FINAL TECHNICAL REPORT: 1994

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CONTENTS

TABLES

FIGURES

APPENDICES

Final Technical Report for USGS Joint Operating Agreement
1434-92-A-0963
Washington Regional Seismograph Network Operations

SUMMARY

This is the final technical report for USGS Joint Operating Agreements 1434-92-A-0963 "Washington Regional Seismograph Network Operations" (now called the *Pacific Northwest Seismograph Network (PNSN)*). This agreement covers network operations in western Washington and Oregon, routine data proces 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 and volcanic hazards in Washington and Oregon and to support research carried out under contract 14-08-0001-G1803 'Earthquake Hazard Investigations in the Pacific Northwest Using Network Data', as well as other projects. This report includes a review of station operations during the contract period, and an update on recent changes in our data acquisition and processing system.

Since 1984, we have issued quarterly bulletins for all of Washington and Oregon. These include catalogs of earthquakes and blasts located in Washington and Oregon, providing up-to-date coverage of seismic and volcanic activity. Appendix 1 contains quarterly bulletins covering this operating agreement period.

INFORMATION - Emergency Notification and Public Education and Outreach

Our automatic processing includes an alarm feature which detects significant local events and initiates electronic mail (e-mail) or faxes to local emergency response agencies, operators of adjacent seismograph networks, and the National Earthquake Information Center in Colorado. When the event has been fully processed, updated final information on it is also faxed and e-mailed.

In addition to monitoring earthquake activity in Washington and much of Oregon, the staff of the PNSN participates in outreach projects to inform and educate the public about seismicity and natural hazards. Our outreach includes lab tours, lectures, educational classes and workshops, TV and radio interviews, field trips, and participation in regional earthquake planning efforts. Details on outreach activities are included in our quarterly reports. We answer from 5-40 questions per day on Pacific Northwest seismicity and seismic hazards, and give about a half-dozen lab tours or presentations each month for a wide variety of groups, including elementary through post-graduate students, retirees, science teachers, emergency educators, and many others. We provide a taped telephone message describing the seismic hazards in Washington and Oregon and a separate taped message on current seismic activity ((206) 543-7010). Both these services are heavily used. Locations of recent earthquakes of magnitude 2 or larger are made available to the public through several methods; via modem by dialing **(206)685-0889** and logging in as **quake** with password **quake**, by sending e-mail to **quake@geophys.washington.edu** or via ethernet using the UNIX utility **finger quake@geophys.washington.edu**. We distribute a one-page information and resource sheet on seismic hazards in Washington and Oregon that we encourage others to reproduce and further distribute.

Summary lists for all earthquakes located by the PNSN since 1969 are available via anonymous ftp on **ftp.geophys.washington.edu** in the *pub/seis_net* subdirectory. In addition, special sub-directories; *pub/kfalls* and *pub/woodburn*; include locations, focal mechanisms, and local station lists for the Klamath Falls and Scotts Mills, Oregon earthquake sequences. This information is also available via the **World-Wide-Web (WWW)** which provides text and graphics for anyone connected to the Internet running a version of "Mosaic" (available for workstations, PC-Windows, and Macintoshes with anonymous ftp at ftp.ncsa.uiuc.edu). Our **WWW** server contains text about earthquakes in the Pacific Northwest, maps of stations, catalogs and maps of recent earthquake activity, and maps and text about recent interesting sequences. It also contains links into other sources of earthquake information around the country and world. To access it use **mosaic http://www.geophys.washington.edu.**

Seismometer Locations and Network Maintenance

Ninety-six stations covering much of western Washington and Oregon, including volcanos in the central Cascades, are supported under JOA 1434-92-A0963. The locations of the stations are given in Table 1 and shown in Fig. 1. All stations are north latitude and west longitude, and coordinates are given in degrees, minutes and seconds. Most stations consist of a single, short-period vertical, component which is telemetered continuously in analog form to the UW.

The University of Washington digitally records 141 channels of seismic data, in a triggered mode. Stations recorded include short and long period vertical components of WWSSN station LON, and horizontal seismometers with Wood-Anderson-response at station SEA on the campus of the University of Washington.

During this contract period, five new stations were installed by the USGS because of earthquake activity in the Klamath Falls, OR area. Data from these stations is telemetered to the UW, and recorded by the PNSN. Four of the Klamath Falls stations were installed in early October; HAM (Hamaker Mt.), LAB (Little Aspen Butte), VSP (Spence Mtn.), and VRC (Rainbow Creek). LAB is a three-component short-period station with an additional low-gain vertical component. The other stations have short-period vertical seismometers. The fifth station, HOG (Hogback Mtn.), was installed in January, 1994. An additional three-component short-period station (WIB) was installed by the USGS at Willapa Bay, Washington in January.

Additional stations under other support are also used in event locations. Quarterly reports contain lists of all stations operated by the PNSN and additional details of station operation. Quarterly reports from October, 1993 through September, 1994 are included as Appendix 1. Aside from station outages, normal maintenance includes a visit to each site at least once every two years to replace batteries and do preventive maintenance. In addition seismometers must be replaced every 4-6 years. More than 30 radio telemetry relay sites are also maintained independently of the seismograph stations.

Under other support (NEHRP Grant 1434-92-G-2195) we completed installation of three new broadband three-component stations (prototype station LON, also broad-band and three-component, began operation earlier). All installed recorders now have GPS time-code receivers and 24 bits/sample dynamic range. Three of the stations (LON at Longmire, LTY at Liberty, and SSW at Satsop; all in Washington) time-stamp, digitize, and record data on-site. Under this agreement, we recover selected broad-band data from these stations via phone lines using automated procedures that run late at night (to minimize long-distance charges). The fourth station, (TTW) near Tolt, Washington, also digitizes and time-stamps data on-site, but continuously telemeters data to the UW Seismology Lab where it is recorded as a continuous data stream.

Tables 1 shows stations partially or fully supported under this agreement. Additional stations operated by the PNSN are listed in the Quarterly Reports (Appendix 1). The first column in Table 1 gives the 3-letter station designator. Column 2 designates the funding agency; stations marked by a % symbol were fully supported by USGS joint operating agreement 1434-92-A-0963, stations marked * are broad-band stations installed under agreement 1434-92-G-2195 but operated under 1434-92-A-0963, stations designated # were installed or maintained by the USGS, but are telemetered to the PNSN. Remaining columns give 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 1
Stations operating under this agreement at the end of the third quarter, 1994

STA	F	LAT	LONG	EL	NAME
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
BBO	%	42 53 12.6	122 40 46.6	1.671	Butler Butte, Oregon
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
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.
CPW	%	46 58 25.8	123 08 10.8	0.792	Capitol Peak
DBO	%	43 07 09.0	123 14 34.0	0.984	Dodson Butte, Oregon

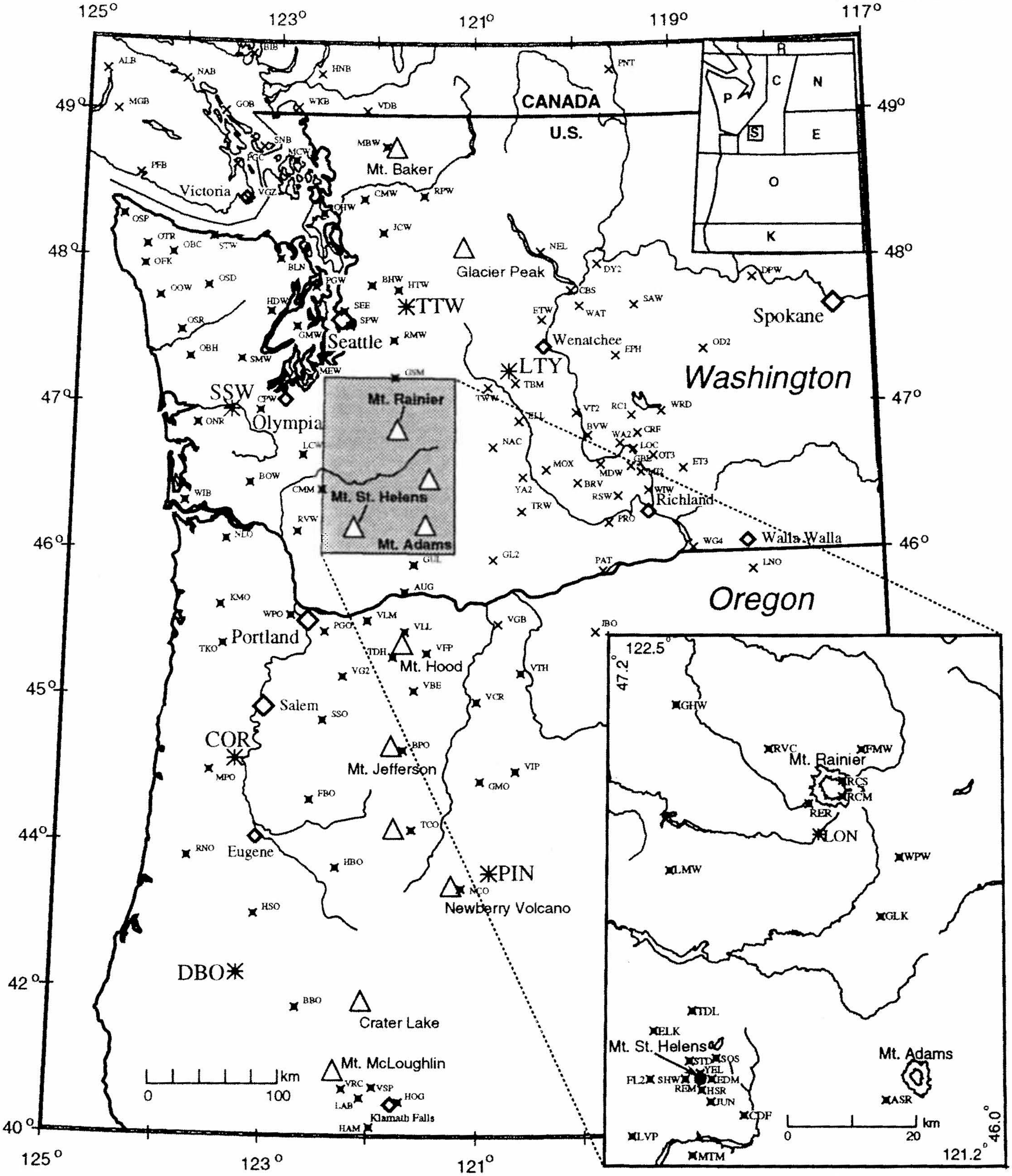

Figure 1. Map view of seismograph stations operated by the Pacific Northwest Seismograph Network between October 1, 1993 and Dec. 31, 1994. White triangles show the position of volcanic centers, and white diamonds indicate the locations of a few cities. Stations are shown by "x" symbols. Those supported under USGS 1434-92-A-0963 are emphasised by black squares over the "x"s. Broad-band stations are indicated by asterisks and larger labels. The upper inset shows the eight regions in which different crustal velocity models are used to locate hypocenters (P, Puget Sound; C, Cascades; S, Mount St. Helens; N, northeast Washington; E, eastern Washington; O, Northern Oregon; K, Southern Oregon; and R, Regional). The lower inset is an enlargement of the shaded region on the main map, and shows seismograph stations in the vicinity of Mounts Rainier, St. Helens and Adams.

