FINAL TECHNICAL REPORT: 1986

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Short Title:	Regional Seismic Monitoring in Western Washington
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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 contract is to gather data for use in evaluation of seismic hazards in western Washington; research carried out under contract 14-08-0001-G1080 entitled 'Earthquake Hazard Investigations in the Pacific Northwest', and by 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, and provide up-to-date coverage of seismic and volcanic activity. Appendix 1 is composed of quarterly bulletins covering the contract period.

'Earthquake Hypocenters in Washington and Northern Oregon - 1980' has been published by the Washington State Department of Natural Resources, Division of Geology and Earth Resources; as Information Circular 82. A similar bulletin for 1981 is in press. The years from 1982 through 1986 will be issued in a single five-year catalog, which is now in preparation. Each of these publications includes 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

The University of Washington records a total of 116 seismic channels or stations, including WWSSN stations LON and Wood-Anderson seismometers at SEA and NEW. Twenty-eight stations covering much of western Washington are supported under this contract. Locations of stations supported under this contract

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

	LAT	LONG	EL	NAME
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 first column in the table gives the 3-letter station designator. Station north latitude and west longitude are given in the second and third columns in degrees, minutes and seconds. The fourth column gives station elevation in km, and the fifth indicates landmarks for which stations were named.

A summary of station installation dates and outages from November 1985 through October 1986 is given in Table 2 for stations operated under this

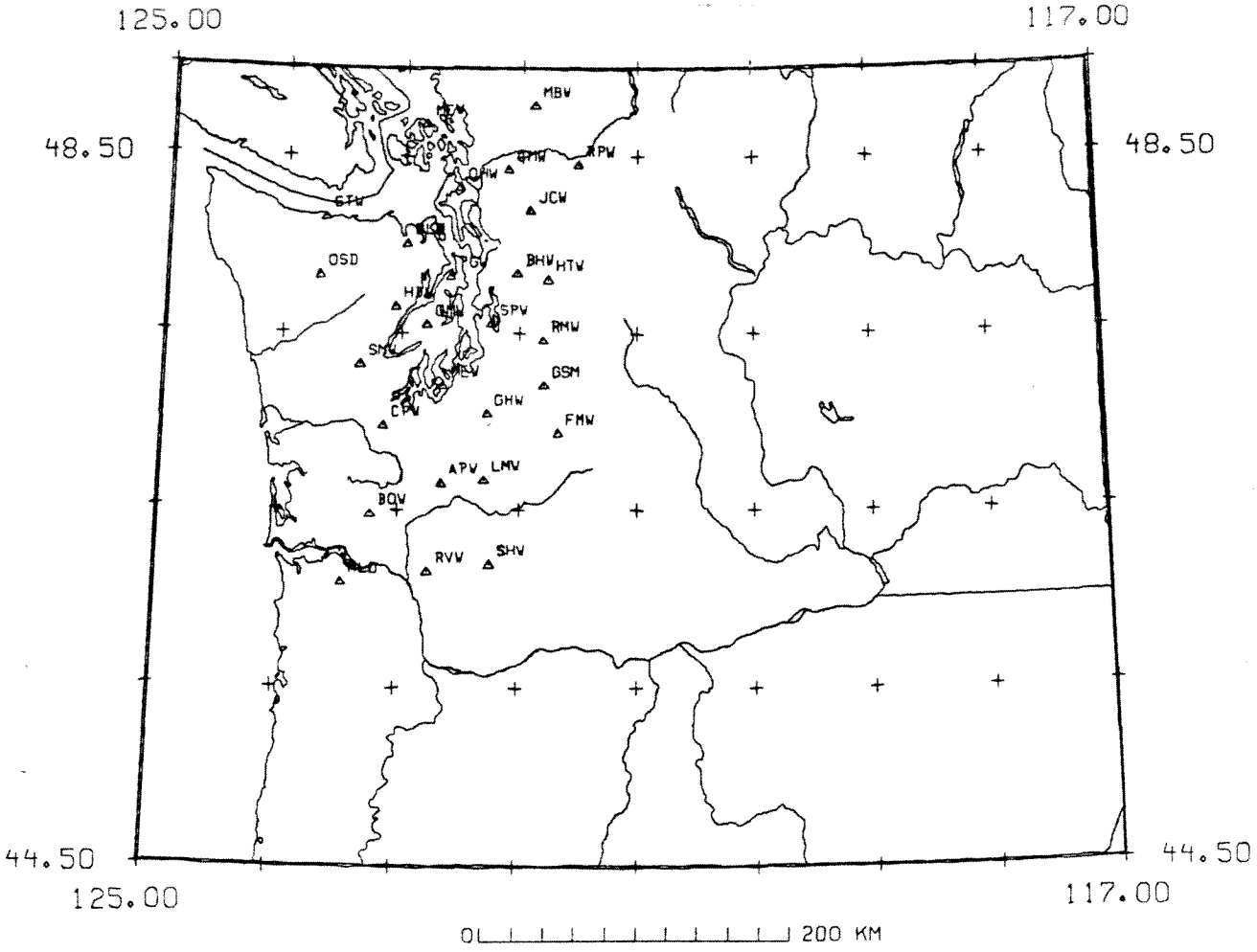

Figure 1. Map view of seismic stations supported under USGS JOA A0266 between Nov. 1, 1985 and Oct. 31, 1986. These twenty-eight stations provide coverage of western Washington.

contract. All stations under this contract were operating at the end of the contract period. One new station was installed in June 1986, in the Cultus Mountains area just south of the Skagit Valley.

TABLE 2

Western Washington Network

Major station outages and changes, November 1, 1985 - October 31, 1986

Station	Date	Comments
BLN	05/07/86-05/16/86	Cable cut by heavy equipment
CMW		NEW STATION, started 6/7/86
CPW	12/08/85-1/06/86	
FMW	12/15/85-08/26/86	Intermittent
GHW	5/21/86-05/28/86	Lightning strike at telemetry link
JCW	5/8/86-05/23/86	
LMW	09/01/86-10/14/86	Vandalized, Transmitter stolen
MEW	4/01/86-06/20/86	
NLO	02/26/86-07/23/86	
OSD	11/19/85-12/12/85	
RVW	03/18/86-05/21/86	
SPW	06/13/86-06/20/86	Dead phone line
	10/22/86-11/03/86	bad cable

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, based on the standard non-linear least-squares inversion scheme of Geiger (1912), 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 is saved for all teleseisms, regional events, and all locatable local events. Each data file has a 'pickfile' which includes arrival times, polarities, and coda lengths for each station read. Times are not routinely read for teleseisms or regional events, but the pickfile may list stations on which the signal is visible.

Phase data for eastern Washington events from 1970 - 1975 are being reformatted to the 'pickfile' format used currently. Arrival times in this data set were picked at the USGS in Menlo Park from 35 mm develocorder film. Magnitudes were computed from either amplitude, coda lengths, or a combination of the two. We are investigating how best to translate this data into the current format, which computes magnitude from coda lengths only. We also hope to recover the amplitude calibration information, since amplitudes were read for all eastern Washington events from 1970-1979.

Calibrated Stations in the UW Network

Since 1982 some stations in the telemetered network have been calibrated so that ground motion amplitude can be determined. Each calibrated station is broken down into 5 parts, each a known frequency response and amplitude factor. These 5 components are the seismometer, VCO, discriminator, recorder and antialiasing filter (optional). In the frequency domain, the component response curves are multiplied together to yield a station response curve. Fig. 2 shows the amplitude magnification curve for station FMW, one of the most frequently read

stations in the UW network. The shape of the curve is nearly constant for all calibrated stations, although the curve will move up or down on the amplitude axis depending mainly on the gain setting of the station. Table 3 lists the calibrated stations, while Fig. 3 shows a map view of sites at which calibrated equipment is currently operating.

Stations in Table 3 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.

Columns 1-5 are identical to those given in Table 1; the sixth column gives the count recorded on the UW digital recording system (DEC 11/34) per meter of ground motion at 1 Hz, and the seventh column indicates the magnification (in thousands) at 1 Hz frequency for a hard-copy of the trace data produced with the UW 'punt' program at unit trace amplitude multiplier.

