WNS	April 3,June 2	Dead
REM	May 9-June 26	Intermittent
YEL	April 26-May 6	Noisy
OSP	Whole Period	Intermittently noisy
STD	Whole Period	Intermittently noisy
HSR	May 17-June 2	Dead
OBC	Whole Period	Intermittent
SOS	Whole Period	Intermittent
CMM	Whole Period	Dead
VFP	April 1-June 15	Dead; then noisy to end of quarter
PGO	Whole Period	Intermittent
WPO	Whole Period	Intermittently noisy; interference
AUG	May 17-June 30	Intermittent
VLM	April 3,May 17	Dead
TDH	April 26-May 17	Dead
GRO	Whole Period	Intermittent
VGB	April 18-June 30	Intermittent
VIP	May 6-June 2	Dead
RPK	Whole Period	Intermittently dead
JBO	April 1-April 14	Dead

STATIONS USED FOR LOCATION OF EVENTS

Table 2 lists stations used in locating seismic events in Washington and Oregon. Stations marked by an asterisk (*) were supported by USGS joint operating agreement 14-08-0001-A0266. Stations marked by ($) were supported by USGS contract 14-08-0001-21978. (+) indicates support under US Dept. of Energy contract DE-AM06-76RL02225. All other stations were supported from other sources.

The first column in the table gives the 3-letter station designator. This is followed by a symbol designating the funding agency, station north latitude and west longitude (in degrees, minutes and seconds), station elevation in km, and comments indicating landmarks for which stations were named.

TABLE 2

Stations Operating at the End of the Second Quarter 1987

STA	F	LAT	LONG	EL	NAME
APW	*	46 39 06.0	122 38 51.0	0.457	Alpha Peak
ASR	$	46 09 02.4	121 35 33.6	1.280	Mt. Adams - Stagman Ridge
AUG	$	45 44 10.0	121 40 50.0	0.865	Augspurger Mtn
BHW	*	47 50 12.6	122 01 55.8	0.198	Bald Hill
BLN	*	48 00 26.5	122 58 18.6	0.585	Blyn Mt.
BOW	*	46 28 30.0	123 13 41.0	0.870	Boistfort Mt.
BRV	+	46 29 07.2	119 59 29.4	0.925	Black Rock Valley
BVW	+	46 48 37.8	119 52 54.1	0.707	Beverly
CHO	+	45 35 27.0	118 34 45.0	1.076	Cabbage Hill, Oregon
CBW	+	47 48 25.5	120 01 57.6	1.160	Chelan Butte
CDF	$	46 06 58.2	122 02 51.0	0.780	Cedar Flats
CMM	$	46 26 07.0	122 30 21.0	0.620	Crazy Man Mt.
CMW	*	48 25 25.3	122 07 08.4	1.190	Cultus Mtns.
COW	$	46 29 27.6	122 00 43.6	0.305	Cowlitz River
CPW	*	46 58 25.8	123 08 10.8	0.792	Capitol Peak
CRF	+	46 49 30.6	119 23 18.0	0.260	Corfu
DPW	+	47 52 14.3	118 12 10.2	0.892	Davenport
DY2	+	47 59 06.9	119 46 13.0	0.884	Dyer Hill 2
EDM		46 11 50.4	122 09 00.0	1.609	East Dome, Mt. St. Helens
ELK	$	46 18 20.0	122 20 27.0	1.270	Elk Rock
ELL	+	46 54 35.0	120 34 06.0	0.805	Ellensburg
EPH	+	47 21 12.8	119 35 46.2	0.628	Ephrata
ETP	+	46 27 53.4	119 03 32.4	0.250	Eltopia
ETW	+	47 36 16.2	120 19 51.6	1.475	Entiat
FL2	$	46 11 47.0	122 21 01.0	1.378	Flat Top 2
FMW	*	46 55 54.0	121 40 19.2	1.890	Mt. Fremont