continued

STA	F	LAT	LONG	EL	NAME
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
FBO	%	44 18 35.6	122 34 40.2	1.080	Farmers Butte, Oregon
FL2	%	46 11 47.0	122 21 01.0	1.378	Flat Top 2
FMW	%	46 56 29.6	121 40 11.3	1.859	Mt. Fremont
GHW	%	47 02 30.0	122 16 21.0	0.268	Garrison Hill
GLK	%	46 33 50.2	121 36 30.7	1.320	Glacier Lake
GMO	%	44 26 20.8	120 57 22.3	1.689	Grizzly Mountain, Oregon
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.
GUL	%	45 55 27.0	121 35 44.0	1.189	Guler Mt.
HAM	#	42 04 08.3	121 58 16.0	1.999	Hamaker Mt., Oregon
HBO	%	43 50 39.5	122 19 11.9	1.615	Huckleberry Mt., Oregon
HDW	%	47 38 54.6	123 03 15.2	1.006	Hoodsport
HOG	#	42 14 32.7	121 42 20.5	1.887	Hogback Mtn., OR
HSO	%	43 31 33.0	123 05 24.0	1.020	Harness Mountain, Oregon
HSR	%	46 10 22.2	122 10 58.2	1.774	South Ridge, Mt. St. Helens
HTW	%	47 48 14.2	121 46 03.5	0.833	Haystack Lookout
JCW	%	48 11 42.7	121 55 31.1	0.792	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
LAB	#	42 16 03.3	122 03 48.7	1.774	Little Aspen Butte, Oregon
LCW	%	46 40 14.4	122 42 02.8	0.396	Lucas Creek
LMW	%	46 40 04.8	122 17 28.8	1.195	Ladd Mt.
LON	*	46 45 00.0	121 48 36.0	0.853	Longmire (Broad-band and DWWSSN
LO2	%	46 45 00.0	121 48 36.0	0.853	Longmire short-period
LTY	*	47 15 21.2	120 39 53.3	0.970	Liberty (Broad-band)
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
MEW	%	47 12 07.0	122 38 45.0	0.097	McNeil Island
MPO	%	44 30 17.4	123 33 00.6	1.249	Mary's Peak, Oregon
MTM	%	46 01 31.8	122 12 42.0	1.121	Mt. Mitchell
NCO	%	43 42 14.4	121 08 18.0	1.908	Newberry Crater, Oregon
NLO	%	46 05 21.9	123 27 01.8	0.826	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
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
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 48 59.2	123 42 13.7	2.008	Olympics - Snow Dome
OSP	%	48 17 05.5	124 35 23.3	0.585	Olympics - Sooes Peak
OSR	%	47 30 20.3	123 57 42.0	0.815	Olympics Salmon Ridge
OTR	%	48 05 00.0	124 20 39.0	0.712	Olympics - Tyee Ridge
PGO	%	45 27 42.6	122 27 11.5	0.253	Gresham, Oregon
PGW	%	47 49 18.8	122 35 57.7	0.122	Port Gamble
RCM	%	46 50 08.9	121 43 54.4	3.085	Mt. Rainier, Camp Muir
RCS	%	46 52 15.6	121 43 52.0	2.877	Mt. Rainier, Camp Schurman
REM	#	46 11 57.0	122 11 03.0	2.102	Rembrandt (Dome station)
RER	%	46 49 09.2	121 50 27.3	1.756	Mt. Rainier, Emerald Ridge
RMW	%	47 27 35.0	121 48 19.2	1.024	Rattlesnake Mt. (West)
RNO	%	43 54 44.0	123 44 26.0	0.875	Roman Nose, Oregon
RPW	%	48 26 54.0	121 30 49.0	0.850	Rockport
RVC	%	46 56 34.5	121 58 17.3	1.000	Mt. Rainier - Voight Creek
RVW	%	46 08 53.2	122 44 32.1	0.460	Rose Valley
SEA		47 39 18.0	122 18 30.0	0.030	Seattle (Wood Anderson)
SHW	%	46 11 50.6	122 14 08.4	1.399	Mt. St. Helens
SMW	%	47 19 10.7	123 20 35.4	0.877	South Mtn.
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
SSO	%	44 51 21.6	122 27 37.8	1.242	Sweet Springs, Oregon
SSW	*	46 58 20.4	123 26 01.8	0.120	Satsop (Broad-band)
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
TCO	%	44 06 21.0	121 36 01.0	1.975	Three Creek Meadows, Oregon.
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
TKO	%	45 22 16.7	123 27 14.0	1.024	Trask Mtn, Oregon
TTW	*	47 41 40.7	121 41 20.0	0.542	Tolt Res, WA (Broad-band)
VBE	%	45 03 37.2	121 35 12.6	1.544	Beaver Butte, Oregon
VCR	%	44 58 58.2	120 59 17.4	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
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
VRC	#	42 19 47.2	122 13 34.9	1.682	Rainbow Creek, Oregon
VSP	#	42 20 30.0	121 57 00.0	1.539	Spence Mtn, Oregon
VTH	%	45 10 52.2	120 33 40.8	0.773	The Trough, Oregon
WIB	#	46 20 34.8	123 52 30.6	0.503	Willapa Bay
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
YEL	#	46 12 35.0	122 11 16.0	1.750	Yellow Rock, Mt. St. Helens

DATA PROCESSING

The seismographic network operated by the University of Washington consists of over one hundred short-period, vertical component, telemetered seismographic stations. The seismic recording system operates in an 'event triggered' mode, recording data at 100 samples per sec. per channel. Arrival times, first motion polarities, signal durations, signal amplitudes, locations and focal mechanisms (when possible) are determined in postprocessing. Digital data are processed for all teleseisms, regional events, and all locatable local events. Each trace data file has an associated 'pickfile' which includes arrival times, polarities, coda lengths, and other data.

This year, we modified both our seismic trace data and pickfile (phase arrival times) formats (and associated data-processing software). The old formats, in use since 1980, did not allow broad-band data to be merged into our network data stream. The modifications were developed and tested in an integrated system called SNAPS (Seismic Network Automated Processing System), a software package for processing network data that allows automated processing steps to be integrated with steps controlled by an analyst.

Our new working seismic trace data format (UW-2) allows us to accommodate data of varying durations, sample rates, start times, and formats. It is extensible without affecting existing processing programs and is backward-compatible with our original (UW-1) format. Conversion programs allow easy exchange between UW-2 and other commonly used trace-data formats such as AH and SEED. The new UW-2 pickfile format provides full support for three-component stations, flexibility to represent arbitrary phase types (our old UW-1 format could only represent P and S phases) such as Pn and PmP, and a number of other advantages. Like the trace-data format, it is also backward compatible. Interactive viewing of both trace and pickfile data is provided through **Xped** (X pick editor), an X window application that allows the user to display trace and pick information, modify picks, run location programs, and perform other data analysis functions. The final, full implementation of the new data formats and processing software took place on Oct. 1, at the end of this contract period.

In addition to the extensive modifications of data-processing software required by the change to UW-2 data formats, we are also updating our data acquisition hardware and software. Since 1988, we have used a Concurrent 5600 computer running *HAWK* software, a derivative of the *CEDAR* system developed at Cal Tech by Carl Johnson. Now, in 1994, rapid advances in computer speed enable us to enhance and streamline data acquisition while lowering our computer costs. The new data acquisition software is called *SUNWORM*. It is being developed in cooperation with the *EARTHWORM* project at the USGS in Menlo Park, and is currently running in test mode on a SUN-SparcStation-5 workstation. *SUNWORM* will replace the *HAWK* system at the beginning of 1995. We have also recently acquired a very large (18 gigabyte) on-line storage disk, which will allow us to store all PNSN digital seismic trace data (since 1980).

Broad-band data (including COR, PIN, and DBO as well as TTW, LTY, SSW, and LON), are merged and archived with data from the PNSN short-period network. For station TTW, which records continuously, individual events are extracted from the data, while for other stations, selected time windows of data are retrieved. File formats and software were upgraded, as discussed above, to allow merging of the broad-band and short-period data. Broad-band event data are also translated to IRIS-SEED format and submitted to the IRIS Data Management Center for archive and distribution.

PNSN Quarterly Reports for 1994 have included moment-tensor focal mechanisms for earthquakes larger than magnitude 3.5. These have been provided to us by Dr. John Nabelek of Oregon State University (OSU) under support from USGS NEHRP Grant 1434-93-G-2326. OSU also provides broad-band data from station COR, which we archive with our trace-data files. The University of Oregon (UO) also provides broad-band data (from stations PIN and DBO), which is likewise archived. Phase data for earthquakes in northern Washington and southern British Columbia are exchanged with the Canadian Pacific Geoscience Centre promptly for significant events, and routinely twice a year. We also exchange data occasionally with the Montana Bureau of Mines, Boise State University, and CALNET.

Publications wholly or partly supported under this operating agreement are listed in Appendix 2.

SEISMICITY

Figure 2 shows earthquakes of magnitude 2.0 or larger located in Washington and Oregon during this reporting period. The PNSN processed 8,457 events between Oct. 1, 1993 and Sept. 30, 1994. Of these, 7,588 were earthquakes or blasts within the network (1,701 of which were too small to locate). The remaining events were regional earthquakes (274) or teleseisms (595). Within our network area, 5,305 earthquakes were located west of 120.5 degrees west longitude, (including 383 near Mount St. Helens, which has not erupted since 1986), and 187 east of 120.5 degrees west longitude.

During this reporting period there were 21 earthquakes reported felt west of the Cascades, and 4 reported felt east of the Cascades. The largest earthquake was magnitude 5.1, and occurred on December 4, 1993 (22:15 UTC) near Klamath Falls, Oregon. This was the largest aftershock following a main-shock pair (magnitudes 5.9 and 6.0) on September 21, 1993 (UTC). The sequence, which had diminished rapidly after the September, 1993 mainshocks, resurged following the December 4 aftershock. Table 2 gives the number of Klamath Falls earthquakes of magnitude 2.0 or greater in each month since the mainshock. Following the December 4 aftershock, five additional shocks of magnitude 4 or larger in the Klamath Falls area followed during December 1993 and January 1994, and smaller earthquakes continued throughout this reporting period.

TABLE 2: Klamath Falls earthquakes; Number per month, magnitude 2.0 or larger

Month	Number of events
September, 1993	105
October, 1993	16
November, 1993	12
December, 1993	112
January, 1994	110
February, 1994	11
March, 1994	15
April, 1994	12
May, 1994	10
June, 1994	6
July, 1994	3
August, 1994	4
September, 1994	1
October, 1994	1

Two other notable felt earthquakes, magnitudes 4.0 and 4.3, occurred within a few days of one another in June and are apparent in Fig. 2. The earlier event, on June 15 at 8:22 UTC, was a deep earthquake (about 45 km) west south-west of Bremerton, Washington. It was widely felt around the south Puget Sound region. Earthquakes of this type (deeper than 30 km and within the subducting Juan de Fuca plate) are well known, and include the damaging earthquakes of 1949 and 1965 (magnitudes 7.1 and 6.5 respectively). Magnitude 4 or larger earthquakes within the subducting plate have occurred about every two years, on average, since 1970 (preceding this event, the last such earthquakes were in 1989, when two deep events larger than magnitude 4 occurred). The other earthquake, magnitude 4.3 on June 18th at 07:01 UTC, was located near Skykomish, Washington with an estimated depth of 6 km, and was followed by 8 aftershocks within the next few days. This event was unusual because, historically, Skykomish is not known to be the source of any significant earthquakes, and no other felt earthquakes, nor any larger than magnitude 2.5, have been located within 10 km of the mainshock since we began locating earthquakes with our regional network in 1970.

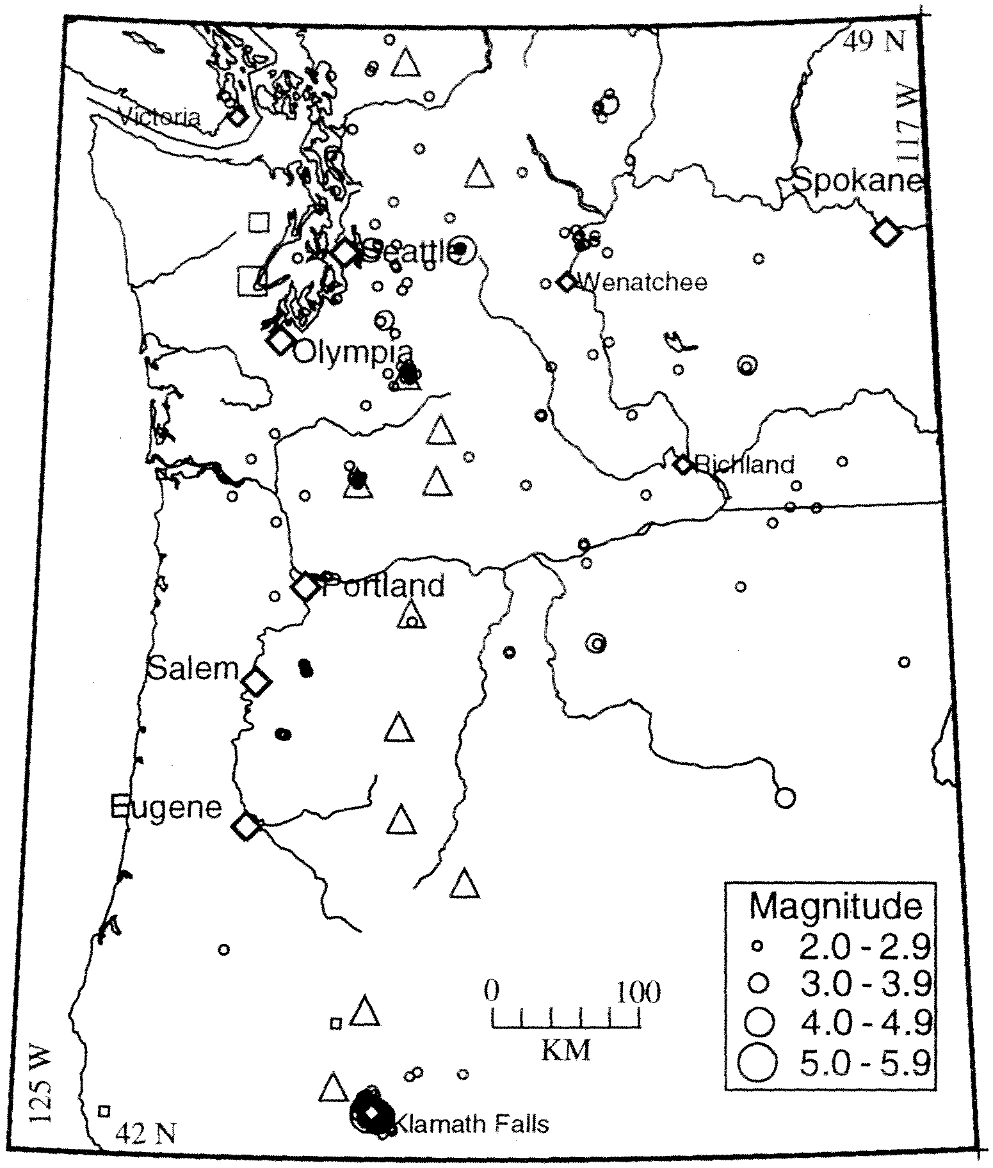

Figure 2. Earthquakes larger than magnitude 2.0 between Oct. 1, 1993 and Sept. 30, 1994. Locations of a few cities are shown as white-filled diamonds. Earthquakes are indicated by filled circles or squares; circles represent earthquakes at depths shallower than 30 km, and squares represent earthquakes at 30 km or deeper.