TABLE 3

Calibrated Stations in the UW Network

	LAT	LONG	EL	NAME	COUNTS/M at 1 Hz	PUNT MAG. $\times 10^3$ at 1 Hz
APW*	46 39 6.0	122 38 51.0	0.457	Alpha Peak	0.32e+09	40.5
BHW*	47 50 12.6	122 1 55.8	0.198	Bald Hill	0.16e+09	20.3
BLN*	48 0 26.5	122 58 18.6	0.585	Blyn Mt.	0.13e+10	163.3
BOW*	46 28 30.0	123 13 41.0	0.870	Boistfort Mt.	0.13e+10	160.3
BVW+	46 48 37.8	119 52 54.1	0.707	Beverly	0.17e+09	21.2
CDF$	46 6 58.2	122 2 51.0	0.780	Cedar Flats	0.63e+09	80.8
CMW*	48 25 25.3	122 7 8.4	1.190	Cultus Mtns.	0.13e+10	167.1
DPW+	47 52 14.3	118 12 10.2	0.892	Davenport	0.11e+10	135.9
ELK$	46 18 20.0	122 20 27.0	1.270	Elk Rock	0.79e+09	100.2
ETW+	47 36 16.2	120 19 51.6	1.475	Entiat	0.45e+09	57.0
FMW*	46 55 54.0	121 40 19.2	1.890	Mt. Fremont	0.15e+10	187.5
FOR$	45 58 14.0	121 45 30.0	1.152	Forlorn Lakes	0.44e+09	56.1
GBL+	46 35 51.6	119 27 35.4	0.330	Gable Mountain	0.45e+09	57.2
GHW*	47 2 30.0	122 16 21.0	0.268	Garrison Hill	0.80e+08	10.2
GL2+	45 57 35.0	120 49 22.5	1.000	New Goldendale	0.42e+09	53.5
GMW*	47 32 52.5	122 47 10.8	0.506	Gold Mt.	0.13e+10	162.2

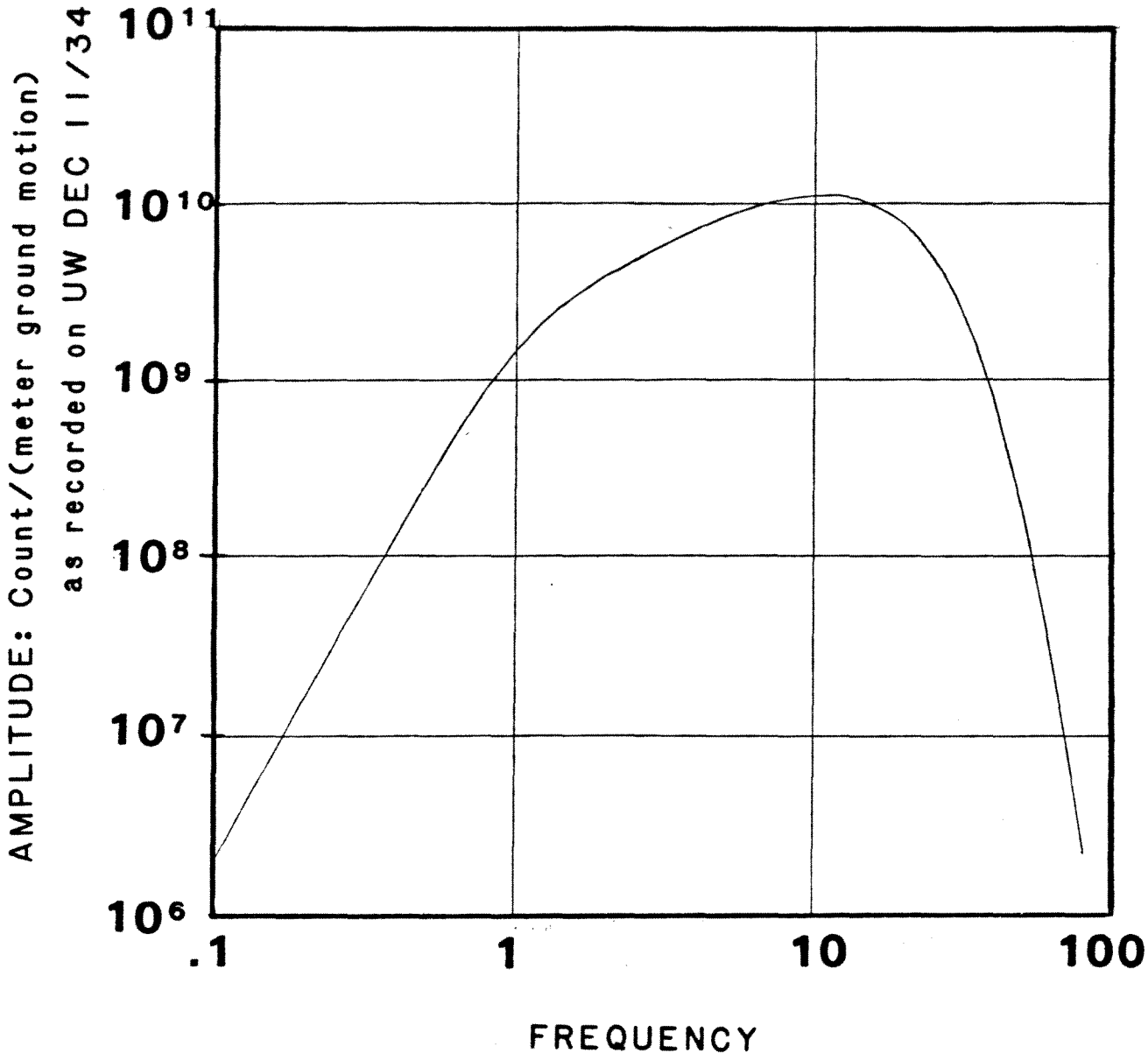

Figure 2. Frequency response curve for calibrated station FMW in log-log scale. The vertical axis is in counts per meter of ground motion as recorded on the U.W. DEC 11/34. The shape of the curve is nearly constant for all stations, although the position will shift vertically on the amplitude axis, due to the gain setting of the station.

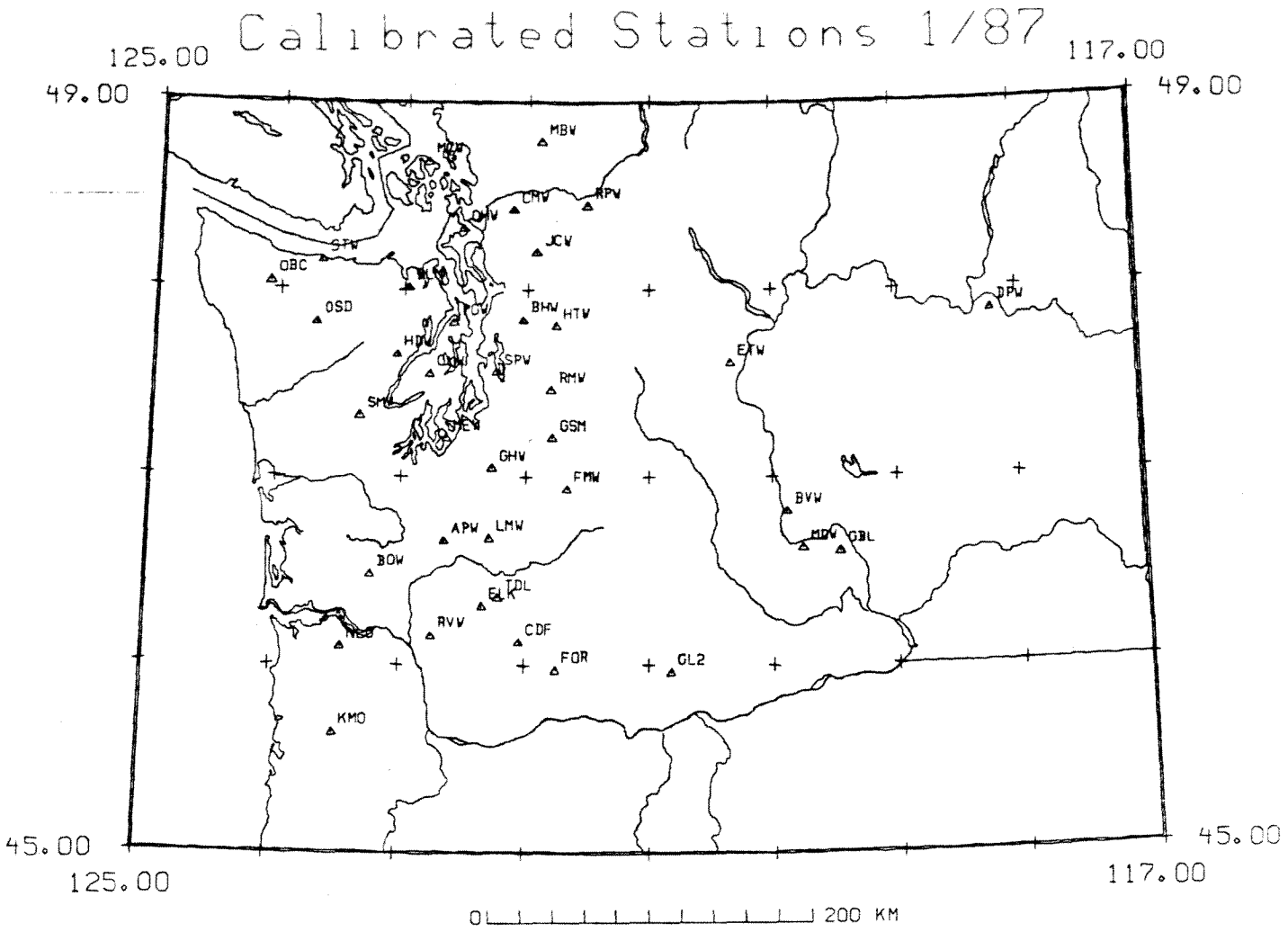

Figure 3. Map view of calibrated stations in the U.W. seismic network. These stations are composed of components with known frequency response. True ground motion amplitude can be determined at these stations.