continued

STA	F	LAT	LONG	EL	NAME
FOX	+	48 19 50.0	119 42 29.0	0.896	Fox Mountain
GBL	+	46 35 51.6	119 27 35.4	0.330	Gable Mountain
GHW	*	47 02 30.0	122 16 21.0	0.268	Garrison Hill
GL2	+	45 57 35.0	120 49 22.5	1.000	New Goldendale
GLK	$	46 33 50.2	121 36 30.7	1.320	Glacier Lake
GMW	*	47 32 52.5	122 47 10.8	0.506	Gold Mt.
GRO	$	45 21 04.5	123 39 43.0	0.945	Grindstone Mt., Oregon
GSM	*	47 12 11.4	121 47 40.2	1.305	Grass Mt.
GUL	$	45 55 27.0	121 35 44.0	1.189	Guler Mt.
HDW	*	47 38 54.6	123 03 15.2	1.006	Hoodsport
HH2	+	46 10 18.0	119 23 01.0	0.490	Horse Heaven Hills (moved HHW)
HSR	$	46 10 22.2	122 10 58.2	1.774	South Ridge, Mt. St. Helens
HTW	*	47 48 12.5	121 46 08.6	0.829	Haystack Lookout
JBO	$	45 27 41.7	119 50 13.3	0.645	Jordan Butte, Oregon
JCW	*	48 11 36.6	121 55 46.2	0.616	Jim Creek
JUN	$	46 08 48.0	122 09 10.8	1.049	June Lake
KMO	$	45 38 07.8	123 29 22.2	0.975	Kings Mt., Oregon
KOS	$	46 27 40.8	122 11 25.8	0.828	Kosmos
LMW	*	46 40 04.8	122 17 28.8	1.195	Ladd Mt.
LNO	+	45 52 15.8	118 17 06.0	0.768	Lincton Mt., Oregon
LON		46 45 00.0	121 48 36.0	0.853	Longmire (WWSSN and DWWSSN)
LVP	$	46 04 06.0	122 24 30.0	1.170	Lakeview Peak
MBW	*	48 47 02.4	121 53 58.8	1.676	Mt. Baker
MCW	*	48 40 46.8	122 49 56.4	0.693	Mt. Constitution
MDW	+	46 36 48.0	119 45 39.0	0.330	Midway
MEW	*	47 12 07.0	122 38 45.0	0.097	McNeil Island
MOX	+	46 34 38.0	120 17 35.0	0.540	Moxie City
MTM	$	46 01 31.8	122 12 42.0	1.121	Mt. Mitchell
NAC	+	46 44 03.8	120 49 33.2	0.738	Naches
NEL	+	48 04 41.8	120 20 17.7	1.490	Nelson Butte
NEW		48 15 50.0	117 07 13.0	1.000	Newport Observatory (USGS)
NLO	*	46 05 18.0	123 27 00.0	0.900	Nicolai Mt., Oregon
OBC	$	48 02 07.1	124 04 39.0	0.938	Olympics - Bonidu Creek
OBH	$	47 19 34.5	123 51 57.0	0.383	Olympics - Burnt Hill
ODS	+	47 18 24.0	118 44 42.0	0.523	Odessa
OFK	$	47 57 00.0	124 21 28.1	0.134	Olympics - Forks
OHW	*	48 19 24.0	122 31 54.6	0.054	Oak Harbor
OLQ	$	47 30 58.1	123 48 31.5	0.121	Olympics - Lake Quinault
ONR	$	46 52 37.5	123 46 16.5	0.257	Olympics - North River
OOW	$	47 44 12.0	124 11 22.0	0.743	Octopus West
OSD	*	47 49 15.0	123 42 06.0	2.010	Olympics - Snow Dome
OSP	$	48 17 05.5	124 35 23.3	-	Olympics - Sooes Peak
OTH	+	46 44 20.4	119 12 59.4	0.260	Othello
OTR	$	48 05 00.0	124 20 39.0	0.712	Olympics - Tyee Ridge
PAT	+	45 52 50.1	119 45 40.1	0.300	Paterson
PGO	$	45 28 00.0	122 27 10.0	0.237	Gresham, Oregon
PGW	*	47 49 18.8	122 35 57.7	0.122	Port Gamble
PRO	+	46 12 45.6	119 41 09.0	0.552	Prosser
REM		46 11 57.0	122 11 03.0	2.102	Rembrandt (Dome station)
RMW	*	47 27 34.9	121 48 19.2	1.024	Rattlesnake Mt. (West)

continued

STA	F	LAT	LONG	EL	NAME
RPK	+	45 45 42.0	120 13 50.0	0.330	Roosevelt Peak
RPW	*	48 26 54.0	121 30 49.0	0.850	Rockport
RSW	+	46 23 28.2	119 35 19.2	1.037	Rattlesnake Mt. (East)
RVC	$	46 56 34.5	121 58 17.3	1.000	Mt. Rainier - Voight Creek
RVW	*	46 08 58.2	122 44 37.2	0.460	Rose Valley
SAW	+	47 42 06.0	119 24 03.6	0.690	St. Andrews
SEA		47 39 18.0	122 18 30.0	0.030	Seattle (Wood Anderson)
SEE		47 39 18.0	122 18 30.0	0.030	Seattle Pseudo-WA (E)
SEN		47 39 18.0	122 18 30.0	0.030	Seattle Pseudo-WA (N)
SHW	*	46 11 33.0	122 14 12.0	1.423	Mt. St. Helens
SMW	*	47 19 10.2	123 20 30.0	0.840	South Mt.
SND	$	46 12 45.0	122 11 09.0	1.800	St. Helens Microphone, unrectif
SOS	$	46 14 38.5	122 08 12.0	1.270	Source of Smith Creek
SPW	*	47 33 13.3	122 14 45.1	0.008	Seward Park, Seattle
STD	$	46 14 16.0	122 13 21.9	1.268	Studebaker Ridge
STW	*	48 09 02.9	123 40 13.1	0.308	Striped Peak
SYR	+	46 51 46.8	119 37 04.2	0.267	Smyrna
TBM	+	47 10 10.1	120 35 54.0	1.064	Table Mt.
TDH	$	45 17 23.4	121 47 25.2	1.541	Tom,Dick,Harry Mt., Oregon
TDL	$	46 21 03.0	122 12 57.0	1.400	Tradedollar Lake
TWW	+	47 08 17.2	120 52 04.5	1.046	Teanaway
VBE	$	45 03 37.2	121 35 12.6	1.544	Beaver Butte, Oregon
VFP	$	45 19 05.0	121 27 54.3	1.716	Flag Point, Oregon
VG2	+	45 09 20.0	122 16 15.0	0.823	Goat Mt., Oregon
VGB	+	45 30 56.4	120 46 39.0	0.729	Gordon Butte, Oregon
VIP	+	44 30 29.4	120 37 07.8	1.731	Ingram Pt., Oregon
VLL	$	45 27 48.0	121 40 45.0	1.195	Laurance Lk., Oregon
VLM	$	45 32 18.6	122 02 21.0	1.150	Little Larch, Oregon
VTG	+	46 57 28.8	119 59 14.4	0.208	Vantage
VTH	+	45 10 52.2	120 33 40.8	0.773	The Trough, Oregon
WA2	+	46 45 24.2	119 33 45.5	0.230	Wahluke Slope
WAT	+	47 41 55.0	119 57 15.0	0.900	Waterville
WBW	+	48 01 04.2	119 08 13.8	0.825	Wilson Butte
WEN	+	47 31 46.2	120 11 39.0	1.061	Wenatchee
WGE	+	46 03 09.0	118 48 08.0	0.262	Wallula Gap East
WG2	+	46 01 50.25	118 51 19.95	0.511	Wooded Island
WIW	+	46 25 48.8	119 17 13.4	0.130	Wooded Island
WNS	+	46 42 37.0	120 34 30.0	1.000	Wenas
WPO	$	45 34 24.0	122 47 22.4	0.334	West Portland, Oregon
WPW	+	46 41 53.4	121 32 48.0	1.250	White Pass
WRD	+	46 58 11.4	119 08 36.0	0.378	Warden
YAK	+	46 31 15.8	120 31 45.2	0.619	Yakima
YEL		46 12 35.0	122 11 16.0	1.750	Yellow Rock, Mt. St. Helens