Acknowledgements

Seismic stations, telemetry links, and data acquisition equipment were maintained by Jim Ramey and Allen Strelow at the UW, Patrick McChesney (stationed at CVO in Vancouver, Washington), Pat Ryan (of the University of Oregon in Eugene, Oregon), Don Hartshorn of Westinghouse Hanford Co., and Lee Bond (consultant). Bill Steele provided information to the public and collected reports on felt earthquakes, while Sandra Hebert provided routine data analysis and archiving of digital trace data; replacing Rick Benson, who left the UW in November of 1993 to join the IRIS Data Management Center. Sandra Stromme and Eric Crosson developed or modified software to retrieve or translate broad-band data, and in connection with our new UW-2 data formats. Ruth Ludwin merged Canadian data into the pick files, wrote reports, provided data to investigators at other institutions, and handled administrative tasks. Under support from NEHRP Grant 1434-92-G-2195, the PNSN completed installation of three new broad-band three-component stations. Moment-tensor focal mechanisms for earthquakes larger than magnitude 3.5 have been provided for publication in our quarterly reports by Dr. John Nabelek of Oregon State University (OSU) under support from USGS NEHRP Grant 1434-93-G-2326. OSU also provides broad-band data from station COR, which we archive with our trace-data files. The University of Oregon (UO) provides broad-band data (from stations PIN and DBO), which is likewise archived.

QUARTERLY NETWORK REPORT 93-D

on

Seismicity of Washington and Western Oregon

October 1 through December 31, 1993

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 western Oregon. Information contained in this report should be considered preliminary, and not cited for publication. The views and conclusions contained in this document should not be interpreted as necessarily representing the official policies, either express or implied, of the U.S. Government.

Seismic network operation in Washington and western Oregon is supported by the following contracts:

U.S. Geological Survey
Joint Operating Agreement 1434-92-A-0963

and

Westinghouse Hanford Company
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CONTENTS

FIGURES

TABLES

INTRODUCTION

This is the fourth quarterly report of 1993 from the University of Washington Geophysics Program covering seismicity of all of Washington and western 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 technical reports covering seismicity in Washington since 1969 are available from the U.W. Geophysics Program.

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 or USGS CALNET seismograph stations. Findings mentioned in these quarterly reports should not be cited for publication. Fig. 1 is a map view of seismograph stations currently in operation.

The area shown in Figs. 1,2, and 3 has been extended to the California border because of seismicity and new seismograph stations in southern Oregon.

NETWORK OPERATIONS

Table 1 gives approximate periods of time when certain 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. There were several station outages during the fourth quarter; at Bald Hill (BHW), Capitol Peak (CPW), and Larch Mountain (VLM).

Because of earthquake activity, four new stations were installed in late September or early October by the USGS in the Klamath Falls area. These stations are HAM (Hamaker Mt.), LAB (Little Aspen Butte), VSP (Spence Mtn.), and VRC (Rainbow Creek). LAB is a three-component short-period station with an additional low-gain vertical component. The other stations have only short-period vertical seismometers. These are shown in Fig. 1. Although the USGS installed these stations, the data are being telemetered to the UW.

A new short-period three-component station (WIB) was installed in December on the coast of Washington near Willapa Bay. This station will help us to more accurately locate offshore earthquakes, and will provide data which can be used in receiver function studies. An additional three-component station is planned for installation during the summer of 1994, as an upgrade of station OBH which has been out of operation since 1992 because of telemetry path problems.

Inoperable stations during the fourth quarter included: BHW due to resiting of its transmitter; CPW, which ceased functioning in late November possibly due to a seismometer problem; FMW, which is intermittent apparently due to lack of capacity of its solar-charged battery; and station VLM which was damaged by water.

The three-component broad-band station near Tolt, Washington (TTW) continues to operate in test mode. Digital data from TTW (50 samples/sec) are continuously telemetered to the UW Seismology Lab and recorded on disk. We are developing techniques to automatically extract and save the seismic data.

Rick Benson, our data analyst for the last ten years, left the University for a new job with IRIS. In the interim before the analyst position is filled by a new permanent employee, an hourly employee has been trained to do routine analysis.

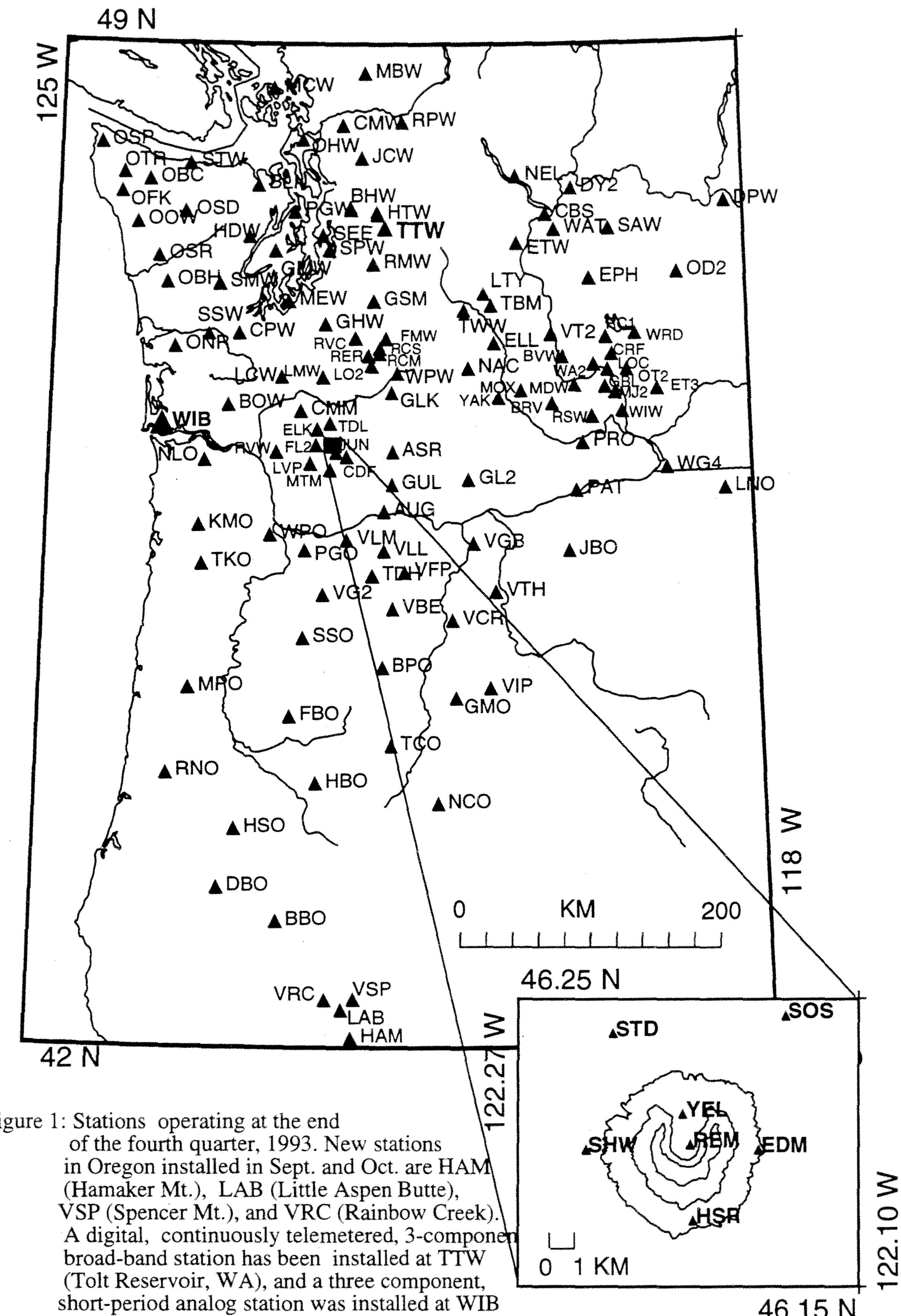

Figure 1: Stations operating at the end of the fourth quarter, 1993. New stations in Oregon installed in Sept. and Oct. are HAM (Hamaker Mt.), LAB (Little Aspen Butte), VSP (Spencer Mt.), and VRC (Rainbow Creek). A digital, continuously telemetered, 3-component broad-band station has been installed at TTW (Tolt Reservoir, WA), and a three component, short-period analog station was installed at WIB (Willapa Bay, WA).

TABLE 1
Station Outages 4th quarter 1993

Station	Outage Dates	Comments
BHW	9/15/93 - end	Transmitter
CPW		Nov. 25 - end
FMW	Nov. 15 - end	Intermittent
HAM		INSTALLED 10/6/93
LAB		INSTALLED 10/7/93 - 4 short-period components
OBH	Mar. 1992-End	Dead
RCM		INSTALLED 9/8/93
TTW		INSTALLED 6/18/93;Testing stage all quarter
VLM	Sept. 13-Nov. 12	Water Damage
VRC		INSTALLED 9/26/93
VSP		INSTALLED 9/26/93
WIB		INSTALLED 12/9/93 - 3 short-period components

OUTREACH ACTIVITIES

In addition to monitoring earthquake activity in Washington and much of Oregon, the staff of the Washington Regional Seismic Network (WRSN) participates in outreach projects to inform and educate the public about seismicity and natural hazards. Our outreach includes lab tours, lectures, TV or radio talk shows, field trips, and participation in regional earthquake planning efforts.

During the fourth quarter, 12 school groups, with a total of 225 students and teachers toured our lab. Representatives from the WRSN lab participated in twelve meetings with over 300 earthquake educators or emergency planners who were preparing or conducting earthquake drills and response plans. Organizations included the U.S.Navy and Coast Guard, the American Red Cross, elementary schools and school districts, and fire departments. We also gave two presentations to community service organizations, serving a total of about 130 people). We participated in two TV science programs for children, one local and one national.

Keeping up with the hundreds of calls we received has been a challenge to staff this quarter. Our information library service continues to be heavily utilized ,still many people are left with follow up questions which are handled on a case by case basis.

Interest in the Klamath Falls earthquake sequence (starting with a pair of mainshocks, magnitudes 5.9 and 6.0, on 9/21/93 UTC) continued to be extremely high, especially following a damaging aftershock (magnitude 5.1) in early December. During the fourth quarter, we provided frequent updates to the Klamath Falls Emergency Operations Center, the Oregon Dept. of Geology and Mineral Industries, the Oregon Institute of Technology, the Klamath Falls hospital and others. We continued to develop a close working relationship with print, radio, and television media. Faculty and staff participated in numerous live and taped interviews and we provided print media with interviews, maps, catalogs, and other information including background resources such as "Washington State Earthquake Hazards" from the Washington State DNR (Information Circular 85, 77 p.), and our one-page flier "Earthquake Hazards in Washington and Oregon".

We provide several computer options for access to our earthquake locations. Any e-mail user can receive a one-page report on the most recent significant earthquakes, including locations of large earthquakes world-wide (provided by the National Earthquake Information Center) and of earthquakes larger than magnitude 2.0 located by the WRSN, by sending e-mail to "quake@geophys.washington.edu". The information will be returned to them by e-mail. For computers using the UNIX operating system with access to the InterNet, the command "finger quake@geophys.washington.edu" will send the same information to the user's terminal. Another InterNet option for non-UNIX users is to "rlogin" to geophys.washington.edu as "quake" with password "quake". The same information is also available via modem: (206) 685-0889; login as "quake"; password: "quake". Additional WRSN information is available over the InterNet via "anonymous ftp", where detailed information about the Klamath Falls, OR earthquake sequence is available in the subdirectory ~ftp/pub/kfalls.

On average, about 40 persons per hour use the "finger quake" utility over InterNet, while about 90 persons per day access information through the other computer methods combined. Following the Los Angeles earthquake on January 17, "finger quake" activity topped 1,000 requests per hour. Fig. 8 (shown on the same page as Fig. 3) shows the time history of "finger quake" requests on January 17 and 18. Similar increases occurred for the other methods of automatic information retrieval, as did telephone requests from the media and public.

STATIONS USED FOR LOCATION OF EVENTS

Table 2 lists stations used in locating seismic events in Washington and Oregon. Stations marked by an asterisk (*) or a (%) were supported by USGS joint operating agreement 1434-92-A-0963, and (+) indicates support under Westinghouse Hanford Company Contract MLR-SVV-666685 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.

Most stations consist of a single, short-period vertical, component which is telemetered continuously in analog form to the UW. In addition, the WRSN operates several three-component broad-band stations; LON, LTW, and SSW; which record in digital form on-site. Selected data from these stations is retrieved periodically over telephone lines. Another recently-installed 3-component broad-band station, TTW, (currently operating in a test mode) continuously transmits time-stamped digital data to the UW.

EARTHQUAKE DATA

There were 3,203 events digitally recorded and processed at the University of Washington between October 1 and December 31, 1993. Locations in Washington, Oregon, or southernmost British Columbia were determined for 2,618 of these events; 2,562 were classified as earthquakes and 56 as known or suspected blasts. The remaining 585 processed events include teleseisms (137 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 routinely processed. During this quarter, the Klamath Falls area was the source of many of the earthquakes, both located and unlocatable.

Table 3, located at the end of this report, is the catalog of earthquakes and blasts located within the network for this quarter. For the Klamath Falls area, only earthquakes of magnitude 1.2 and larger have been included in Table 3. Fig. 2 shows all earthquakes with magnitude greater than or equal to 0.0 ($M_c \geq$ 0.) Fig. 3 shows blasts and probable blasts ($M_c \geq$ 0.) Fig. 4 shows earthquakes located at Mt. Rainier ($M_c \geq$ 0). Fig. 5 shows earthquakes located at Mt. St. Helens ($M_c \geq$ 0).

This quarter, the Klamath Falls, Oregon area continued to have an extremely high rate of seismicity, following magnitude 5.9 and 6.0 earthquakes on September 21, 1993 at 03:29 and 05:45 UTC (local time was September 20, at 8:39 and 10:45 PM Pacific Daylight Time). Fig. 6 includes a spike plot showing magnitude versus time, and another showing the number of earthquakes per day from Sept. 18 through the end of 1993. Fig. 7 is a map showing Klamath Falls epicenters of earthquakes magnitude 1.6 and greater for the 4th quarter. Fig. 8 shows the time history of "finger quake" InterNet information requests following the 1/17/94 Los Angeles earthquake. Please note that the area covered in Figs. 1, 2, and 3 has been expanded from that shown in previous quarterly reports to cover latitudes 42-49.5° N. Previously, the area included was 42.5-49.5° N.