TABLE 3 - UW Calibrated Stations - continued

	LAT	LONG	EL	NAME	COUNTS/M at 1 Hz	PUNT MAG. $\times 10^3$ at 1 Hz
APW*	46 39 6.0	122 38 51.0	0.457	Alpha Peak	0.32e+09	40.5
BHW*	47 50 12.6	122 1 55.8	0.198	Bald Hill	0.16e+09	20.3
GSM*	47 12 11.4	121 47 40.2	1.305	Grass Mt.	0.64e+09	81.3
HDW*	47 38 54.6	123 3 15.2	1.006	Hoodsport	0.13e+10	161.3
HTW*	47 48 12.5	121 46 8.6	0.829	Haystack Lookout	0.63e+09	80.3
JCW*	48 11 36.6	121 55 46.2	0.616	Jim Creek	0.13e+10	162.2
KMO$	45 38 7.8	123 29 22.2	0.975	Kings Mt., Oregon	0.99e+09	126.5
LMW*	46 40 4.8	122 17 28.8	1.195	Ladd Mt.	0.64e+09	81.9
MBW*	48 47 2.4	121 53 58.8	1.676	Mt. Baker	0.13e+10	162.2
MCW*	48 40 46.8	122 49 56.4	0.693	Mt. Constitution	0.13e+10	162.2
MDW+	46 36 48.0	119 45 39.0	0.330	Midway	0.58e+08	7.4
MEW*	47 12 7.0	122 38 45.0	0.097	McNeil Island	0.16e+09	20.4
NLO*	46 5 18.0	123 27 0.	0.900	Nicolai Mt., Oregon	0.32e+09	40.2
OBC$	48 2 7.1	124 4 39.0	0.938	Olympics - Bonidu Creek	0.11e+09	13.5
OHW*	48 19 24.0	122 31 54.6	0.054	Oak Harbor	0.79e+08	10.1
OSD*	47 49 15.0	123 42 6.0	2.010	Olympics - Snow Dome	0.13e+10	16.3
PGW*	47 49 18.8	122 35 57.7	0.122	Port Gamble	0.12e+09	15.0
RMW*	47 27 35.0	121 48 19.2	1.024	Rattlesnake Mt. (West)	0.13e+10	162.2
RPW*	48 26 54.0	121 30 49.0	0.850	Rockport	0.25e+10	323.6
RVW*	46 8 58.2	122 44 37.2	0.460	Rose Valley	0.32e+09	40.5
SMW*	47 19 10.2	123 20 30.0	0.840	South Mt.	0.32e+09	40.5
SPW*	47 33 13.3	122 14 45.1	0.008	Seward Park, Seattle	0.32e+09	40.7
STW*	48 9 2.9	123 40 13.1	0.308	Striped Peak	0.64e+09	81.3
TDL$	46 21 3.0	122 12 57.0	1.400	Tradedollar Lake	0.35e+09	44.6
WA2+	46 45 24.2	119 33 45.5	0.230	Wahluke Slope	0.21e+09	27.3

Publications

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

Acknowledgements

Laurens Engel, who does all the field work on the 28 stations supported under this contract, continues his battle with nature and entropy. Moisture, which seems to work its way into everything in the Pacific Northwest, is a constant problem, as are lightning storms and vandalism, and heavy machinery working near our sites. Rick Benson, Anne Rathbun, Chris Jonientz-Trisler and Cindy Roe helped compile data for quarterly reports, which were written by Ruth Ludwin and Tony Qamar.

APPENDIX 1

U. W. Seismic Network Quarterly Reports

85-D, 86-A, 86-B, 86-C

QUARTERLY NETWORK REPORT 85-D
on
Seismicity of Washington and Northern Oregon

October 1 through December 31, 1985

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
Contract 14-08-0001-A0266
and
Contract 14-08-0001-21861
and
Contract 14-08-0001-22007
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 fourth quarterly report of 1985 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 1970-1979. Annual earthquake catalogs for the whole state are in preparation, beginning with 1980.

This quarterly report discusses network operations, seismicity of the region, and unusual events or findings. This report is preliminary, and not a substitute for detailed technical reports, an annual catalog, or technical papers. In particular, event magnitudes are preliminary, and subject to revision. Some earthquake locations may be revised if new data become available, such as P and S readings from Canadian seismic stations. Findings mentioned in these quarterly reports should not be cited for publication. Fig. 1 shows the major geographical features in the state of Washington and northern Oregon and the seismograph stations currently 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.

Station DIG, in the crater of Mt. St. Helens, was removed on October 29. This three-component low-gain calibrated station had been installed during the eruption of May, 1985. Since the station site was potentially in the path of mudflows, we decided to remove the equipment before snowfall made the site inaccessible. The USGS station SUG, on the flank of Mt. St. Helens, was replaced by station NSP, located on the dome, on October 1. HSR, installed on the south side of Mt. St. Helens in the third quarter has not yet provided data. Station SHW, also at St.

TABLE 1
Station Outages

Station	Outage Dates	Comments
ASR	Oct. 24 - Nov. 1	Sporadic
	Nov. 15 - Dec. 10	Sporadic
AUG	Oct. 1 - Oct. 22	
BRV	Dec. 19 - Dec. 31	
CPW	Dec. 18 - Dec. 31	
DIG		Station removed Oct. 29
EDM	Oct. 15 - Oct.30	
GLK	Nov. 15 - Dec. 31	Sporadic
GL2	Nov. 25 - Dec. 31	
HSR	Oct. 1 - Dec. 31	
JUN	Oct.1 -Oct. 3	
LVP	Oct. 1 - Oct. 2	
NEL	Oct. 1 - Oct. 18	
NSP		New Station Oct. 1
OBC	Oct. 1 - Nov. 6	Sporadic
	Nov. 17-Dec.10	Sporadic
OBH	Nov. 5 - Dec. 31	Sporadic
OHW	Oct. 26-Nov.15	
ONR	Oct. 4 - Oct. 17	
OOW	Nov. 20- Dec. 10	
OSD	Nov. 19 - Dec. 12	
OSP	Nov. 25 - Dec. 11	
OTR	Oct 25-Nov. 4	
	Nov. 22-Dec. 11	
RSW	Nov. 28 - Dec. 11	
SUG		Moved to NSP Oct. 1
VHO	Oct. 1 - Dec. 31	
WBW	Nov. 12 - Dec. 31	Sporadic

Helens, continues to record intermittent radio interference. The same carrier frequency is used by several stations around the state, in each case for a single short telemetry leg. One such station, NEL, shows the same interference. NEL and SHW are about 300 km apart. We have not been able to trace the source of the interference. Because SHW is the station used for event counts during eruptions, continuous operation is essential to maintain consistency of event counts. We will consider changing the frequency of this station if the interference problem cannot be solved.

Several stations on the Olympic Peninsula lost function for most of the quarter. Telemetry path problems, low batteries, snow, and problems with phone lines all contributed. Station MEW on McNeil Island in south Puget Sound is very low-gain, and also needs a new transmitter.

EARTHQUAKE DATA

There were 434 events processed by the University of Washington digitally recording seismic network between October 1 and December 31, 1985. We determined locations for 274 of these in Washington and Northern Oregon; 227 were classified as earthquakes and 47 as known or suspected blasts. The remaining unlocatable events were regional events outside the U. W. network, or teleseisms. Helicorder records are scanned daily to ensure that significant events are not missed by the on-line digital system. Table 2 is the event catalog for this quarter. Although seven events of M_C 3.0 or larger were located, only one quake (M_C 2.6) was reported felt. We believe that some of the other events may have been felt, but were not reported. In the Mt. St. Helens area, only 19 events were located during the quarter. Fig. 2 shows all earthquakes greater than magnitude 1.0. Fig. 3 shows blasts and probable blasts. Fig. 4 shows all earthquakes located in western Washington. Fig. 5 shows all earthquakes located in eastern Washington. Fig. 6 shows earthquakes located at Mount St. Helens.