EARTHQUAKE DATA

There were 486 events processed by the University of Washington digitally recording seismic network between April 1 and June 30, 1987. We determined locations for 293 of these in Washington and Northern Oregon; 219 were classified as earthquakes and 74 as known or suspected blasts. The remaining 193 processed events include teleseisms (108 events), regional events outside the U. W. network (29), and unlocated events within the U. W. network. Unlocated events within the U.W. network include very small earthquakes and some known blasts. For example, only a few of the frequent mine blasts at Centralia are located. In addition, during eruptive phases of Mount St. Helens, we may locate only a representative sample of the earthquakes that occur under the volcano.

Table 3 is the catalog of earthquakes and blasts located within the network for this quarter. Fig. 2 shows all earthquakes with magnitude greater than or equal to 1.0 ($M_c \geq$ 1.) Fig. 3 shows blasts and probable blasts ($M_c \geq$ 0.) Fig. 4 shows all earthquakes located in western Washington ($M_c \geq$ 0.) Fig. 5 shows all earthquakes located in eastern Washington ($M_c \geq$ 0.) Fig. 6 shows earthquakes located at Mount St. Helens ($M_c \geq 0$).

Western Washington and Oregon

184 earthquakes were located between 44.5° and 49.5° north latitude and between 121° and 125° west longitude during the second quarter of 1987. Most of these occurred at depths less than 30 km with, as usual, a small number of earthquakes in the Puget Sound lowland at depths greater than 30 km. These included the deepest earthquake located during the quarter, a M_c = 1.1 at 65 km depth near Issaquah that occurred on May 2. In addition to the deep Puget Lowland earthquakes, two deep earthquakes were located in the Olympic Mountains near the Olympic Hot Springs and 2 were located slightly offshore in the general vicinity of Aberdeen in southwest Washington.

Five minor earthquakes were reported felt in western Washington during the second quarter of 1987. A M_c = 2.8 earthquake on April 5 in the Darrington area Washington occurred near the location of seven smaller earthquakes recorded in May and June. These events were at depths less than 20 km. Last quarter ten earthquakes were recorded in the same area, of which two were reported felt.

More intense activity occurred in the Darrington area during 1985 and 1986.

A M_c = 2.8 earthquake on April 28 was located about 10 km northwest of Bremerton on the Kitsap peninsula at a depth of 20 to 25 km. Three earthquakes too small to be felt were recorded in the same area in May and June.

A M_c = 2.4 earthquake on June 18 was located on the Kitsap Peninsula 10 km northwest of Belfair at a depth of about 20 km. An earthquake of the same size and location on Jan. 2 was not reported felt.

A M_c = 2.3 earthquake at about 20 km depth occurred on May 16, 10 km north of Vancouver, near Battle Ground, Washington.

A June 19, M_c = 3.9 earthquake occurred a short distance southwest of Aberdeen at a depth of nearly 40 km. This was the largest earthquake located in Washington and Oregon during the quarter. About 12 deep earthquakes (greater than 30 km in depth) have occurred within 50 km of the June 19 event since 1980. The largest was a M_c = 3.3 earthquake on Sept. 6, 1981 about 40 km to the southeast, near Raymond, Washington.

In April and May, a cluster of five earthquakes occurred near Tukwila in the Duwamish River valley including a M_c = 2.6 on April 7 and a M_c = 2.5 on April 15. These earthquakes were located at depths of 20 to 25 km.

A cluster of five earthquakes occurred on the southeast side of Mt. Hood, Oregon during the quarter. The largest earthquake in the cluster was a M_c = 1.4. These events were located at depths less than 10 km. Small clusters of earthquakes have occurred in the same area in the past including a cluster of four earthquakes, the largest a M_c = 3.4 in August 1982. Only two other events were recorded in western Oregon during the quarter. A M_c = 2.8 earthquake on June 30 located in the Deschutes River Valley about 25 km northwest of Antelope, Oregon, and a M = 1.2 earthquake on April 17, 25 km west of Mt. Hood.

Eastern Washington and Oregon

During the second quarter of 1987, 35 earthquakes were located in eastern Washington. The largest was a less than 20 km deep, $M_c = 3.0$ earthquake on June 11 in the Cleeman Mts. near the town of Naches. A shallow (less than 1 km) $M_c = 1.4$ earthquake occurred at the same location on June 13.

The Entiat area south of Lake Chelan was again active and ten earthquakes under magnitude 2 were located there at depths less than 15 km during the second quarter.

Two shallow earthquakes, a $M_c = 1.9$ in April and a $M_c = 1.7$ in June, occurred close to the town of Chelan near the epicenter of a $M_c = 2.6$ earthquake reported felt last quarter (February 28).