WESTERN WASHINGTON AND OREGON

During the fourth quarter of 1993, 2,513 earthquakes were located between 42.0° and 49.5° north latitude and between 121° and 125° west longitude; a enormous increase over the 509 located in the third quarter. The vast majority were located near Klamath Falls, Oregon. Most earthquakes in the western parts of Washington and Oregon were at depths shallower than 30 km with, as usual, a small number of earthquakes at depths greater than 30 km in the Puget Sound lowland and near the Olympic Peninsula.

Five earthquakes were reported felt in western Washington or Oregon during the fourth quarter of 1993. Three were associated with the Klamath Falls sequence and are discussed in the Klamath Falls section below. Klamath Falls is a considerable distance from the UW, and additional earthquakes may have been felt but not reported to us. The other felt earthquakes included a near-surface M_c 2.8 earthquake on October 6 (11:20 UTC) about 12 km southeast of Deming, WA and reported felt in Deming; and a M_c 1.6 earthquake at a depth of about 40 km on Nov. 11 (05:29 UTC) that was located 20.4 km SSE of Victoria, British Columbia, and felt in Port Angeles, Washington.

The 1993 Klamath Falls, Oregon Earthquake Sequence

Beginning on September 21 (UTC) a highly unusual sequence of earthquakes began near Klamath Falls, Oregon in an area which normally has no detectable seismicity. This sequence included a felt foreshock, mainshocks; and many aftershocks. The mainshocks (M_c 5.9 and 6.0) are among the largest earthquakes to have occurred in Oregon in this century (the felt area of the 1936 Oregon/Washington border earthquake was larger). Aftershock activity continued through the fourth quarter, and included a damaging M_c 5.1 earthquake on December 4, at 22:15 UTC, and felt earthquakes of M_c 4.0 and 4.1 on December 25 (12:33 UTC) and December 31 (18:08 UTC) respectively.

The Klamath Falls area lies at the westernmost edge of the Basin and Range geomorphic province, which extends from Oregon into Idaho and Nevada, and geologists have long recognized many potentially active north-to-northwest trending normal faults in the region. Earthquakes in the current sequence have occurred on several different subsurface fault segments along the western margin of the Klamath Graben; a down-dropped area bounded by normal faults. Focal mechanisms of the December 4 earthquake and both main shocks in September correspond to normal faulting along northwest striking faults.

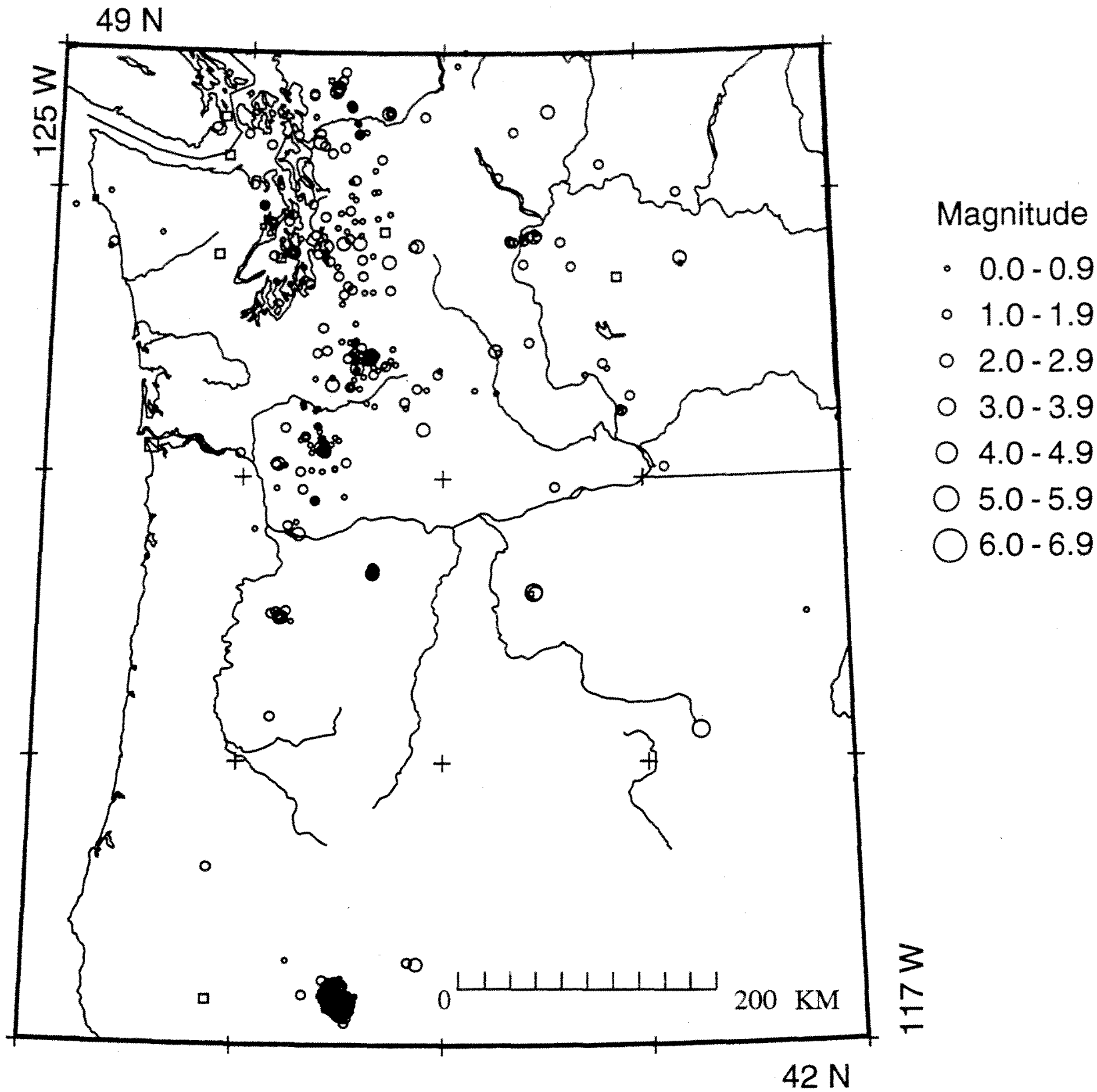

Figure 2: Earthquakes located in Washington and Oregon with magnitudes greater than or equal to 0.0 during the fourth quarter of 1993. Square symbols indicate events located at depths of 30 km or more.

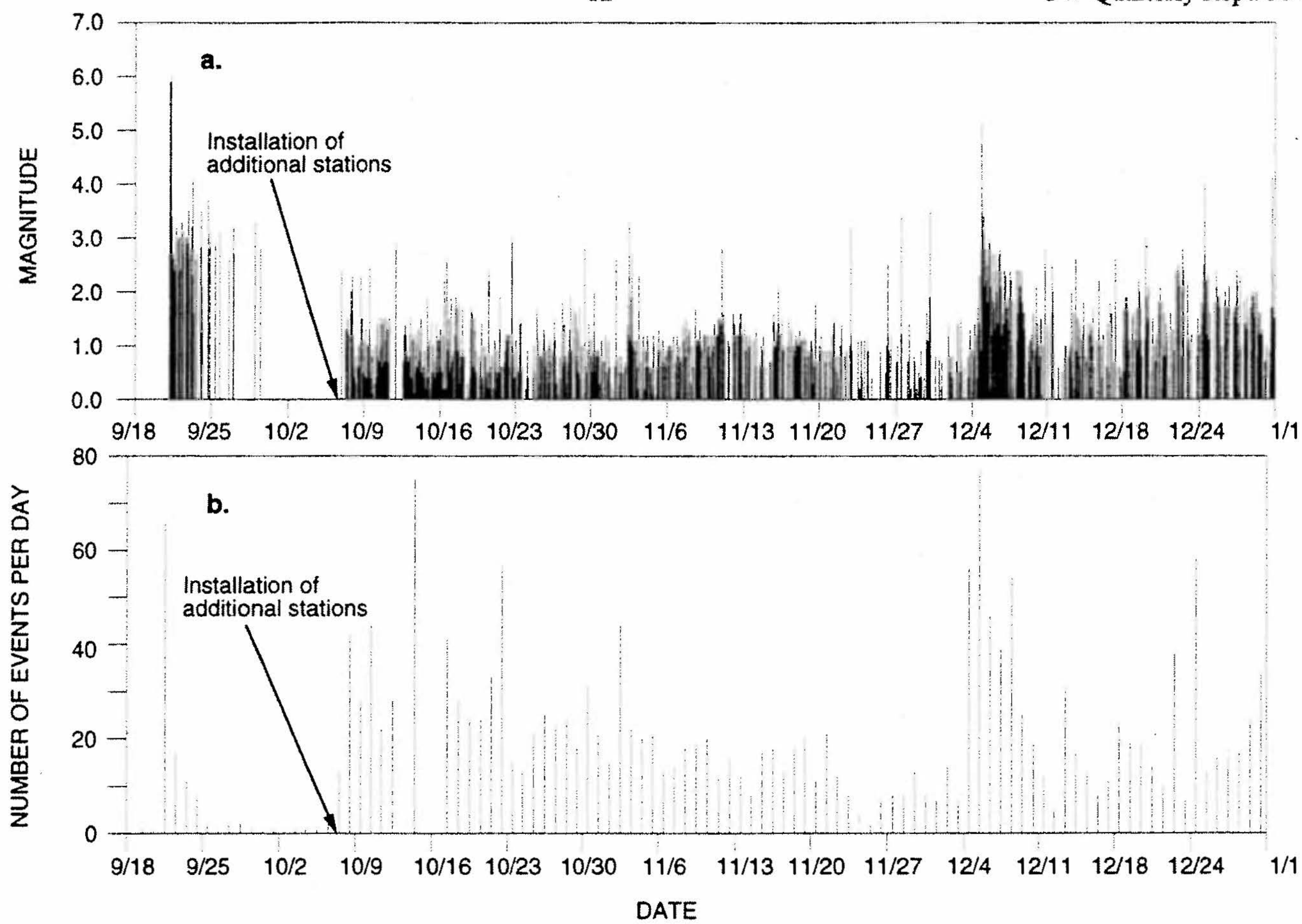

Figure 6. Klamath Falls earthquake sequence, Sept. 18, 1993 - Jan. 1, 1994. Earthquakes located by the WRSN.
a. Magnitude vs. time
b. Number of events per day vs. time.

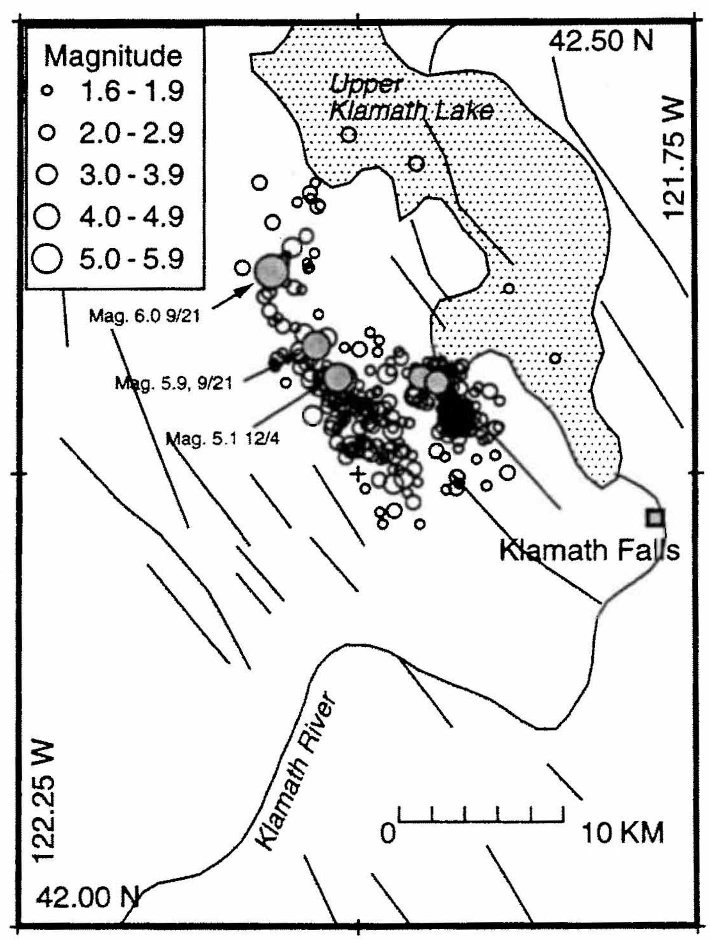

Figure 7. Map view of Klamath Falls earthquakes of magnitude 1.6 or greater during the fourth quarter of 1993. September mainshocks (magnitude 5.9 and 6.0) are shown as shaded circles. The magnitude 5.1 shock of Dec. 4, and the magnitude 4.0 and 4.1 earthquakes of Dec. 25 and Dec. 31 are also shaded.

Because seismic activity in southern Oregon has been historically low, there were no seismographs near Klamath Falls when the earthquakes struck on September 21 (UTC). The nearest station in the WRSN was 70 km to the north, while the nearest USGS station in California was 70 km to the south. Thus, the earthquakes were "outside" each network. This made determination of the epicenters and depths of the earthquakes difficult. Data from the two networks were merged to improve the location of the early events. Because the activity was initially outside the WRSN network, events smaller than 2.4 did not reliably trigger our data recording system. Tom Yelin of the USGS estimates that our records from Sept. 21 - Oct. 7 are complete for events of M_c 2.4 and greater. The addition of four telemetered stations in early October improved both triggering sensitivity and location accuracy.