Western Washington and Oregon

During the fourth quarter of 1985 161 earthquakes were located between 44.5° and 49.5° latitude and between 121° and 125° longitude. Excluding Mt. St. Helens, 142 earthquakes occurred in western Washington. One felt event of M_C 2.6 on November 1 was located in northern Washington about 20 km east of Bellingham, near where swarm activity occurred during the second quarter. Two other western Washington earthquakes had magnitudes larger than 3.0 but were not reported felt, These included an event near the Elk Lake area on Dec. 26, and one near Mt. Rainier on Dec. 27. In Oregon, a M_C 3.0 event on Nov. 22 was located about 60 km south of Portland. Seismicity in the Puget Lowland was diffuse, and very light. Several shocks were recorded near Darrington, close to the site of a felt event in July, 1985.

Eastern Washington and Oregon

During the fourth quarter of 1985 161 earthquakes were located between 44.5° and 49.5° latitude and between 117° and 121° longitude. Four events above M_C 3.0 were located, 2 were close

together about 40 km NE. of Yakima on Oct. 1, one was near Wenachee on Oct. 10, and one was about 20 km north of Potholes Reservoir on Nov. 22.

Mount St. Helens Area

Only 19 events were located at Mt. St. Helens during the quarter. An interesting sequence took place on Dec. 31, when a high-frequency event of M_C 1.5 occurred in the midst of a swarm of several dozen events too small to locate. Another high-frequency M_C 2.2 quake was recorded on Dec. 22. These high-frequency quakes are larger than usual for a non-eruptive period.

INTRODUCTION

This is the first 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. 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 1970-1979. Annual earthquake catalogs for the whole state are in preparation, beginning with 1980.

This quarterly report discusses network operations, seismicity of the region, and unusual events or findings. This report is preliminary, and not a substitute for detailed technical reports, an annual catalog, or technical papers. In particular, event magnitudes are preliminary, and subject to revision. Some earthquake locations may be revised if new data become available, such as P and S readings from Canadian seismic stations. Findings mentioned in these quarterly reports should not be cited for publication. Fig. 1 shows the major geographical features in the state of Washington and northern Oregon and the seismograph stations currently 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.

Because of winter snow conditions many stations remained out during the first quarter of 1986 because they were inaccessible. A number of stations failed because of depleted batteries. Deep snow or ice conditions affected some radio antennae causing failures at FMW, SOS, ASR, and GLK. A receiving antenna at SMW was moved to improve radio reception of the signal from station OBH.

We were able to reach the station HSR on the south flank of Mount St. Helens and replace the radio transmitter there (the coordinates of HSR in Table 3 have been corrected from values published in Quarterly 85-D). Station GL2 will probably not be fixed until we obtain permission to reroute the signal to the university via a microwave radio link. Intermittent radio interference at our Mount St. Helens station, SHW, continued during the quarter but we were able to determine that the interference was coming from an unknown radio source east of the Cascades.

TABLE 1
Station Outages

Station	Outage Dates	Comments
ASR	Whole Period	Antenna at AUG
DY2	Mar 5 -	Batteries
EST	Whole Period	Bad Cable
FMW	Jan 26 - Feb 27	Intermittent. Snow.
FOX	Mar 9 -	Batteries at DY2
GL2	Whole Period	
GLK	Feb 3 - Feb 19	Snow
HSR	Jan 1 - Mar 5	Radio Transmitter
JUN	Feb 15 - Mar 20	
KOS	Mar 11 - Mar 20	Batteries
NLO	Feb 26 -	
OBC	Jan 22 - Jan 26	
RVW	Mar 18 -	Drifting VCO. Intermittent.
SOS	Jan 26 - Feb 27	Deep Snow
VIP	Jan 26 -	Batteries
VLL	Jan 22 -	Batteries
WBW	Feb 19 -	Batteries
WPW	Feb 5 - Feb 9	

EARTHQUAKE DATA

There were 409 events processed by the University of Washington digitally recording seismic network between January 1 and March 31, 1986. We determined locations for 306 of these in Washington and Northern Oregon; 261 were classified as earthquakes and 45 as known or suspected blasts. The remaining unlocatable events were teleseisms or regional events outside the U. W. network. Helicorder records are scanned daily to ensure that significant events are not missed by the on-line digital system. Table 2 is the event catalog for this quarter. There were eight events of M_c 3.0 or larger, one in eastern Washington and the rest in western Washington. Eleven earthquakes were

reported felt, including one near Vancouver, Washington and another near Tacoma. The other felt earthquakes were the result of two earthquake swarms in northwest Washington, one south of Concrete in the Skagit valley, the other west of Darrington. 46 Earthquakes were located in the Mount St. Helens area. Fig. 2 shows all earthquakes greater than magnitude 1.0. Fig. 3 shows blasts and probable blasts. Fig. 4 shows all earthquakes located in western Washington. Fig. 5 shows all earthquakes located in eastern Washington. Fig. 6 shows earthquakes located at Mount St. Helens.

Western Washington and Oregon

204 earthquakes were located between 44.5° and 49.5° latitude and between 121° and 125° longitude during the first quarter of 1986 . Excluding Mt. St. Helens, 158 earthquakes occurred in western Washington. One felt event of M_c 3.1 was felt in Couger and Vancouver, Washington on March 11. On the same day a smaller earthquake of M_c 2.9 was reported felt at Gig Harbor near Tacoma.

On February 10, a swarm of earthquakes began about 15 km south of Concrete, Washington in the mountains between the Skagit River Valley and the north fork of the Stillaguamish. Two earthquakes of M_c 3.1 and 3.9 were felt on Feb. 10. The larger one was felt at Concrete, Mount Vernon, Sedro Woolley, Cape Horn, Clear Lake, and Day Creek. The fault plane solution for the M_c 3.9 earthquake indicates 1) a combination of thrust and strike slip motion, 2) a fault striking NW-SE or NE-SW, and 3) maximum compression directed NNW-SSE. In all, we located 11 earthquakes in the swarm with $M_c \leq 3.9$ between February 10 and March 9. They occurred in an area which has not had earthquake activity in recent years.

On March 24 another earthquake swarm began 20 km to the southeast at a location about 10 km west of Darrington. At least seven earthquakes were felt including an M_c 3.6 earthquake on March 28 which was felt in Darrington as well as in Concrete and Duvall, Washington. We located 16 earthquakes in this swarm with $M_c \leq 3.6$ from March 24 through the end of the quarter. Nine additional earthquakes $M_c \leq 1.8$ occurred in April. A preliminary fault plane solution of the largest (M_c 3.6) earthquake indicates an east-west trending thrust fault. This general region has had activity in past years including an earthquake swarm in 1985 which occurred immediately to the west

of the 1986 swarm. We are studying these earthquakes in greater detail.

Eastern Washington and Oregon

During the first quarter of 1986, 57 earthquakes were located in eastern Washington. Only one earthquake exceeding M_c 3 occurred, the one on Feb. 4, 1986 (M_c 3.2) near Wallula, Washington, 40 km west of Walla Walla. A number of small earthquakes occurred south of Lake Chelan near Entiat. This area is persistently active. A small cluster of earthquakes occurred on the Hanford reservation and several other clusters occurred near Ellensburg, Yakima and the intersection of the Saddle Mountains with the Columbia River.

Mt. St. Helens Area

Seismic activity at Mount St. Helens remained very low during the first quarter of 1986. We recorded an equal number of rockfalls within the crater and earthquakes under the dome. We list locations for 46 earthquakes in the catalog. The largest earthquake had magnitude M_c 2.6.

Earthquake Magnitudes in Eastern Washington 1969-1974

From 1969-1974 the eastern Washington network was operated by the US Geological Survey under the direction of Mitch Pitt in Menlo Park, California. In the early part of this period, earthquake magnitudes (denoted M_{amp} here) were computed from recorded wave amplitudes. Later, magnitudes were calculated by averaging estimates based on amplitudes with estimates based on the duration of the seismic signals. After 1975 magnitudes have been computed from the duration of seismic signals only ("coda length"). Today we use the relation

$$M_c = -2.46+2.82*\log(T_c).$$

M_c is the coda magnitude and T_c is the duration of the seismic signal in seconds. Recently, Dai McClurg has examined the relationship between the amplitude magnitude M_{amp} and the coda magnitude M_c used today. Using a number of stations in eastern Washington and 31 earthquakes in 1969 and 1970 he found

$$M_c = -0.278+0.984*M_{amp}$$

Figure 7 shows the fit of this equation to the data used in the study. We plan to use this relationship to ensure that the magnitudes for our historical earthquake database are consistent from 1969 to present.