A $M_c = 2.4$ earthquake on April 3 southwest of Moses Lake was followed by a $M_c = 2.1$ earthquake at the same location on May 16. Both earthquakes occurred at depths less than 2 km. Elsewhere in Eastern Washington, earthquakes generally occurred as isolated events rather than in clusters. The only earthquake recorded in Eastern Oregon during the second quarter was a $M_c = 2.3$ event located at about 20 km depth that occurred on June 16, 20 km west of Pendleton.

Mount St. Helens Area

Only 13 earthquakes were located in the Mt. St. Helens area during the second quarter of 1987. Of these, nine were located in or close to the crater. The largest earthquake in the Mt. St. Helens area was a $M_c = 1.8$ event on June 30. This is typical of earthquake activity during a quiescent period between eruptions.

QUARTERLY NETWORK REPORT 87-C
on
Seismicity of Washington and Northern Oregon

July 1 through September 30, 1987

Geophysics Program
University of Washington
Seattle, Washington

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This quarter saw an expansion of the network into Oregon with the addition of five new stations. They are BPO, NCO,TCO, GMO, and VCR. Because they are quite distant from the University of Washington, there are plans to hire a technician who will live in Oregon and maintain these sites. These stations are being telemetered through the BPA microwave network.

In August, technician Jack Libby moved to Ellensburg, Washington for the more efficient maintanence of eastern Washington stations. Paul Farley will remain in Seattle to assist with station maintenance west of the cascades.

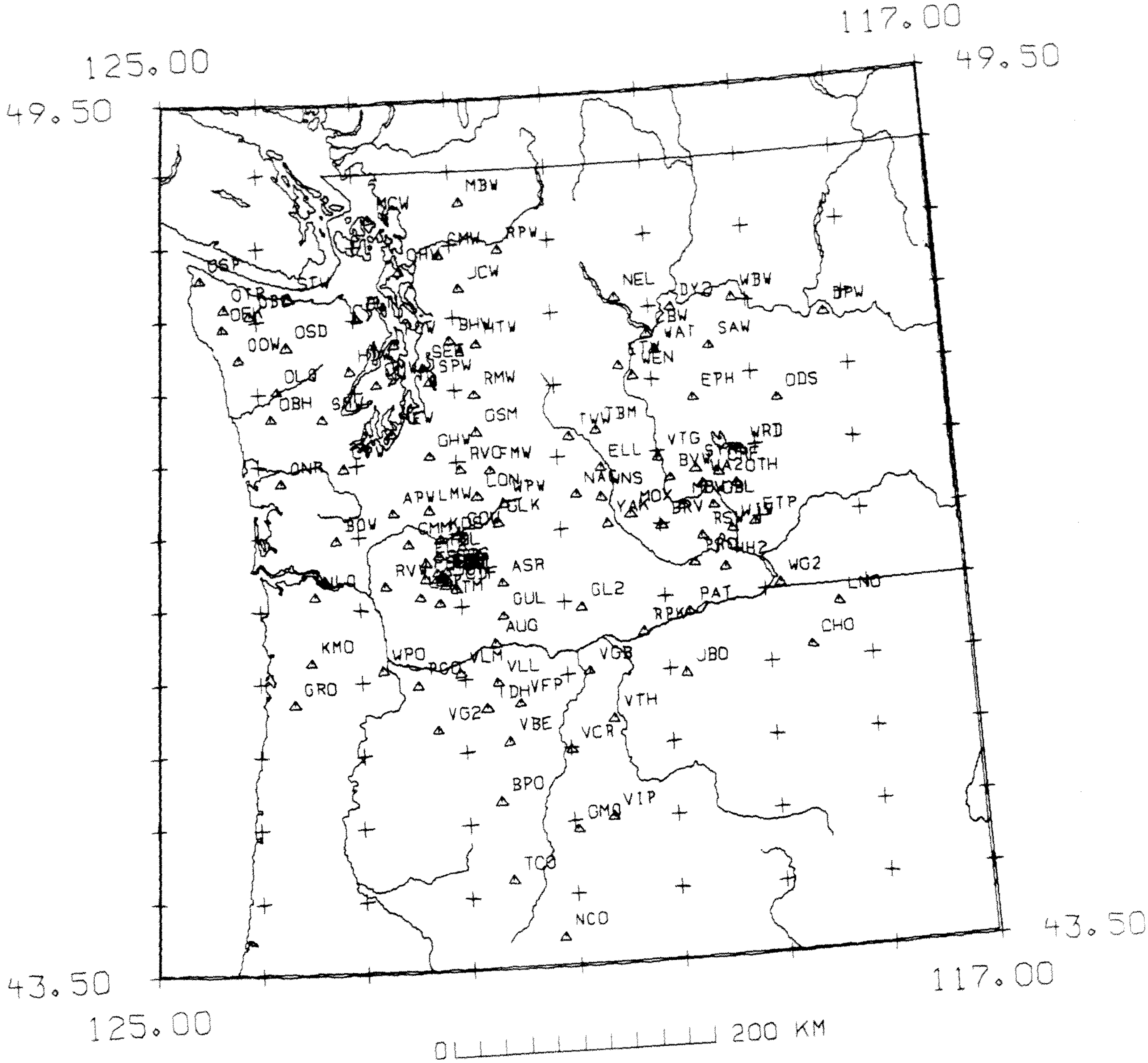

Figure 1. Seismograph stations operating during the 3rd quarter 1987.