Figure 6a shows the distribution of earthquake magnitudes as a function of time from the beginning of the sequence through the end of the fourth quarter, Fig. 6b is a histogram of the number of events per day for the same period, Table 4 gives the number of earthquakes per month in several magnitude ranges for the general Klamath Falls area; 42-43N, 121.5-123W, and Fig. 7 is a map view showing fourth quarter seismicity and the September mainshocks. After the initial shocks, activity fell off rapidly. Only a few events large enough to trigger our data-recording system occurred between September 25 and October 7 (after October 7, we were able to record much smaller earthquakes). Two aftershocks greater than magnitude 4.0 were recorded within the first few days after the Sept. 21 (UTC) mainshocks, then ten weeks passed without any events larger than 3.5.

Vigorous activity resumed on December 4, with a magnitude 5.1 earthquake at 2:15 PST (22:15 UTC). While this event was similar in location to the September mainshocks, it initiated a new phase of activity, characterized by a notable increase in the frequency of earthquakes, and a shift of activity from the original fault zone to a new eastern fault. While the initial segment continued to produce some events, the majority of seismicity moved over to the eastern segment (clearly visible in Fig. 7), which produced felt earthquakes of magnitude 4.0 and 4.1 on Dec. 25 (12:33 UTC) and Dec. 31 (18:08 UTC) respectively.

Table 4 illustrates the decrease of events larger than magnitude 2.5 during October and November, and the renewal of aftershock activity in December. The apparent increase in events smaller than magnitude 2.5 in December relative to September is undoubtedly due to the increased sensitivity of the network.

TABLE 4 - Klamath Falls earthquakes: magnitude distribution by month

Month	2.0-2.4	2.5-2.9	3.0-3.4	3.0-3.9	4.0 and greater
Sept.	41	46	17	7	4
Oct.	9	5	1	0	0
Nov.	3	5	3	1	0
Dec.	83	25	8	2	3

A special issue of **Earthquakes and Volcanos** (Vol. 24, No. 3.) with several articles on the Klamath Falls sequence, will be published in spring '94. Subscriptions to **Earthquakes and Volcanos** are available from the Supt. of Documents, US Government Printing Office, Washington, DC 20402, or individual issues can be ordered from the USGS Map Distribution, Box 25286, Bldg 810, Denver Federal Center, Denver, CO 80225.

Mount Rainier Area

There were 92 events in the region near Mt. Rainier, as seen in Fig. 5. Of these, 30 were located in what is called the 'western Rainier seismic zone', a north-south trending lineation of seismicity approximately 15 km west of the summit of Mt. Rainier (defined for search purposes as 46.6-47° N latitude, 121.83-122° W longitude). Closer to the summit (within 5 km), there was a combination of 21 tectonic and 23 non-tectonic events. The non-tectonic events are flagged type "S" or type "L" (see "Key to Earthquake Catalog"). The remaining events were scattered around the cone of Rainier as seen in Fig. 5. Activity at Mt. Rainier includes surface events (avalanches, rockfalls, ice quakes, etc.) and tectonic earthquakes. Events with very low frequency signals (1-3 Hz) believed to be icequakes are assigned type "L" in the catalog. Emergent, very long duration signals probably due to rockfalls or avalanches are assigned type "S". Shallow tectonic earthquakes have a higher frequency and presumably a different source. The number of events in close proximity to the cone of Mt. Rainier varies over the course of the year, since the source of much of the shallow surface-type activity is presumably ice movement or avalanching, which is

QUARTERLY NETWORK REPORT 94-A

on

Seismicity of Washington and Western Oregon

January 1 through March 31, 1994

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 western Oregon. Information contained in this report should be considered preliminary, and not cited for publication. The views and conclusions contained in this document should not be interpreted as necessarily representing the official policies, either express or implied, of the U.S. Government.

Seismic network operation in Washington and western Oregon is supported by the following contracts:

U.S. Geological Survey
Joint Operating Agreement 1434-92-A-0963

and

Westinghouse Hanford Company
Contract MLR-SVV-666685

Moment-tensor focal mechanisms for earthquakes in the Pacific Northwest were computed by Oregon State University under USGS NEHRP Grant 1434-93-G-2326 and are included in this report.

CONTENTS

FIGURES

TABLES

INTRODUCTION

This is the first quarterly report of 1994 from the University of Washington Geophysics Program covering seismicity of all of Washington and western 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 technical reports covering seismicity in Washington since 1969 are available from the U.W. Geophysics Program.

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 or USGS CALNET seismograph stations. Findings mentioned in these quarterly reports should not be cited for publication. Fig. 1 is a map view of seismograph stations currently in operation.

NETWORK OPERATIONS

Table 1 gives approximate periods of time when certain 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. There were several station outages during the first quarter, caused possibly by battery problems or snow-covered solar panels. Many stations are inaccessible at this time of year.

In the Klamath Falls, Oregon area, an additional station (Hogback Mtn. - HOG) was installed in January. Previously, after the occurrence of a pair of damaging earthquakes in September (Sept. 21, 03:29 and 05:45 GMT; @ M sub c @ 5.9 and 6.0 respectively), four stations (HAM, LAB, VSP, and VRC) had been installed. In December, a @ M sub c @ 5.1 aftershock (Dec. 5), initiated activity to the east and south, on structures not active in the earlier part of the sequence. Station HOG was added to improve azimuthal coverage and depth control on these earthquakes.

On the Olympic Peninsula, a new short-period three-component station (WIB) was installed at Willapa Bay in December and began operating in January. This station improves our ability to detect and locate events near the southern Washington coast. Station OBH, which has been out of operation since 1992 because of telemetry path problems, will be upgraded to a three-component station with a reconfigured telemetry path during the summer of 1994.

Station TTW , a three-component broad-band station near Tolt, Washington that continuously telemeters digital data (50 samples/sec) to the UW Seismology Lab, has moved beyond test mode, and is providing useful information. Semi-automated techniques to automatically save seismic data from TTW are now in use. Because TTW data is usually a good indicator of the data quality on our other broad-band stations, we are using it to help select which data windows to retrieve from the other stations via telephone modem.

Inoperable stations during the first quarter included CPW (repaired) which had a VCO problem; FMW, which is intermittent apparently due to lack of capacity of its solar-charged battery; and TWW, LMW, HTW, and HDW - all inaccessible due to snow conditions.

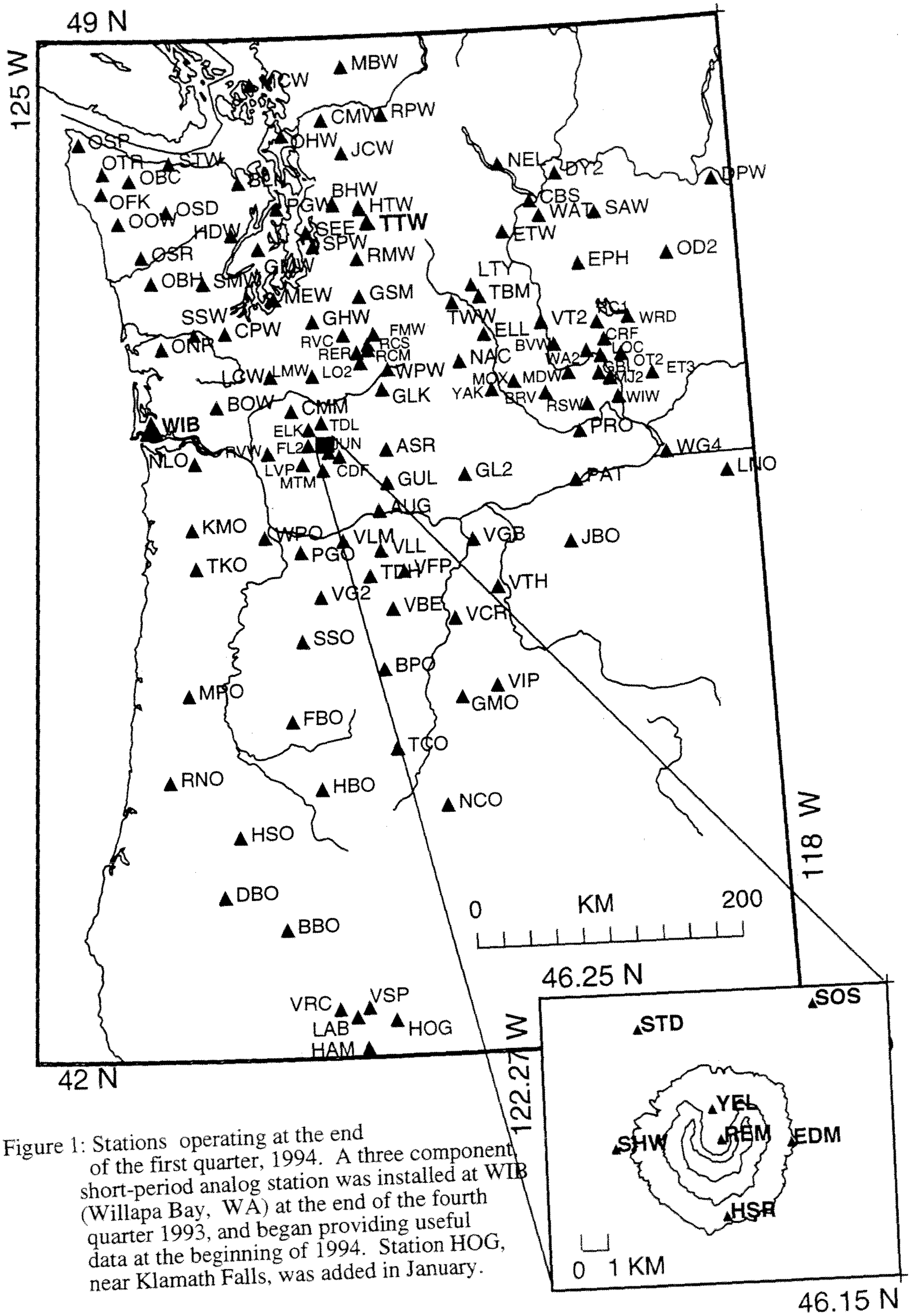

Figure 1: Stations operating at the end of the first quarter, 1994. A three component short-period analog station was installed at WIB (Willapa Bay, WA) at the end of the fourth quarter 1993, and began providing useful data at the beginning of 1994. Station HOG, near Klamath Falls, was added in January.

TABLE 1
Station Outages 1st quarter 1994

Station	Outage Dates	Comments
BHW	Sept. 1993 - 1/12	Transmitter moved
CPW	Nov. 1993-3/16	VCO repaired
DBO	3/12 - end	Intermittent
FMW	Nov. 1993 - end	Intermittent
HDW	3/10 - end	Dead
HOG		INSTALLED 01/21/94
HTW	3/8 - end	Dead
LMW	1/1 - end	Dead
LNO	2/7 - 3/15	Bad connection
OBH	Mar. 1992-End	Dead
TWW	Fall '93 - end	Dead
WIB		3-component; INSTALLED 01/03

The trace- and phase-data formats used by the WRSN have been in use since 1980. Our original trace-data format, called UW-1, was developed when trace-data from all stations were telemetered in analog format to a central location (the UW) and digitized and time stamped simultaneously. The UW-1 format is very compact, but accommodates only a single digitization rate and time-stamp, so that trace-data from other sources (such as broad-band data, or data from the Canadian Pacific Geoscience Centre) cannot be combined into UW-1 trace-data files. The recent addition of on-site digitally recorded and time-stamped broad-band stations to the WRSN has made the UW-1 format less useful. We have therefore updated both our trace- and phase-data formats. The new formats are known as UW-2, and have been in use for developmental and testing purposes for several quarters. We are still modifying our software to accommodate all of the features available in the new data formats, and anticipate making a complete transition to the UW-2 formats by the end of 1994.

OUTREACH ACTIVITIES

In addition to monitoring earthquake activity in Washington and much of Oregon, the staff of the Washington Regional Seismic Network (WRSN) participates in outreach projects to inform and educate the public about seismicity and natural hazards. Our outreach includes lab tours, lectures, TV or radio talk shows, field trips, and participation in regional earthquake planning efforts.

Interest in the Klamath Falls, Oregon earthquakes remained high in the first quarter of 1994 because of continuing aftershocks. In late January, the UW's Anthony Qamar participated with the USGS in several days of informational meetings in Klamath Falls. The meetings were set up by Klamath Falls emergency coordinator Ed Dolan and other local officials, and included presentations to the public (2 three-hour programs each attended by about 200 persons), the Dept. of Emergency Services, and the Red Cross (4 hours, attended by ~100). While in Klamath Falls, interviews were also provided to radio, newspaper and print media and the USGS completed installation of station HOG just east of Klamath Falls.

The M_B 6.7 Northridge, CA earthquake on January 17 provided a special opportunity to educate the public to the seismic hazards in our region, and to encourage all residents in the Pacific Northwest to prepare for damaging earthquakes. It triggered an intense demand for information on earthquake hazards in our region, both from the media and from members of the public. UW faculty, staff, and graduate students participated in about 40 live TV and radio interviews in the 48 hours following the earthquake, as well as answering numerous requests from the print media. Educating media providers, and giving them accurate and timely information is our most effective tool for reaching the public, and often generates additional interest. Requests for information this quarter were numerous - we responded to 80 calls from the emergency management community, 125 calls from the media, and over 300 calls from the public requesting information.

During the first quarter, 17 school groups, with a total of 498 students and teachers toured our lab. Representatives from the WRSN lab participated in 12 meetings with over 287 earthquake educators or emergency planners who were preparing or conducting earthquake drills and response plans. Organizations included the Coast Guard, The Washington State D.C.D. Emergency Management Division, the American Red Cross, elementary schools and school districts, and fire departments. We also gave 10 presentations to community service organizations, serving a total of about 380 people. Educational presentations were also conducted for the insurance industry, serving over 100 individuals representing numerous national and local firms. Insurers have been requesting more information, due to an industry-wide reassessment of risk following losses due to the Northridge, CA earthquake.