Canadian Data and Accuracy of Earthquake locations in Northern Washington

For a number of years we have shared earthquake readings with Canadian seismologists at the Pacific Geoscience Centre at Sydney, British Columbia. Figure 8 shows that readings from Canadian seismographs are critical in determining accurate epicenters for the earthquakes in Northern Washington. Figure 8 shows all earthquakes in northwest Washington and southern British Columbia for which seismic readings from both the University of Washington and Canada were available in 1985. Canadian seismic data are combined with data from the University of Washington several months after the earthquakes occur, usually after publication of the Network Quarterlies. Hence, the coordinates of some earthquake epicenters in northern Washington, which are published in the Quarterlies, are later revised.

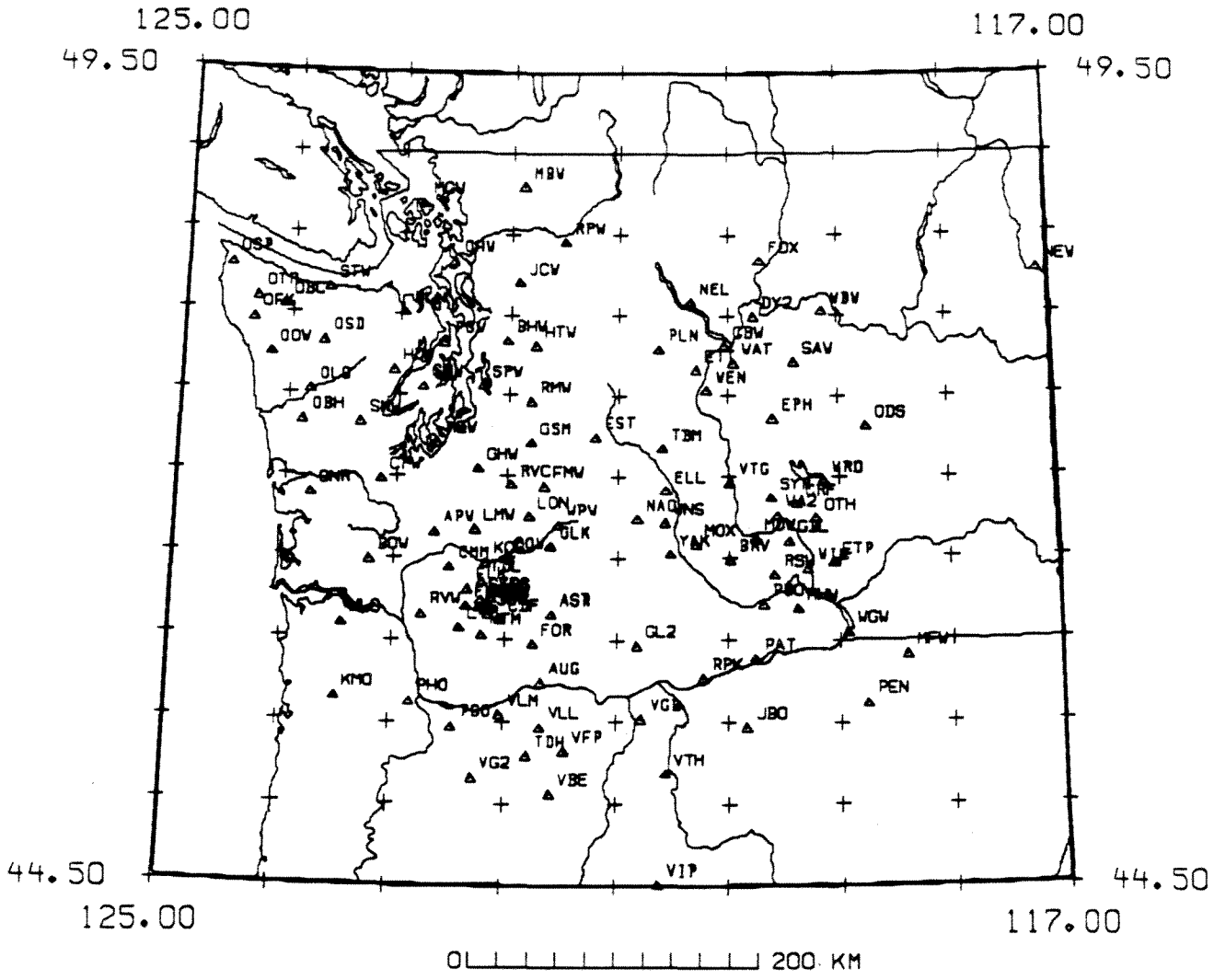

Figure 1. Seismograph stations operating during the first quarter 1986.

INTRODUCTION

This is the second 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. 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 1970-1979. Annual earthquake catalogs for the whole state are in preparation, beginning with 1980.

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 readings 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.

TABLE 1
Station Outages

Station	Outage Dates	Comments
ASR	Whole Period	Intermittent
AUG	Whole Period	Intermittent
BHW	May 21 - May 28	
BLN	May 7 - May 16	Cable cut by heavy equipment
CMW		NEW STATION - Started 6/7
CRF	April 29 -	Phone line discontinued - waiting for link
ELK	April 1 - June 27	Intermittent
		Reinstalled as a calibrated station
EPH	April 8 -	Phone line discontinued - waiting for link
EST	April 1 - April 21	Cable to phone drop broken
ETT	April 8 -	Phone line discontinued - waiting for link
FL2	April 21 - May 14	Inaccessible for repair
FMW	Whole Period	Intermittent
GBL	April 29 - June 17	Switched to BPA microwave link
GHW	May 21 - May 28	Lightning strike at telemetry link
GL2	April 1 - June 20	Bad transmitter
GRO		NEW STATION - Started 6/27
	June 27 - June 30	Intermittent - bad telemetry reception
HHW	April 25 - June 17	Switched to BPA microwave link
HSR	April 1 - April 30	
JCW	May 8 - May 23	
MDW	April 29 - June 17	Switched to BPA microwave link
MEW	April 1 - June 20	
NLO	April 1 -	
NSP	April 19 -	Destroyed in eruption
ODS	April 8 -	Phone line discontinued - waiting for link
OOW	May 20 -	
OTH	April 29 -	Phone line discontinued - waiting for link
PLN	April 8 -	Phone line discontinued - waiting for link
RVC	May 21 - June 24	
RVW	April 1 - May 21	
SPW	June 13 - June 20	Dead phone line
SYR	April 29 -	Phone line discontinued - waiting for link
VBE	April 22 -	
VFP	April 1 - June 6	Intermittent
VG2	Whole Period	Intermittent
VIP	April 1 - June 4	
VLL	April 1 - May 21	
VLM	April 13 - June 12	
VTG	April 8 -	Phone line discontinued - waiting for link
VTH	April 1 - May 15	Intermittent
WA2	April 29 - June 17	Switched to BPA microwave link
WBW	April 1 - May 2	
WEN	April 8 -	Phone line discontinued - waiting for link
WIW	April 29 - June 17	Switched to BPA microwave link
YEL	May 5 - May 14	

Western Washington

A new station, Cultus Mountains (CMW), was installed near the Skagit Valley in early June. This is the second station in the area, and restores coverage lost when a telephone data-line was discontinued in 1982. Telemetry for both Skagit Valley stations (RPW and CMW) is through a microwave link provided by Puget Power. Laurens Engel, the technician for western Washington stations, was kept busy with small emergencies; several stations were struck by lightning and a cable was severed by heavy equipment. Rapid repair resulted in minimal down time. As field conditions improved repairs were made at several sites, and other sites received maintenance visits. Station FMW remained inaccessible due to snow pack at high elevations.

Eastern Washington and Northern Oregon

The eastern and southern parts of the network are currently undergoing a major realignment which resulted in more station outages than usual. Two telephone lines were discontinued, and telemetry is being re-routed through the Bonneville Power Administration microwave network. The change in telemetry routes also makes it necessary to reposition some stations. The use of the BPA network, which has been provided for a one time start-up charge and much reduced operation costs, will result in substantial savings on our telephone data-line charges. A new station, GRO, was installed at Grindstone Mountain in northern Oregon. GRO replaces station VHO. VHO was transferred to our network from the Cascades Volcanic Network in 1981, and has been inoperable since October of 1983

Mt. St. Helens

Station NSP was destroyed by a large rock on April 19th at the start of an eruptive phase of Mt. St. Helens. This station was short-lived, having been installed by the U.S.G.S. at the beginning of October 1985.