TABLE 1
Station Outages 3rd quarter 1987

Station	Outage Dates	Comments
MEW	July 1-August 8	Dead
RVC	August 3-August 29	Receiver dead
NEL	Whole period	Intermittently noisy,unreadable
OTH	Sept 1-Sept 24	Wire connection bad
SAW	July 1-Sept 9	Intermittent, dead batteries
WIW	July 17-Sept 13	Intermittently noisy,unreadable
CBW	Whole period	Intermittent, loose discriminator
BPO	Sept 15-Sept 22	New station on Sept 15
PRO	July 17-Sept 22	Intermittently noisy, unreadable
CHO	July 1-July 13	Dead
ODS	July 1-July 8	Dead,converted to solar power
WG2	July 1-Sept 22	Intermittent, VCO problems
ETP	July 1-July 20	Dead, VCO problems
LNO	Whole Period	Intermittent, VCO problems.
TWW	July 1-July 8	Seismometer stolen
REM	August 29-Sept 30	Intermittent, low signal
YEL	Whole Period	Intermittent, low signal
OSP	Whole Period	Intermittently noisy, unreadable
HSR	Intermittently	Loose discriminator
OBC	Whole period	Intermittently noisy, unreadable
SOS	Intermittently	Wind noise
CMM	July 1-July 15	Dead batteries
OLQ	August 29-Sept 13	Intermittently noisy,unreadable
GMO	July 1-August 27	New station on August 27
WPO	July 1-August 21	VCO problems
AUG	Whole period	Intermittently noisy,unreadable
TDH	July 1-August 3	Dead
VCR	July 1-August 20	New station August 20
GLK	Sept 18-Sept 24	Dead
COW	July 1-July 17	Dead
TCO	July 1-August 27	New station August 27
VTH	August 11-Sept 13	Intermittently noisy, unreadable
NCO	July 1-September 16	New station Sept 16

STATIONS USED FOR LOCATION OF EVENTS

Table 2 lists stations used in locating seismic events in Washington and Oregon. Stations marked by an asterisk (*) were supported by USGS joint operating agreement 14-08-0001-A0266. Stations marked by ($) were supported by USGS contract 14-08-0001-21978. (+) indicates support under US Dept. of Energy contract DE-AM06-76RL02225. All other stations were supported from other sources.

The first column in the table gives the 3-letter station designator. This is followed by a symbol designating the funding agency, station north latitude and west longitude (in degrees, minutes and seconds), station elevation in km, and comments indicating landmarks for which stations were named.

TABLE 2
Stations Operating at the End of the Third Quarter 1987

STA	F	LAT	LONG	EL	NAME
APW	*	46 39 06.0	122 38 51.0	0.457	Alpha Peak
ASR	$	46 09 02.4	121 35 33.6	1.280	Mt. Adams - Stagman Ridge
AUG	$	45 44 10.0	121 40 50.0	0.865	Augspurger Mtn
BHW	*	47 50 12.6	122 01 55.8	0.198	Bald Hill
BLN	*	48 00 26.5	122 58 18.6	0.585	Blyn Mt.
BOW	*	46 28 30.0	123 13 41.0	0.870	Boistfort Mt.
BPO		44 39 06.9	121 41 19.2	1.957	Bald Peter, Oregon
BRV	+	46 29 07.2	119 59 29.4	0.925	Black Rock Valley
BVW	+	46 48 37.8	119 52 54.1	0.707	Beverly
CHO	+	45 35 27.0	118 34 45.0	1.076	Cabbage Hill, Oregon
CBW	+	47 48 25.5	120 01 57.6	1.160	Chelan Butte
CDF	$	46 06 58.2	122 02 51.0	0.780	Cedar Flats
CMM	$	46 26 07.0	122 30 21.0	0.620	Crazy Man Mt.
CMW	*	48 25 25.3	122 07 08.4	1.190	Cultus Mtns.
COW	$	46 29 27.6	122 00 43.6	0.305	Cowlitz River
CPW	*	46 58 25.8	123 08 10.8	0.792	Capitol Peak
CRF	+	46 49 30.6	119 23 18.0	0.260	Corfu
DPW	+	47 52 14.3	118 12 10.2	0.892	Davenport
DY2	+	47 59 06.9	119 46 13.0	0.884	Dyer Hill 2
EDM		46 11 50.4	122 09 00.0	1.609	East Dome, Mt. St. Helens
ELK	$	46 18 20.0	122 20 27.0	1.270	Elk Rock
ELL	+	46 54 35.0	120 34 06.0	0.805	Ellensburg
EPH	+	47 21 12.8	119 35 46.2	0.628	Ephrata
ETP	+	46 27 53.4	119 03 32.4	0.250	Eltopia
ETW	+	47 36 16.2	120 19 51.6	1.475	Entiat
FL2	$	46 11 47.0	122 21 01.0	1.378	Flat Top 2
FMW	*	46 55 54.0	121 40 19.2	1.890	Mt. Fremont