We provide several computer options for access to our earthquake locations. Any e-mail user can receive a one-page report on the most recent earthquakes larger than magnitude 2.0 located by the WRSN, and that also contains e-mail addresses for U.S. or global earthquake information, by sending e-mail to "quake@geophys.washington.edu". The report will be returned by e-mail. For computers with access to the InterNet, the command "finger quake@geophys.washington.edu" will send the same information to the user's terminal. Another InterNet option for non-UNIX users is to "rlogin" to geophys.washington.edu as "quake" with password "quake". The same information is also available via modem: (206) 685-0889 (Modem setting 8 bits, 1 stop bit, No parity); login as "quake"; password: "quake". Additional WRSN information, such as catalogs and station information is available over the InterNet via "anonymous ftp" in the subdirectory ~ftp/pub/seis_net. Detailed information about the Klamath Falls, OR earthquake sequence is available in the subdirectory ~ftp/pub/kfalls.

Prior to the January 17 Northridge, CA earthquake, about 40 persons per hour on average were using the "finger quake" utility over InterNet, while about 90 persons per day accessed information through the other computer methods combined. Immediately following the earthquake, "finger quake" activity topped 1,000 requests per hour. Currently, about 70 persons per hour on average are using the "finger quake" utility over InterNet, while about 115 persons per day are accessing information through the other computer methods combined.

Computer information servers for earthquake data are being developed both here at the University of Washington and at other regional network labs. The "finger quake" service is now available from seven other regional networks as well as for world-wide earthquake catalogs from the National Earthquake Information Service (NEIS) which can be obtained by doing "finger quake@gldfs.cr.usgs.gov". Another service which we have just begun is a World-Wide-Web (WWW) information server which provides text and graphics for anyone connected to the InterNet runing a version of "Mosaic" (available for workstations, PC-Windows, and Macintoshes with anonymous ftp at ftp.ncsa.uiuc.edu). Our WWW server contains text about earthquakes in the Pacific Northwest, maps of stations, catalogs and maps of recent earthquake activity, and maps and text about recent interesting sequences. It also contains links into other sources of earthquake information around the country and world. To access it use "mosaic http://www.geophys.washington.edu".

This quarter, the WRSN, in cooperation with the USGS, compiled a catalog of events for the production of a seismicity map on a full-color shaded-relief 1:1,000,000 base. This map will be issued in early summer of 1994 as a USGS Open-File Report, and should be very useful in our ongoing effort to educate the public about Pacific Northwest seismic hazards.

STATIONS USED FOR LOCATION OF EVENTS

Table 2 lists stations used in locating seismic events in Washington and Oregon. Stations marked by an asterisk (*) or a (%) were supported by USGS joint operating agreement 1434-92-A-0963, and (+) indicates support under Westinghouse Hanford Company Contract MLR-SVV-666685 All other stations were supported from other sources.

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EARTHQUAKE DATA

There were 2,322 events digitally recorded and processed at the University of Washington between January 1 and March 31, 1994. Locations in Washington, Oregon, or southernmost British Columbia were determined for 1,584 of these events; 1,513 were classified as earthquakes and 71 known or suspected blasts. The remaining 738 processed events include teleseisms (122 events), regional events outside the U. W. network (75), 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 routinely processed. During this quarter, the Klamath Falls area was the source of many of the earthquakes, both located (1,215) and unlocatable (456). This is aftershock activity following a pair of damaging earthquakes in September (Sept. 21, 03:29 and 05:45 GMT; M_c 5.9 and 6.0 respectively).

Table 3, located at the end of this report, is the catalog of earthquakes and blasts located within the network for this quarter. For the Klamath Falls area, only earthquakes of magnitude 1.6 and larger have been included in Table 3.

We are now using an improved velocity model (K3) for earthquakes in southern Oregon from 42° to 43° N latitude, and from 117° to 125° W longitude. It is based on a velocity model of the Modoc Plateau (Zucca et al., 1986, JGR, V. 9, pp. 7359-7382), and includes station corrections derived from a "master event" analysis of Klamath Falls earthquakes.

Fig. 2 shows all earthquakes with magnitude greater than or equal to 0.0 ($M_c \geq 0.$) Fig. 3 shows blasts and probable blasts ($M_c \geq 0.$) Fig. 4 shows earthquakes located at Mt. Rainier ($M_c \geq 0$). Fig. 5 shows earthquakes located at Mt. St. Helens ($M_c \geq 0$).

This quarter, the Klamath Falls, Oregon area continued to have an elevated rate of seismicity, following magnitude 5.9 and 6.0 earthquakes on September 21, 1993 at 03:29 and 05:45 UTC (local time was September 20, at 8:39 and 10:45 PM Pacific Daylight Time). Fig. 6 is a map showing epicenters of earthquakes near Klamath Falls, magnitude 1.6 and greater for the 1st quarter.

MOMENT TENSOR FOCAL MECHANISM SOLUTIONS

Beginning this quarter, moment-tensor focal mechanisms for earthquakes in the Pacific Northwest will be included in this report. These solutions were computed under other support (USGS NEHRP Grant 1434-93-G-2326), at the Oregon State University under the direction of Dr. John Nabelek. The operation of broadband stations in Oregon was supported by grants and contracts from the National Science Foundation (EAR-9207181) and the Oregon Department of Geology and Mineral Industries.

Figure 7 is a map showing the locations of 3-component broad band stations used in determining moment-tensor focal mechanisms. Figure 8 shows the location of focal mechanisms for events $M_w \geq 5.0$, and Figure 9 shows focal mechanisms in the Klamath Falls, Oregon area. Moment tensors, best-fit double-couple mechanism, M_w, seismic moment, and depth are given in Table 4. The coordinate conventions of Aki and Richards (Quantitative Seismology: Theory and Methods, W. H. Freeman, San Francisco, 1980) are followed.

These solutions use data from 3-component broad-band stations in Washington, Oregon, California, and British Columbia. The inversions are performed in the 0.01 - 0.1 Hz range, with the frequency band adjusted according to the earthquake magnitude and the station epicentral distance.

OREGON SEISMICITY

During the first quarter of 1994, 1,234 earthquakes were located in Oregon between 42.0° and 45.5° north latitude and between 117° and 125° west longitude. Of these only 19 were located outside the Klamath Falls area.

Three earthquakes greater than magnitude 4 were reported felt in the Klamath Falls, Oregon area during the first quarter of 1994. They occurred on January 7 at 09:39 UTC (M_c 4.0), on January 9 at 19:02 UTC (M_c 4.3), and on January 19 at 22:27 UTC (M_c 4.3). All three earthquakes were at very shallow depths (less than 3 km) and are shown in Fig. 6 as shaded symbols. Klamath Falls is at a considerable distance from the UW, and not all felt earthquakes are reported to us. After January, earthquake activity near Klamath Falls decreased somewhat. During January, 618 events were located in the area, but in February

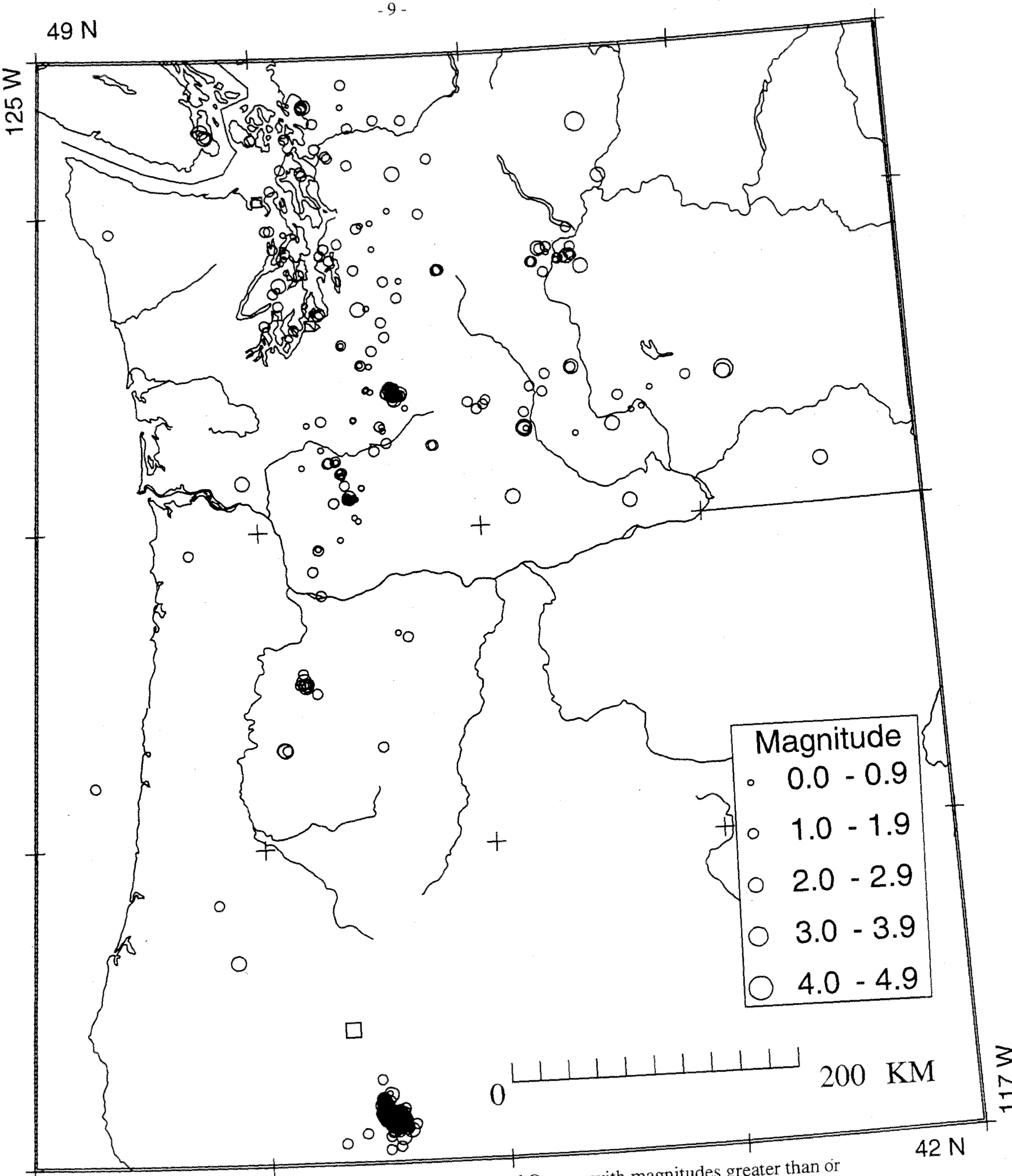

Figure 2: Earthquakes located in Washington and Oregon with magnitudes greater than or equal to 0.0 during the first quarter of 1994. Square symbols indicate events located at depths of 30 km or more.

and March, the rate of activity decreased to 299 and 298 events respectively and no earthquakes larger than magnitude 2.8 were recorded. Table 5 shows monthly activity since the beginning of the sequence.

A special issue of **Earthquakes and Volcanos** (Vol. 24, No. 3, 1993) with several articles on the Klamath Falls sequence, will be published in spring '94. Subscriptions to **Earthquakes and Volcanos** are available from the Supt. of Documents, US Government Printing Office, Washington, DC 20402. Individual issues can be ordered from the USGS Map Distribution, Box 25286, Bldg 810, Denver Federal Center, Denver, CO 80 225.

TABLE 5 - Klamath Falls earthquakes: magnitude distribution by month

Month	2.5-2.9	3.0-3.4	3.5-3.9	4.0 and greater
Sept.	46	17	7	4
Oct.	5	1	0	0
Nov.	6	3	1	0
Dec.	24	8	2	3
Jan.	14	4	1	3
Feb.	1	0	0	0
Mar.	3	0	0	0

WESTERN WASHINGTON SEISMICITY

During the first quarter of 1994, 234 earthquakes were located between 45.5° and 49.5° north latitude and between 121° and 125° west longitude. Most earthquakes in the western part of Washington were at depths shallower than 30 km with, as usual, a small number of earthquakes at depths greater than 30 km in the Puget Sound lowland and near the Olympic Peninsula.

One earthquake was reported felt in western Washington during the first quarter of 1994. It was a shallow (~10 km) M_c 2.8 earthquake on March 10 at 12:10 UTC near the town of Darrington in northwestern Washington.

Mount Rainier Area

There were 73 events in the region near Mt. Rainier, as seen in Fig. 5. Of these, 11 were located in what is called the 'western Rainier seismic zone', a north-south trending lineation of seismicity approximately 15 km west of the summit of Mt. Rainier (for counting purposes, the western zone is defined as 46.6-47° N latitude, 121.83-122° W longitude) of 26 tectonic and 26 non-tectonic events. The non-tectonic events are flagged type "S" or type "L" (see "Key to Earthquake Catalog"). The remaining events were scattered around the cone of Rainier as seen in Fig. 5. Activity at Mt. Rainier includes near-surface events (avalanches, rockfalls, ice quakes, etc.) and tectonic earthquakes. Events with very low frequency signals (1-3 Hz) believed to be icequakes are assigned type "L" in the catalog. Emergent, very long duration signals probably due to rockfalls or avalanches are assigned type "S". Shallow tectonic earthquakes have a higher frequency and presumably a different source than type "S" or "L" events. The number of events in close proximity to the cone of Mt. Rainier varies over the course of the year, since the source of much of the shallow surface-type activity is presumably ice movement or avalanching, which is seasonal in nature.