On the positive side, the persistent telemetry noise at SHW was apparently resolved shortly before the eruptive phase began. This intermittent interference was often strong enough to completely obliterate the seismic data. Because SHW has been the station used for event counts to

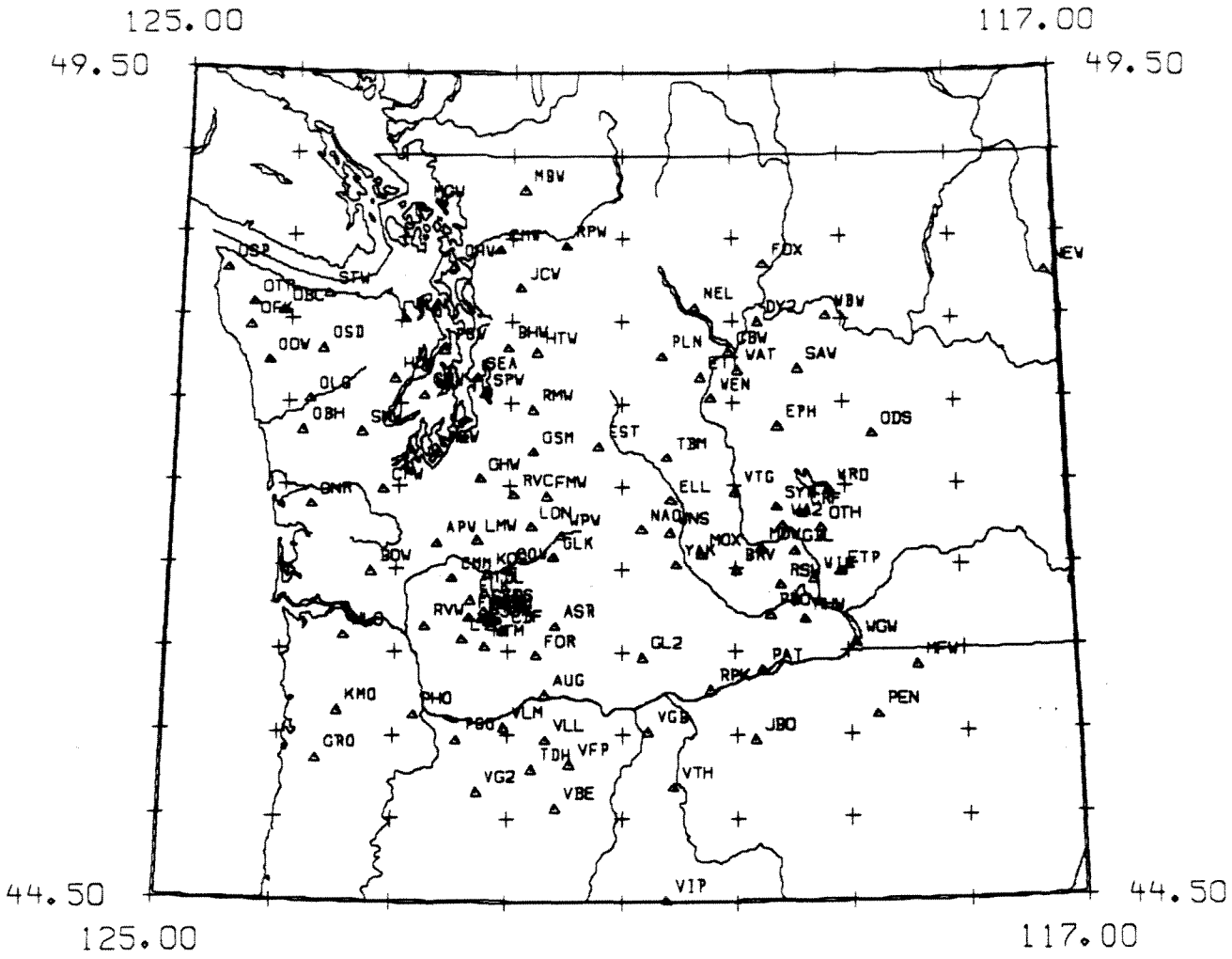

Figure 1. Seismograph stations operating during the 2nd quarter 1986.

determine seismic moment release at Mt. St. Helens during all eruptions since 1980, disruption of the signal has been a matter of concern.

Laurens Engel began investigating the interference in January and located the approximate location of the interference source with the help of Tom Carney at Rockwell Hanford Operations in Richland, WA. Mike Terry of The Dept. of the Interior, Division of Telecommunications, in Washington D.C. identified and notified the source, resulting in cessation of the interference on May 3. Activity counts during the eruption proceeded unhampered. The timely help received is greatly appreciated!

EARTHQUAKE DATA

There were 852 events processed by the University of Washington digitally recording seismic network between April 1 and June 30, 1986. We determined locations for 464 of these in Washington and Northern Oregon; 422 were classified as earthquakes and 42 as known or suspected blasts. The remaining unlocated events were teleseisms, regional events outside the U. W. network, or events at Mt. St. Helens during the eruptive phase (only a representative sample of events at St. Helens are located during eruptive phases). Helicorder records are scanned daily to ensure that significant events are not missed by the on-line digital system. Table 2 is the event catalog for this quarter. There were 3 events of M_c 3.0 or larger, one in eastern Washington, one in western Washington, and one located in British Columbia, Canada. Two earthquakes were reported felt, one in eastern Washington, and one in western Washington. Fig. 2 shows all earthquakes greater than magnitude 1.0. Fig. 3 shows blasts and probable blasts. Fig. 4 shows all earthquakes located in western Washington. Fig. 5 shows all earthquakes located in eastern Washington. Fig. 6 shows earthquakes located at Mount St. Helens.

Western Washington and Oregon

422 earthquakes were located between 44.5° and 49.5° latitude and between 121° and 125° longitude during the 2nd quarter of 1986. Excluding Mt. St. Helens, 104 earthquakes occurred in