continued

STA	F	LAT	LONG	EL	NAME
FOX	+	48 19 50.0	119 42 29.0	0.896	Fox Mountain
GBL	+	46 35 51.6	119 27 35.4	0.330	Gable Mountain
GHW	*	47 02 30.0	122 16 21.0	0.268	Garrison Hill
GL2	+	45 57 35.0	120 49 22.5	1.000	New Goldendale
GLK	$	46 33 50.2	121 36 30.7	1.320	Glacier Lake
GMO		44 26 20.8	120 57 22.3	1.689	Grizzlie Mountain, Or.
GMW	*	47 32 52.5	122 47 10.8	0.506	Gold Mt.
GRO	$	45 21 04.5	123 39 43.0	0.945	Grindstone Mt., Oregon
GSM	*	47 12 11.4	121 47 40.2	1.305	Grass Mt.
GUL	$	45 55 27.0	121 35 44.0	1.189	Guler Mt.
HDW	*	47 38 54.6	123 03 15.2	1.006	Hoodsport
HH2	+	46 10 18.0	119 23 01.0	0.490	Horse Heaven Hills (moved HHW)
HSR	$	46 10 22.2	122 10 58.2	1.774	South Ridge, Mt. St. Helens
HTW	*	47 48 12.5	121 46 08.6	0.829	Haystack Lookout
JBO	$	45 27 41.7	119 50 13.3	0.645	Jordan Butte, Oregon
JCW	*	48 11 36.6	121 55 46.2	0.616	Jim Creek
JUN	$	46 08 48.0	122 09 10.8	1.049	June Lake
KMO	$	45 38 07.8	123 29 22.2	0.975	Kings Mt., Oregon
KOS	$	46 27 40.8	122 11 25.8	0.828	Kosmos
LMW	*	46 40 04.8	122 17 28.8	1.195	Ladd Mt.
LNO	+	45 52 15.8	118 17 06.0	0.768	Lincton Mt., Oregon
LON		46 45 00.0	121 48 36.0	0.853	Longmire (WWSSN and DWWSSN)
LVP	$	46 04 06.0	122 24 30.0	1.170	Lakeview Peak
MBW	*	48 47 02.4	121 53 58.8	1.676	Mt. Baker
MCW	*	48 40 46.8	122 49 56.4	0.693	Mt. Constitution
MDW	+	46 36 48.0	119 45 39.0	0.330	Midway
MEW	*	47 12 07.0	122 38 45.0	0.097	McNeil Island
MOX	+	46 34 38.0	120 17 35.0	0.540	Moxie City
MTM	$	46 01 31.8	122 12 42.0	1.121	Mt. Mitchell
NAC	+	46 44 03.8	120 49 33.2	0.738	Naches
NCO		43 42 18.2	121 08 06.0	1.908	Newberry Crater, Oregon
NEL	+	48 04 41.8	120 20 17.7	1.490	Nelson Butte
NLO	*	46 05 18.0	123 27 00.0	0.900	Nicolai Mt., Oregon
OBC	$	48 02 07.1	124 04 39.0	0.938	Olympics - Bonidu Creek
OBH	$	47 19 34.5	123 51 57.0	0.383	Olympics - Burnt Hill
ODS	+	47 18 24.0	118 44 42.0	0.523	Odessa
OFK	$	47 57 00.0	124 21 28.1	0.134	Olympics - Forks
OHW	*	48 19 24.0	122 31 54.6	0.054	Oak Harbor
OLQ	$	47 30 58.1	123 48 31.5	0.121	Olympics - Lake Quinault
ONR	$	46 52 37.5	123 46 16.5	0.257	Olympics - North River
OOW	$	47 44 12.0	124 11 22.0	0.743	Octopus West
OSD	*	47 49 15.0	123 42 06.0	2.010	Olympics - Snow Dome
OSP	$	48 17 05.5	124 35 23.3	-	Olympics - Sooes Peak
OTH	+	46 44 20.4	119 12 59.4	0.260	Othello
OTR	$	48 05 00.0	124 20 39.0	0.712	Olympics - Tyee Ridge
PAT	+	45 52 50.1	119 45 40.1	0.300	Paterson
PGO	$	45 28 00.0	122 27 10.0	0.237	Gresham, Oregon
PGW	*	47 49 18.8	122 35 57.7	0.122	Port Gamble
PRO	+	46 12 45.6	119 41 09.0	0.552	Prosser
REM		46 11 57.0	122 11 03.0	2.102	Rembrandt (Dome station)

continued

STA	F	LAT	LONG	EL	NAME
RMW	*	47 27 34.9	121 48 19.2	1.024	Rattlesnake Mt. (West)
RPK	+	45 45 42.0	120 13 50.0	0.330	Roosevelt Peak
RPW	*	48 26 54.0	121 30 49.0	0.850	Rockport
RSW	+	46 23 28.2	119 35 19.2	1.037	Rattlesnake Mt. (East)
RVC	$	46 56 34.5	121 58 17.3	1.000	Mt. Rainier - Voight Creek
RVW	*	46 08 58.2	122 44 37.2	0.460	Rose Valley
SAW	+	47 42 06.0	119 24 03.6	0.690	St. Andrews
SEA		47 39 18.0	122 18 30.0	0.030	Seattle (Wood Anderson)
SEE		47 39 18.0	122 18 30.0	0.030	Seattle Pseudo-WA (E)
SEN		47 39 18.0	122 18 30.0	0.030	Seattle Pseudo-WA (N)
SHW	*	46 11 33.0	122 14 12.0	1.423	Mt. St. Helens
SMW	*	47 19 10.2	123 20 30.0	0.840	South Mt.
SND	$	46 12 45.0	122 11 09.0	1.800	St. Helens Microphone, unrectif
SOS	$	46 14 38.5	122 08 12.0	1.270	Source of Smith Creek
SPW	*	47 33 13.3	122 14 45.1	0.008	Seward Park, Seattle
STD	$	46 14 16.0	122 13 21.9	1.268	Studebaker Ridge
STW	*	48 09 02.9	123 40 13.1	0.308	Striped Peak
SYR	+	46 51 46.8	119 37 04.2	0.267	Smyrna
TBM	+	47 10 10.1	120 35 54.0	1.064	Table Mt.
TCO		44 06 27.0	121 36 00.0	1.975	Three Creek Meadows, Or.
TDH	$	45 17 23.4	121 47 25.2	1.541	Tom,Dick,Harry Mt., Oregon
TDL	$	46 21 03.0	122 12 57.0	1.400	Tradedollar Lake
TWW	+	47 08 17.2	120 52 04.5	1.046	Teanaway
VBE	$	45 03 37.2	121 35 12.6	1.544	Beaver Butte, Oregon
VCR		44 58 58.2	120 59 17.3	1.015	Criterion Ridge, Oregon
VFP	$	45 19 05.0	121 27 54.3	1.716	Flag Point, Oregon
VG2	+	45 09 20.0	122 16 15.0	0.823	Goat Mt., Oregon
VGB	+	45 30 56.4	120 46 39.0	0.729	Gordon Butte, Oregon
VIP	+	44 30 29.4	120 37 07.8	1.731	Ingram Pt., Oregon
VLL	$	45 27 48.0	121 40 45.0	1.195	Laurance Lk., Oregon
VLM	$	45 32 18.6	122 02 21.0	1.150	Little Larch, Oregon
VTG	+	46 57 28.8	119 59 14.4	0.208	Vantage
VTH	+	45 10 52.2	120 33 40.8	0.773	The Trough, Oregon
WA2	+	46 45 24.2	119 33 45.5	0.230	Wahluke Slope
WAT	+	47 41 55.0	119 57 15.0	0.900	Waterville
WBW	+	48 01 04.2	119 08 13.8	0.825	Wilson Butte
WEN	+	47 31 46.2	120 11 39.0	1.061	Wenatchee
WG2	+	46 01 50.25	118 51 19.95	0.511	Wallula Gap
WIW	+	46 25 48.8	119 17 13.4	0.130	Wooded Island
WNS	+	46 42 37.0	120 34 30.0	1.000	Wenas
WPO	$	45 34 24.0	122 47 22.4	0.334	West Portland, Oregon
WPW	+	46 41 53.4	121 32 48.0	1.250	White Pass
WRD	+	46 58 11.4	119 08 36.0	0.378	Warden
YAK	+	46 31 15.8	120 31 45.2	0.619	Yakima
YEL		46 12 35.0	122 11 16.0	1.750	Yellow Rock, Mt. St. Helens