Mount St. Helens Area

In the first quarter, 43 events (tectonic or non-tectonic) were located at Mt. St. Helens in the area shown in Fig. 5. 10 earthquakes were deeper than 4 km. The largest event, magnitude 2.2 was surficial. It occurred on Feb. 2 at 14:21 UCT.

EASTERN WASHINGTON SEISMICITY

During this quarter, 45 earthquakes were located in eastern Washington. The largest event in eastern Washington this quarter, an M_c 3.0 event at a very shallow depth (less than 1 km) on January 5 at 03:37 UTC, was not reported felt to the UW. One event was reported felt. It was a shallow (less than 5 km deep) M_c 2.5 earthquake and occurred near Entiat on Feb. 6 at 14:53 UTC,

OTHER SOURCES OF EARTHQUAKE INFORMATION

We provide automatic computer-generated alert messages on significant Washington and Oregon earthquakes by E-Mail or FAX to institutions needing such information, and we regularly exchange phase data via E-mail with other regional seismograph network operators. The "Outreach Activities" section describes how to access WRSN data over modem, InterNet, and World-Wide-Web. To request additional information by E-mail, contact bill@geophys.washington.edu.

Earthquake information in the quarterlies is published in final form by the Washington State Department of Natural Resources as information circulars entitled "Earthquake Hypocenters in Washington and Northern Oregon" covering the period 1970-1986 (see circulars Nos. 53, 56, 64-66, 72, 79, 82-84). A catalog covering earthquakes in 1987-1989 has been submitted to the Washington State Department of Natural Resources for publication. These circulars, plus circular No. 85, "Washington State Earthquake Hazards", are available from Washington Dept. of Natural Resources, Division of Geology and Earth Resources, Post Office Box 47007, Olympia, Wa. 98504-7007, or by telephone at (206) 902-1450.

Other regional agencies provide earthquake information. These include the Geological Survey of Canada (Pacific Geoscience Centre, Sidney, B.C.; (604) 363-6500, FAX (604) 363-6565), which produces monthly summaries of Canadian earthquakes; the United States Geological Survey which produces weekly reports called "Seismicity Reports for Northern California" (USGS, attn: Steve Walter, 345 Middlefield Rd, MS-977, Menlo Park, Ca, 94025) and "Weekly Earthquake Report for Southern California" (USGS, attn: Dr. Kate Hutton or Dr. Lucy Jones, California Institute of Technology, Pasadena, Ca.)

QUARTERLY NETWORK REPORT 94-B

on

Seismicity of Washington and Western Oregon

April 1 through June 30, 1994

Geophysics Program

University of Washington

Seattle, Washington

This report is prepared as a preliminary description of the seismic activity in Washington State and western Oregon. Information contained in this report should be considered preliminary, and not cited for publication. The views and conclusions contained in this document should not be interpreted as necessarily representing the official policies, either express or implied, of the U.S. Government.

Seismic network operation in Washington and western Oregon is supported by the following contracts:

U.S. Geological Survey
Joint Operating Agreement 1434-92-A-0963

and

Westinghouse Hanford Company
Contract MLR-SVV-666685

Moment-tensor focal mechanisms for earthquakes in the Pacific Northwest were computed by Oregon State University under USGS NEHRP Grant 1434-93-G-2326 and are included in this report.

CONTENTS

FIGURES

TABLES

INTRODUCTION

This is the second quarterly report of 1994 from the University of Washington Geophysics Program *Washington Regional Seismic Network (WRSN)* covering seismicity of all of Washington and western 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 technical reports covering seismicity in Washington since 1969 are available from the U.W. Geophysics Program.

This quarterly report discusses network operations, seismicity of the region, unusual events or findings, and our educational and outreach activities. 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 or USGS CALNET seismograph stations. Findings mentioned in these quarterly reports should not be cited for publication. Fig. 1 is a map view of seismograph stations currently in operation.

NETWORK OPERATIONS

Table 1 gives approximate periods of time when certain 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. There were several station outages during the second quarter. Some stations are still inaccessible at this time of year. Inoperable stations during the second quarter included FL2, YEL, and OBH. The equipment at YAK was removed at the end of June and will be reinstalled at a different site in July. FMW, which was intermittent last quarter, apparently due to lack of capacity of its solar-charged battery, performed much better this quarter.

TABLE 1
Station Outages 2nd quarter 1994

Station	Outage Dates	Comments
CMW	5/1-6/30	Intermittent
FL2	5/25-end	Dead
GSM	4/27-5/3	Intermittent
JBO	4/6-5/11	Repaired - Damaged antenna
KMO	5/7-5/18	Intermittent
LMW	1/1-6/1	Repaired - Dead batteries
LVP	5/25-end	Dead
HDW	3/8-6/29	Repaired - Low VCO
HTW	3/10-5/11	Repaired - Dead batteries
MBW	6/1-7/1	Intermittent
OBC	4/3-6/29	Intermittent
OBH	March 1992-end	Waiting for telemetry
RNO	4/27-5/11	Repaired - Stolen solar panel
RVC	6/1-end	Intermittent
TWW	Fall 93-5/11	Repaired - Bad cable connection
YAK	6/29-end	Equipment Removed
YEL	4/15-end	Dead

To provide flexibility to integrate broadband data into our normal network data stream, we have made changes to both our trace data and pickfile formats. These changes have been developed and tested in the context of an integrated network processing software package called SNAPS (Seismic Network Automated Processing System). The SNAPS package has been extensively tested in our network environment and is currently (2nd half of 1994) being integrated into our routine network processing. It provides a framework for integrating automated processing steps with steps controlled by an analyst.

Our new working trace data format (UW-2) offers needed advantages over our old format (UW-1) in being able to incorporate data of varying durations, sample rates, start times, and formats (e.g., integer, floating point, ...). In addition, the format is extensible without affecting existing processing programs, and it was designed for backward compatibility with UW-1 to avoid the necessity for massive reformatting. A variety of format conversion programs have already been written, or are being developed, to allow easy conversion to/from our working format to/from other commonly used formats such as AH and SEED.

For a variety of reasons, our existing pickfile format was also changed to accommodate the requirements of network changes. Our new pickfile format is also backward compatible with the old format, and provides full support for three-component stations, flexibility to represent arbitrary phase types (for

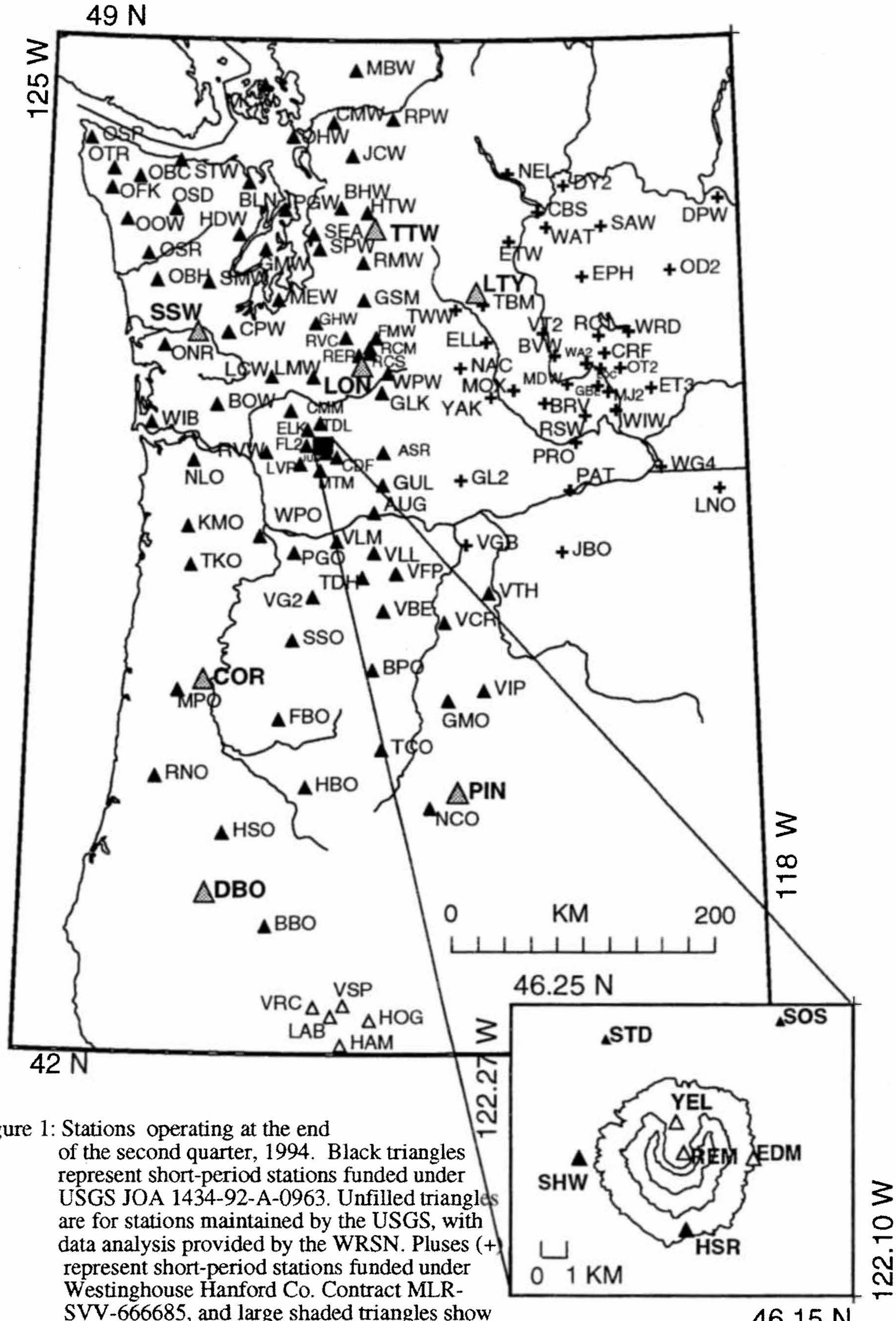

Figure 1: Stations operating at the end of the second quarter, 1994. Black triangles represent short-period stations funded under USGS JOA 1434-92-A-0963. Unfilled triangles are for stations maintained by the USGS, with data analysis provided by the WRSN. Pluses (+) represent short-period stations funded under Westinghouse Hanford Co. Contract MLR-SVV-666685, and large shaded triangles show the locations of broad-band three-component instruments, funded either via JOA 1434-92-A-0963, NSF EAR-9207181, or DOGAMI.

example, our old format could only represent P and S phases) such as Pn and PmP, variable precision for numerical data, and a number of other advantages. Analyst and researcher access to the data is provided through an X window application called **Xped** (X pick editor). The current version of Xped allows the user to efficiently display trace and pick information on a workstation screen, to modify picks and other parameters, run location programs, and to perform other data analysis functions.

Since 1988, our data acquisition has used a Concurrent 5600 computer running *HAWK* software, a derivative of the CEDAR system first conceived and implemented at Cal Tech by Carl Johnson. The basic concept of the real-time part of *HAWK* is to digitize all incoming data, and to save it briefly (nominally 20 sec.) in a circular ring-buffer disk file. Within this ring-buffer, digital data are continuously tested for the presence of earthquake signals. When such a signal is detected, data are saved in a special multiplexed format. After the end of the event, the data are demultiplexed into standard UW-1 format files. This system has worked well since 1988, but can no longer meet all of our data-handling needs. Rapid advances in computer speed now allow us to enhance and streamline our data acquisition while lowering computer costs.

We are replacing the Concurrent 5600 with a SUN-SparcStation-5 workstation running the Solaris-1 operating system. The hardware has been installed, and a partial installation of the data acquisition system is operating in test mode. This updated hardware configuration is substantially more powerful than the old system. The software is being developed in cooperation with the EARTHWORM project at the USGS in Menlo Park, and has a modular design so that additional capabilities can easily be added. It will allow us to seamlessly merge data from our short-period network, our broad-band instruments, and from National Net stations. One important feature of the new system is its ability to present any selected time segment of data to processing routines in real-time through a shared-memory mechanism. The immediate availability of continuous data will allow us to develop a variety of data-acquisition options; such as using more robust triggering algorithms that are better able to discriminate seismic events from noise, recording summary data for monitoring station functionality, producing real-time spectral estimates, continuously recording digitally anti-alias filtered data at low sample rates, and continuously recording a subset of stations at our normal sample rate.

OUTREACH ACTIVITIES

In addition to monitoring earthquake activity in Washington and much of Oregon, the staff of the WRSN participates in outreach projects to inform and educate the public about seismicity and natural hazards. Our outreach includes lab tours, lectures, educational classes and workshops, TV and radio talk shows, field trips, and participation in regional earthquake planning efforts. We provide a taped telephone message describing the seismic hazards in Washington and Oregon and a separate taped message on current seismic activity. Both these services are heavily used. We have recently updated our one-page information and resource sheet on seismic hazards in Washington and Oregon. Thousands of these have been mailed out in response to phone requests or distributed in the lab and at meetings. We also encourage others to reproduce and further distribute this sheet.

Educating media providers and giving them accurate and timely information is our most effective tool for reaching the public, and often generates additional interest. Requests for information this quarter were numerous - we responded to 85 calls from the media, 30 calls from the emergency management community, 45 calls from educators, and over 500 calls from the public and business community requesting information. Events which attracted particular interest this quarter included the release by The National Research Council of the report, "Mount Rainier - Active Cascade Volcano" (National Academy Press), and the unusual number of felt Puget Basin events in the month of June.