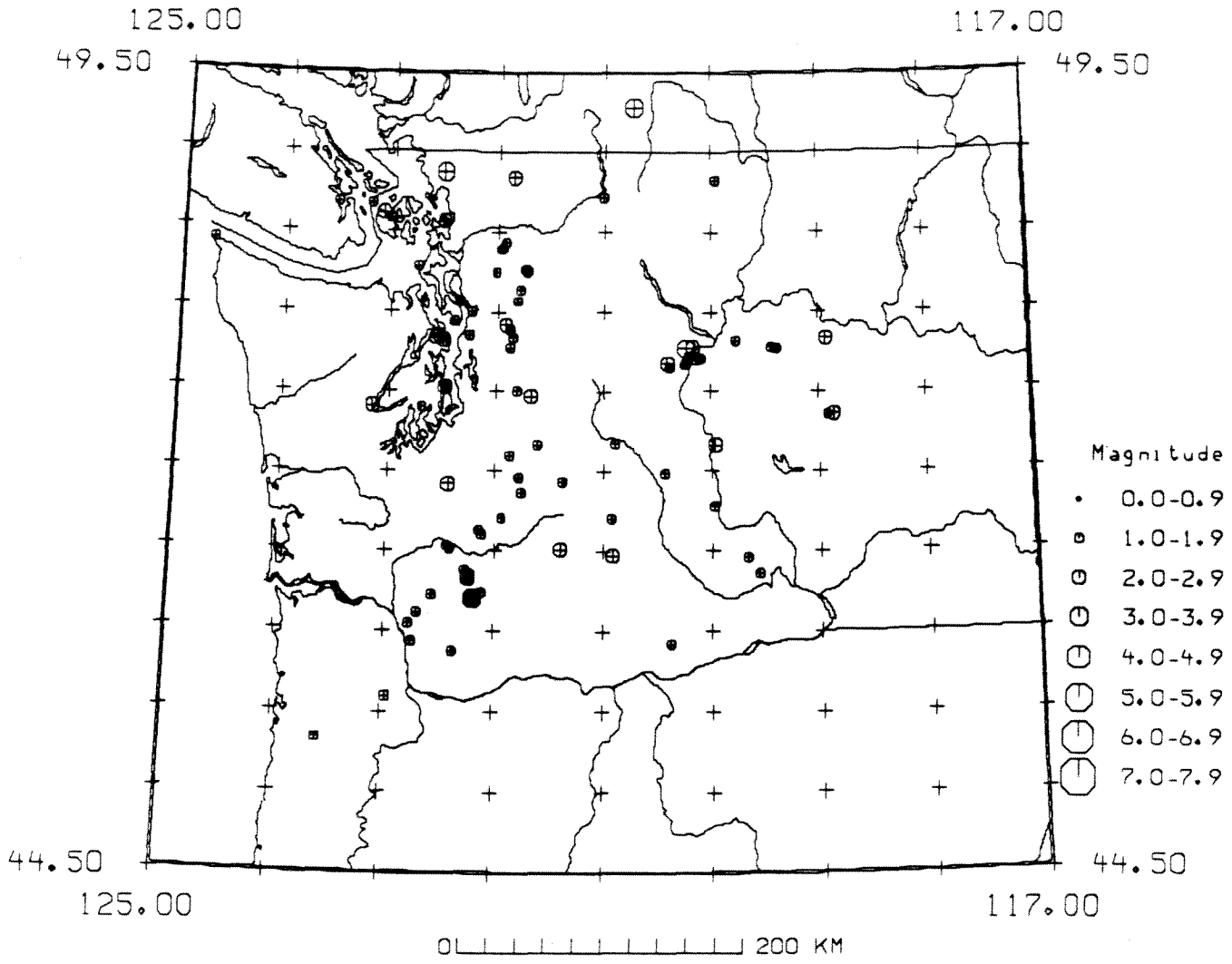

Figure 2. Earthquakes located in the state of Washington and northern Oregon with magnitudes greater than 1.0 2nd quarter 1986. Square symbol indicates that event was located with a depth greater than or equal to 30 km. Octagonal symbols are used for events shallower than 30 km.

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

July 1 through September 30, 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 operations 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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Contract 14-08-0001-21978

and

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

INTRODUCTION

This is the third 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. 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 1970-1979. Annual earthquake catalogs for the whole state are in preparation, beginning with 1980.

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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.

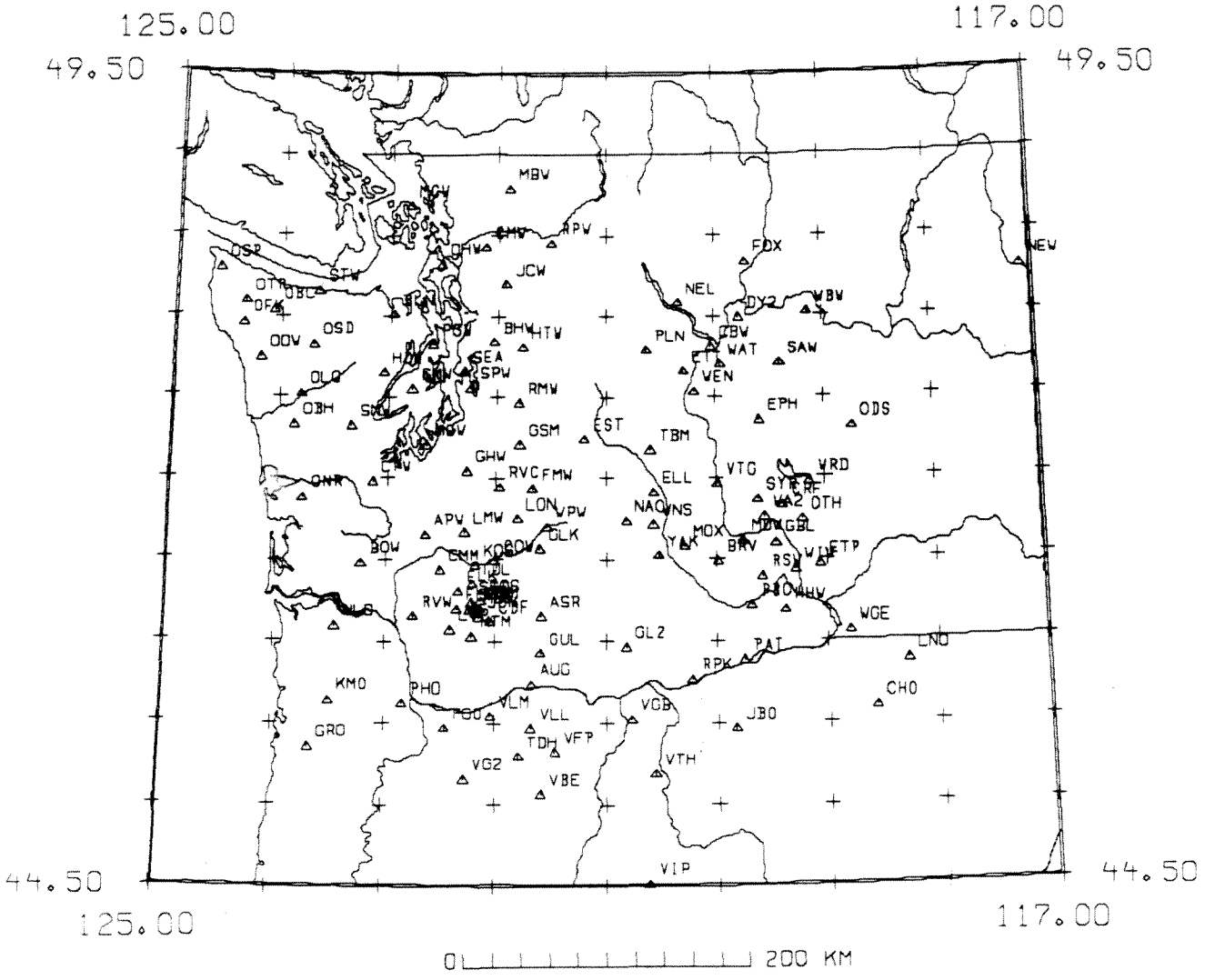


Figure 1. Seismograph stations operating during the 3rd quarter 1986.

TABLE 1
Station Outages 3rd quarter 1986

Station	Outage Dates	Comments
ASR	Whole Period	Intermittent
FMW	July 1 - July 30	Intermittent
NLO	July 1 - July 23	
LMW	Sept. 1 -	Vandalized, Transmitter stolen
NEL	Whole Period	Switched to BPA microwave link, Batteries
SYR	July 1 - July 23	Switched to BPA microwave link
WBW	July 1 - July 20	Rodent chewed cable
CRF	July 1 - July 30	Switched to BPA microwave link
WAT	July 1 - July 20	Intermittent (BPA link)
FOX	Whole Period	Intermittent
CBW	July 13 - July 20	Intermittent (BPA link)
DY2	July 1 - July 20	Intermittent (BPA link)
BRV	July 22-	Waiting for telemetry link
ETT	Whole Period	Replaced by ETW Oct. 1
PLN	Whole Period	Removed Permanently
CHO	July 1 - Aug. 26	NEW STATION - started Aug. 26 - replaces PEN
PEN	Aug. 30 -	Removed - replaced by CHO
EPH	Whole Period	Waiting for telemetry link
RSW	August 24 -	
ODS	Whole Period	Waiting for telemetry link
WGW	July 14 -	Removed - replaced by WGE
WGE	July 1 - Sept. 10	NEW STATION - started Aug. 29 - replaces WGW
WEN	Whole Period	Waiting for telemetry link
BVW	July 1 - Sept. 26	NEW STATION - started Sept. 30
VTG	July 1 - July 25	Switched to BPA microwave link
MFW	Aug. 30 -	Removed - replaced by LNO
LNO	July 1 - Aug. 30	NEW STATION - started Aug. 27 - replaces MFW
WRD	Whole Period	Waiting for BPA link
EST	Whole Period	Intermittent
DIO	July 1 - Aug. 20	NEW USGS STATION - started Aug. 20 - Mt. St. Helens
FOR	Aug. 1 -	Removed - replaced by GUL
GUL	July 1 - July 31	NEW STATION - started July 31 - replaces FOR
GRO	Whole Period	Intermittent
VIP	July 1 - Aug. 1	Intermittent
RPK	July 1 - Sept. 2	
VBE	July 1 - Aug 1	Switched to BPA microwave link
GL2	July 1 - July 20	Telemetry path switched
	Sept. 20 -	Batteries

The western Washington stations operated well during the third quarter except for FMW, which operated intermittently in July, and LMW, which was vandalized in September.

Much of the eastern Washington network underwent a major restructuring during the third quarter in order to reroute the seismic signals via Bonneville Power Administration (BPA) microwave transmitters, a less expensive alternative to transmitting data over telephone lines. As a result, many stations did not operate during the quarter since we lacked funds for the more costly telephone lines (the lack of hypocenters reported for the Entiat area is probably due to the decreased sensitivity of the network in this region due to inoperative stations). A number of stations (Table 1) were moved to new sites in order to utilize the BPA links.