EARTHQUAKE DATA

There were 625 events processed by the University of Washington digitally recording seismic network between July 1 and September 30, 1987. Locations were determined for 448 of these in Washington and Northern Oregon; 292 were classified as earthquakes and 156 as known or suspected blasts. The remaining 177 processed events include teleseisms (113 events), regional events outside the U. W. network (39), and unlocated events within the U. W. network. Unlocated events within the U.W. network include very small earthquakes and some known blasts. For example, only a few of the frequent mine blasts at Centralia are located. In addition, during eruptive phases of Mount St. Helens, we may locate only a representative sample of the earthquakes that occur under the volcano.

Table 3 is the catalog of earthquakes and blasts located within the network for this quarter. Fig. 2 shows all earthquakes with magnitude greater than or equal to 1.0 ($M_c \geq 1.$) Fig. 3 shows blasts and probable blasts ($M_c \geq 0.$) Fig. 4 shows all earthquakes located in western Washington ($M_c \geq 0.$) Fig. 5 shows all earthquakes located in eastern Washington ($M_c \geq 0.$) Fig. 6 shows earthquakes located at Mount St. Helens ($M_c \geq 0$).

Western Washington and Oregon

213 earthquakes were located between 44.5° and 49.5° north latitude and between 121° and 125° west longitude during the third quarter of 1987. Most of these occurred at depths less than 30 km with, as usual, a small number of earthquakes in the Puget Sound lowland at depths greater than 30 km. The deepest earthquake located during the quarter was a $M_c = 1.2$ at 59.6 km near Mercer Island on August 1. The largest deep earthquake during the quarter was a $M_c = 2.8$ on Sept. 20, located at 55 km depth on the Olympic Peninsula near Sequim. In addition to the deep Puget Sound lowland earthquakes, an earthquake on July 27 occurred at nearly 40 km in depth about 25 km east of Lake Quinault on the Olympic Peninsula.

Three minor earthquakes were reported felt in western Washington during the third quarter of 1987. A $M_c = 2.7$ earthquake occurred on August 6 near Port Townsend, and a $M_c = 2.8$

earthquake occurred on September 20 in the same area. Both earthquakes occurred at a depth of about 20 km. On September 16, a $M_c = 3.3$ earthquake occurred in southern British Columbia and was felt in Blaine, Washington. It was the largest earthquake in the region during the third quarter. A $M_c = 2.6$ earthquake occurred in the same area on September 18. No other earthquakes were recorded nearby during the third quarter of 1987.

A cluster of 5 earthquakes with magnitudes of .9 to 2.0 and depths less than 15 km occurred near Bellingham in August 1987. Near Mt. Rainier, a cluster of 7 earthquakes occurred with magnitudes of .8 to 2.1 and depths less than 5 km.

A cluster of four earthquakes were recorded about 10 km southeast of Mt. Hood, Oregon during the third quarter. The largest earthquake in the cluster was a $M_c = 2.4$ earthquake on July 27. These events were located at depths of about 10 km. Small clusters of earthquakes have occurred in the same area in the past, including a cluster of four earthquakes (the largest having $M_c = 3.4$) in August 1982.

A cluster of 4 earthquakes located northwest of Mt. Hood between August 25 and Sept. 28 had magnitudes from 1.5 to 1.7. These may be blasts, but have not yet been confirmed.

Eastern Washington and Oregon

During the third quarter of 1987, 79 earthquakes were located in eastern Washington. The Entiat area south of Lake Chelan was again active and fifteen earthquakes from magnitude .8 to 2.2 were located there at depths less than 8 km.

In August, two earthquakes occurred near Ritzville, one having $M_c = 2.1$ and another having $M_c = 2.0$. A cluster of 5 earthquakes occurred near Corfu in August and September. Magnitudes ranged from .9 to 2.2 and depths were less than 1 km. Elsewhere in eastern Washington, earthquakes generally occurred as isolated events rather than in clusters.

A $M_c = 2.4$ earthquake occurred on August 28 in the North Cascades with a fixed depth at 34 km. Only one earthquake, a $M_c = 2.2$ in 1983, had been previously located in this area. The location and depth may change somewhat when data from the Canadian seismograph network are added because this earthquake is at the edge of our network.

Twenty-eight earthquakes were located in eastern Oregon during the third quarter of 1987. All except one of these earthquakes occurred within one of two clusters, each of which included a felt earthquake. One cluster of twenty-one earthquakes larger than $M_c = 1.0$ was located east of the Deschutes Valley, near Maupin, Oregon between August 8 and 24. The largest event was a $M_c = 2.4$ at 12 km depth. A $M_L = 4.8$ earthquake occurred at the same location in 1976. In 1982, eight earthquakes between a $M_c = 1.0$ and 2.1 were located in the same area. The second cluster, which occurred between Sept. 4 and 29, was located about 60 km east of the first one and included 6 earthquakes larger than $M_c = 1.0$. Most of these were shallower than 1 km, including a $M_c = 3.1$ and a $M_c = 2.7$. Only one earthquake had previously been located in this area, a $M_c = 2.5$ earthquake on Nov. 10, 1986.

Mount St. Helens Area

Only 19 earthquakes were located in the Mt. St. Helens area during the third quarter of 1987. Of these, fifteen were located in or close to the crater. The largest earthquake in the Mt. St. Helens area was a $M_c = 1.6$ event on August 11. This is typical of earthquake activity during a quiescent period between eruptions.

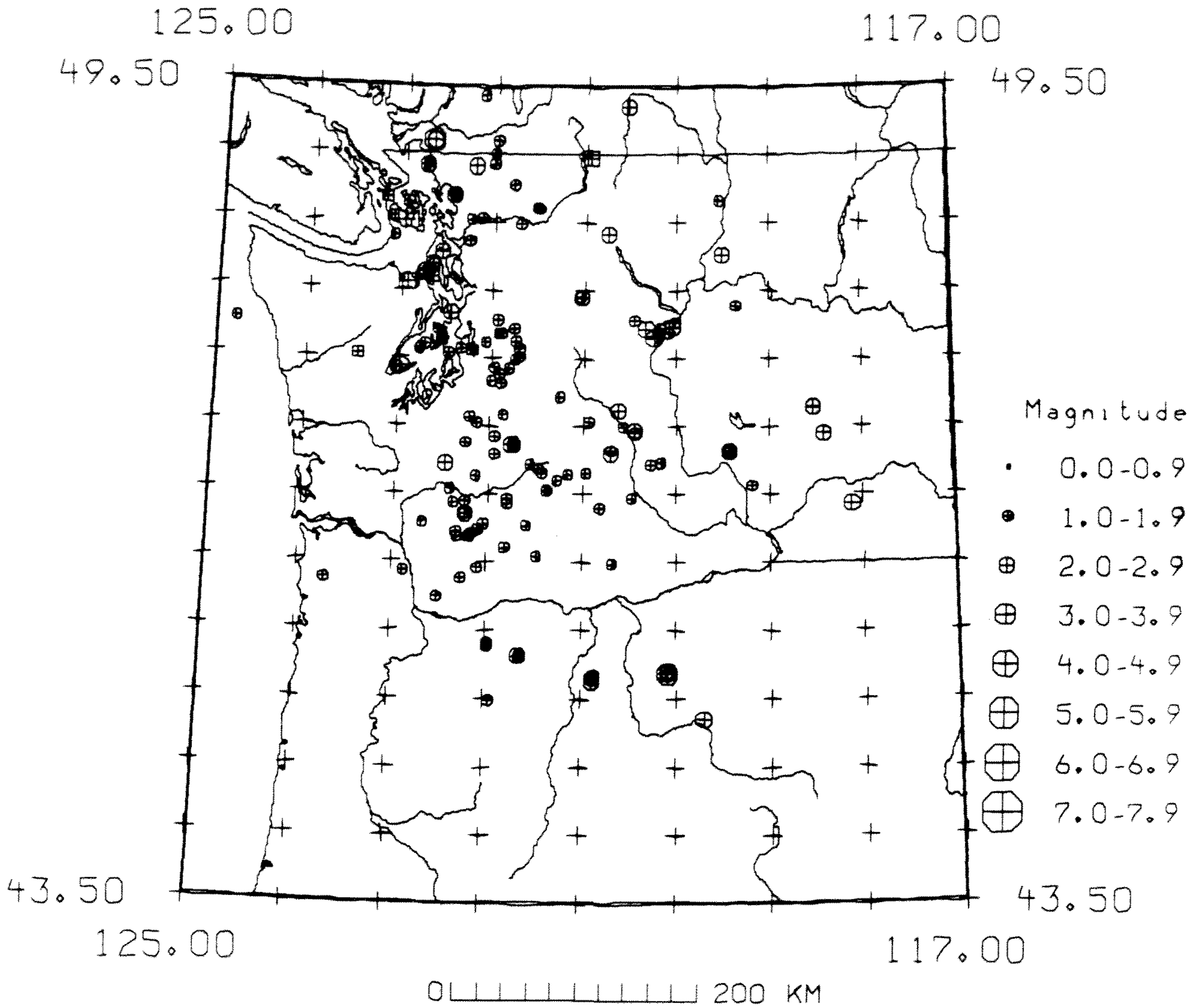

Figure 2. Earthquakes located in Washington and northern Oregon with magnitudes greater than 1.0, 3rd quarter 1987. A square symbol indicates that a event located with a depth greater than or equal to 30 km. Octagonal symbols are used for events shallower than 30 km.