EARTHQUAKE DATA

There were 470 events processed by the University of Washington digitally recording seismic network between July 1 and September 30, 1986. We determined locations for 361 of these in Washington and Northern Oregon; 295 were classified as earthquakes and 66 as known or suspected blasts. The remaining events were teleseisms (72 events), regional events (21) 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 may not locate all known blasts. For example, only a few of the frequent mine blasts at Centralia are located. Helicorder records are scanned daily to ensure that significant events are not missed by the on-line digital system.

Table 2 is the event catalog for this quarter. There were two events of M_c 3.0 or larger, one in eastern Washington and another in western Washington. Seven earthquakes were reported felt in western Washington. 85 Earthquakes were located in the Mount St. Helens area. Fig. 2 shows all earthquakes with magnitude greater than or equal to 1.0 ($M \geq 1$). 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 Mount

St. Helens ($M \geq 0$).

Western Washington and Oregon

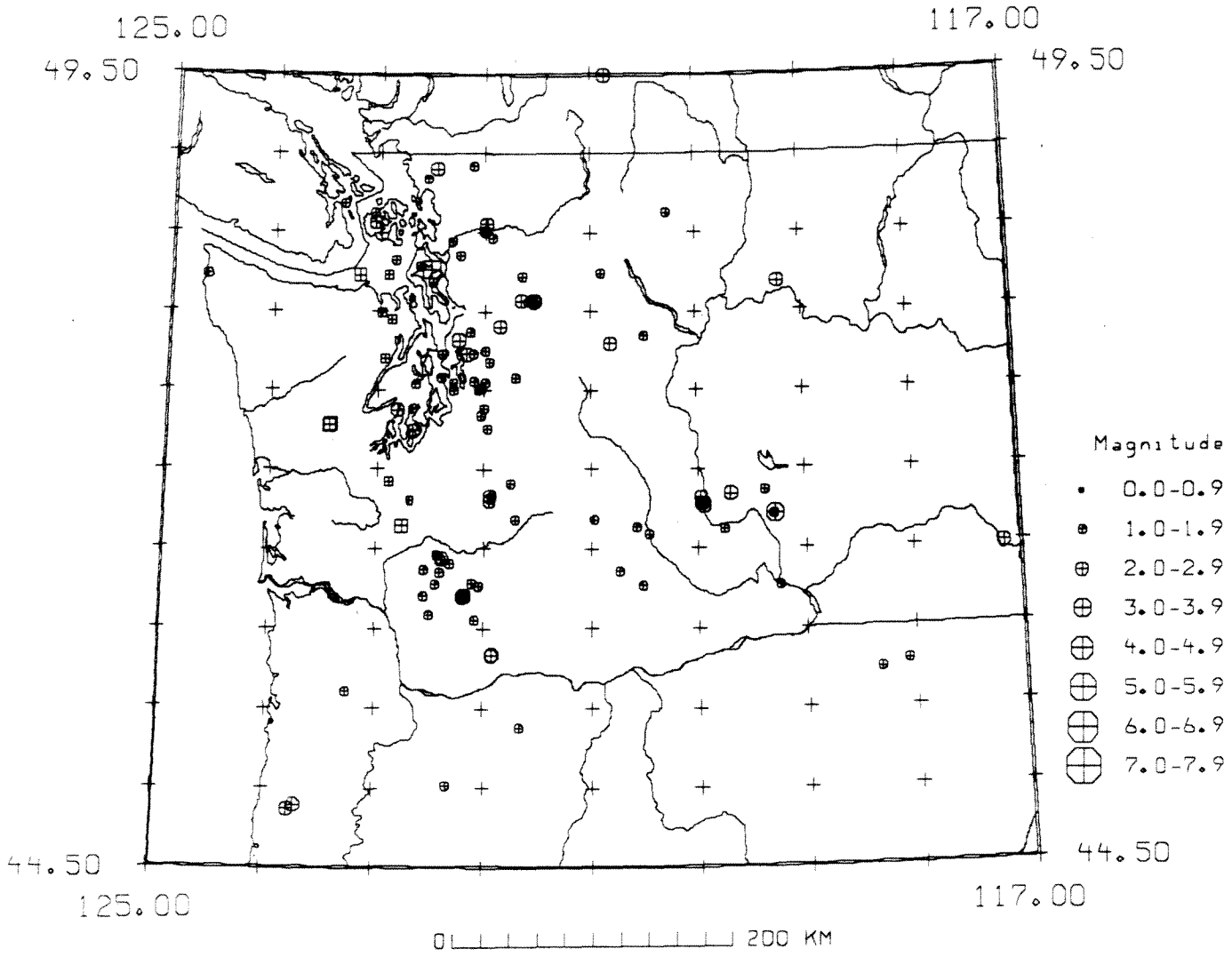
243 earthquakes were located between 44.5° and 49.5° north latitude and between 121° and 125° west longitude during the third quarter of 1986. Excluding Mt. St. Helens, 158 earthquakes occurred in western Washington. As usual, a number of deep earthquakes occurred in the Puget Sound lowland including the largest and deepest earthquake of the quarter (M_c 3.5) on July 8, 1986. It occurred 63 km below Saratoga passage (east of Oak Harbor) between Whidbey and Camano islands and was reported felt on both islands as well as in the towns of Mount Vernon and Marysville. Jiggling windows, dishes and beds were reported on Fidalgo and Whidbey islands. Sounds like an explosion were reported from Whidbey island and a couch "jumped" on the second floor of a building in Marysville.

A number of shallow earthquakes occurred east of Seattle and Tacoma, west of Mount Rainier, and northwest of Mount St. Helens. Three earthquakes were reported felt on September 16 near Darrington. They had magnitudes of 1.6, 2.8, and 2.4 and were the largest of a dozen earthquakes that occurred in this region during the quarter.

On September 26 and 29 two shallow earthquakes of magnitude 2.4 and 2.2 were reported felt at Sedro Wooley. The only other shallow earthquake reported felt in western Washington occurred in southwest part of the state on August 28, 1986. It had a magnitude of 2.7 and was reported felt near Carson.

Eastern Washington and Oregon

During the third quarter of 1986, 52 earthquakes were located in eastern Washington. The largest earthquake in eastern Washington during the third quarter was a magnitude 3.4 earthquake on September 1 near the northwest corner of the Hanford reservation. Twenty seven earthquakes occurred in the Saddle Mountains south of Vantage with magnitudes up to 2.4. Most of these occurred from September 25 to the end of the quarter. Earthquakes elsewhere in eastern Washington were scattered and we report very few earthquakes in the Entiat region south of Lake



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APPENDIX 2

Publications supported under this contract

Articles:

Ludwin, R. S., S.D. Malone, R.S. Crosson, 1987 (in press), Washington Earthquakes 1983, National Earthquake Information Service.

Ludwin, R. S., S.D. Malone, R.S. Crosson, 1987 (in press), Washington Earthquakes 1984, National Earthquake Information Service.

Ludwin, R. S., S.D. Malone, R.S. Crosson, 1987 (in preparation), Washington Earthquakes 1985, National Earthquake Information Service.

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Zervas, C.E., and R.S. Crosson, 1986, Pn Observations and Interpretations in Washington, Bull. Seis. Soc. of America, V. 76, No. 2, pp. 521-546.

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Quarterly Network Report 86-A on Seismicity of Washington and Northern Oregon, 1986, University of Washington Geophysics Program

Quarterly Network Report 86-B on Seismicity of Washington and Northern Oregon, 1986, University of Washington Geophysics Program

Quarterly Network Report 86-C on Seismicity of Washington and Northern Oregon, 1986, University of Washington Geophysics Program

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Earthquake Hypocenters in Washington and Northern Oregon; 1982-1986, 1987, University of Washington Geophysics Program (in preparation)

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Ma, Li, and R.S. Ludwin, 1986, Can Focal Mechanisms be used to Separate Subduction Zone from Intra-plate Earthquakes in Washington?, EOS, V. 68, No. 3.

J. Lees, 1986, Tomographic Inversion for Lateral Velocity Variations in western Washington, EOS, V. 68, No. 3.

Ludwin, R. S. and R.S. Crosson, 1986, Teleseismic Residuals and Slab Structure in the Pacific Northwest, Earthquake Notes, V. 57, No. 1, p. 10.

R. S. Crosson, 1986, Where is the Subducted Slab beneath the Pacific Northwest, Earthquake Notes, V. 57, No. 1, p. 9.