During the second quarter, 34 school groups, with a total of 575 students and teachers toured our lab. Staff also participated in 4 workshops for elementary school teachers developing earth sciences curriculum. WRSN Staff shared an exhibit space, answered questions and participated in discussions at the METRO conference, "When the Earth Moves Again", where about 200 representatives from all levels of the governments of Oregon and the greater Portland area attended three days of workshops on hazards and emergency preparedness. At this conference the USGS and WRSN presented a new full-color map "Earthquakes in Washington and Oregon 1872-1993" (Susan Goter, 1994, USGS Open-File Report 94-226A), and its companion pamphlet "Washington and Oregon Earthquake History and Hazards", (Yelin et al., 1994, USGS

Open-File Report 94-226B). The order form for these items is attached to the end of this report. Representatives from the WRSN participated in 12 meetings with over 590 earthquake educators, emergency planners, and participants who were preparing or conducting earthquake drills and response plans. Organizations included the U.S. Coast Guard, the U.S. Navy, communications industry representatives, WA Emergency Management Division, the American Red Cross, Cowlitz and Grays Harbor Cos. personnel and public, and several local Seattle groups. The county-level meetings involved significant travel and coordination with other scientists from NOAA and DNR Dept. of Geology and Earth Resources, These meetings were well attended by local press, policy makers, and emergency services providers, and we responded to many questions from the public. We made additional educational presentations to other community service organizations and an insurance industry group, serving a total of about 400 people. The insurance industry has been reevaluating its position since the Northridge, CA earthquake. Some companies are no longer selling new policies. Understanding the differences in the nature of seismic hazards between the Pacific Northwest and California may help them make informed decisions.

We have several computer-accessible information services that provide access to our earthquake locations. The most widely used of these is "finger quake@geophys.washington.edu". This is based on the UNIX "finger" utility, which returns information about a login user name. By placing a brief summary of current local earthquake activity greater than magnitude 2.0 in a specific file (.plan) under the login name "quake", any UNIX user with access to Internet can view the information. This use of the "finger quake" utility has been adopted by many regional seismic networks. Another Internet option for non-UNIX users is to "rlogin" or "telnet" to geophys.washington.edu as "quake" with password "quake". For computer users without direct access to Internet, the same information is available via e-mail (by sending e-mail to "quake@geophys.washington.edu") or modem ((206) 685-0889; Modem setting: 8 bits, 1 stop bit, No parity; login as "quake"; password: "quake") Additional WRSN information, such as catalogs and station information is available over the Internet via "anonymous ftp" in the subdirectory ~ftp/pub/seis_net.

Another service which we have just begun is a World-Wide-Web (WWW) information server which provides text and graphics for anyone connected to the Internet running a version of "Mosaic" (available for workstations, PC-Windows, and Macintoshes with anonymous ftp at ftp.ncsa.uiuc.edu). Our WWW server contains text about earthquakes in the Pacific Northwest, maps of stations, catalogs and maps of recent earthquake activity, and maps and text about recent interesting sequences. It also contains links into other sources of earthquake information around the country and world. To access it use "mosaic http://www.geophys.washington.edu".

We find that there is considerable public interest and a rapidly increasing demand for on-line information services - and that making more information readily available has resulted in several types of interaction with the public that are new to us. First, school groups are retrieving and using our catalogs for classroom projects, and are asking us for research-type interpretive information. Second, we are receiving specific information requests over the Internet, which we cannot adequately respond to on an individual basis because of time constraints. Finally, we are now receiving very rapid feedback from the general public on details of our earthquake locations and magnitudes. We are working to improve our on-line outreach as demand for it increases.

STATIONS USED FOR LOCATION OF EVENTS

Table 2A lists short-period, mostly one-component stations used in locating seismic events in Washington and Oregon. Table 2B lists broad-band, three-component stations operating in Washington and Oregon that provide data to the WRSN. The first column in the table gives the 3-letter station designator, followed by a symbol designating the funding agency; stations marked by a percent sign (%) were supported by USGS joint operating agreement 1434-92-A-0963, and (+) indicates support under Westinghouse Hanford Company Contract MLR-SVV-666685. Other stations were supported from other sources. Additional columns give station north latitude and west longitude (in degrees, minutes and seconds), station elevation in km, and comments indicating landmarks for which stations were named.

EARTHQUAKE DATA

There were 1,270 events digitally recorded and processed at the University of Washington between April 1 and June 30, 1994. Locations in Washington, Oregon, or southernmost British Columbia were determined for 871 of these events; 779 were classified as earthquakes and 92 known or suspected blasts. The remaining 399 processed events include teleseisms (181 events), regional events outside the WRSN (64), and unlocated events within the WRSN. Unlocated events within the WRSN include very small earthquakes and some known blasts. For example, only a few of the frequent mine blasts at Centralia are routinely processed.

During this quarter we continued to record aftershock activity in the Klamath Falls area following a pair of damaging earthquakes in September, 1993 (Sept. 21, 03:29 and 05:45 UCT; M_c 5.9 and 6.0 respectively), but at a much lower rate than during the first quarter (354 locatable events in quarter 94B vs. 1,215 in 94A). Table 4, located at the end of this report, is the catalog of earthquakes and blasts located within the network for this quarter. For the Klamath Falls area, only earthquakes of magnitude 1.6 and larger have been included in Table 4.

Fig. 2 shows all earthquakes with magnitude greater than or equal to 0.0 ($M_c \geq 0.$) Fig. 3 shows blasts and probable blasts ($M_c \geq 0.$) Fig. 4 shows tectonic earthquakes located near Mt. Rainier ($M_c \geq 0$). Fig. 5 shows tectonic earthquakes located at Mt. St. Helens ($M_c \geq 0$). Fig. 6 is a map showing epicenters of earthquakes near Klamath Falls, magnitude 1.6 and greater for the 2nd quarter.

MOMENT TENSOR FOCAL MECHANISM SOLUTIONS

Moment-tensor focal mechanisms for earthquakes with $M_w > 3.5$ in the Pacific Northwest are included in this report. These solutions were computed under other support (USGS NEHRP Grant 1434-93-G-2326), at the Oregon State University under the direction of Dr. John Nabelek. The operation of broadband stations in Oregon was supported by grants and contracts from the National Science Foundation (EAR-9207181, COR) and the Oregon Department of Geology and Mineral Industries (COR, DBO and PIN).

These solutions use data from 3-component broad-band stations in Washington, Oregon, California and British Columbia and from US National Seismic Network stations in the western states of the US. Figure 7 is a map showing the locations of stations used in determining these moment-tensor focal mechanisms. Figure 8 shows earthquake locations for events with focal mechanisms listed in Table 3. Relocated events (7,9,13,14) are marked with R. Moment tensors, best-fit double-couple mechanism, M_w, seismic moment, and depth are given in Table 3. The coordinate conventions of Aki and Richards (Quantitative Seismology: Theory and Methods, W. H. Freeman, San Francisco, 1980) are followed. The inversions are performed in the 0.01 - 0.1 Hz range, with the frequency band adjusted according to the earthquake magnitude and the station epicentral distance.

Events 1 through 5 were calculated since the last quarterly report and are included here. The dip and rake of fault planes for event 32 are not well resolved.

OREGON SEISMICITY

During the second quarter of 1994, 370 earthquakes were located in Oregon between 42.0° and 45.5° north latitude and between 117° and 125° west longitude. Of these, 16 were located outside the Klamath Falls area. Activity in the Klamath Falls area decreased considerably compared with the first quarter (354 located quakes in 94B vs. 1,215 in 94A). The largest earthquake at Klamath Falls during the second quarter, and the only event reported felt, was a magnitude 3.5 event on April 13 at 20:41 UCT. This was the largest earthquake since a magnitude 4.3 on January 19. No earthquakes in the magnitude 3.0-3.4 range were located in the Klamath Falls area this quarter, and only three in the 2.5-2.9 range.

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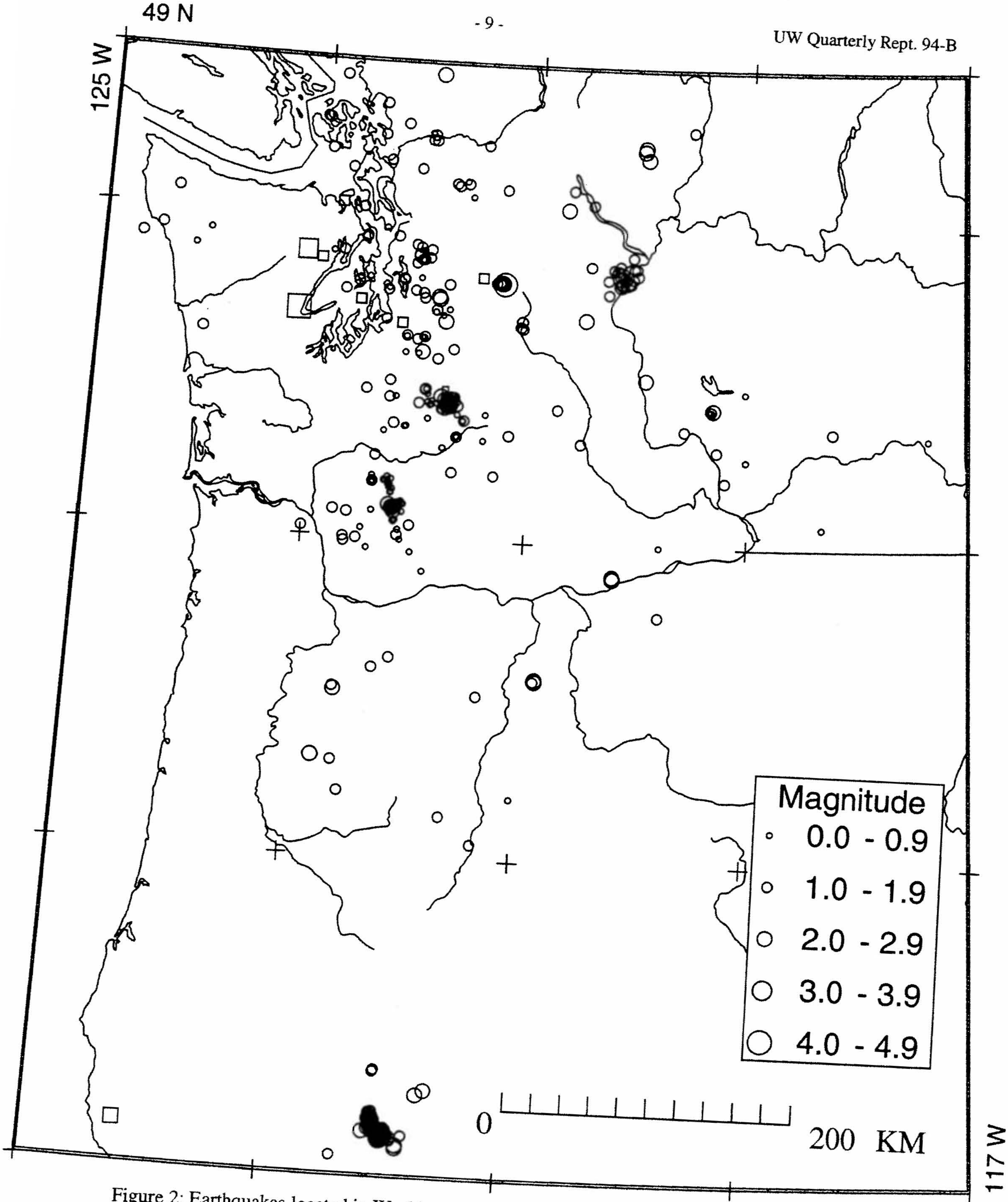

Figure 2: Earthquakes located in Washington and Oregon with magnitudes greater than or equal to 0.0 during the second quarter of 1994. Square symbols indicate events located at depths of 30 km or more.

QUARTERLY NETWORK REPORT 94-C

on

Seismicity of Washington and Western Oregon

July 1 through Sept 31, 1994

Geophysics Program

University of Washington

Seattle, Washington

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CONTENTS

FIGURES

TABLES

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NETWORK OPERATIONS

Table 1 gives approximate periods of time when certain 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. Most stations were operable during the third quarter, when all of our sites are accessible. Eastern Washington stations YAK and OT2 were re-sited and renamed YA2 and OT3, respectively. An additional battery was installed at FMW to improve uptime during the winter months when little sunlight reaches the site. Telemetry for OBH is now available, and installation of the three-component short-period station will be completed in the fourth quarter.

TABLE 1
Station Outages 3rd quarter 1994

Station	Outage Dates	Comments
CMW	8/11-8/29	Intermittent
DPW	8/16-end	Repaired - Damaged cable
FL2	5/25-7/5	Repaired - Bad VCO
KMO	5/7-7/20	Repaired - insufficient power supply
LVP	6/30-7/22	Repaired - Bad VCO
OT3	8/26	Installed to replace OT2
OT2	8/26-End	Removed - Replaced by OT3
OBH	March 1992-end	Waiting for telemetry or installation
OSD	7/13-9/13	Repaired - Damaged receiver
RVC	7/1-end	Repaired - Damaged VCO
TBM	8/2-end	Dead
YA2	7/22	Installed to Replace YAK
YAK	7/18	Removed - Replaced by YA2
YEL	4/15-7/21	Repaired - Dead batteries

We are in the process of updating our data acquisition and processing procedures. The changes to our processing procedures took effect at the beginning of the fourth quarter, and were driven by the need to integrate broadband data into our normal data stream, which required modification of both trace and phase data formats. We are currently testing the updated data acquisition procedure, and expect to implement it for regular use by the end of the fourth quarter.

OUTREACH ACTIVITIES

In addition to monitoring earthquake activity in Washington and much of Oregon, the staff of the PNSN participates in outreach projects to inform and educate the public about seismicity and natural hazards. Our outreach includes lab tours, lectures, educational classes and workshops, TV and radio talk shows, field trips, and participation in regional earthquake planning efforts. We provide a taped telephone message describing the seismic hazards in Washington and Oregon and a separate taped message on current seismic activity. Both these services are heavily used. We have recently updated our one-page information and resource sheet on seismic hazards in Washington and Oregon. Thousands of these have been mailed

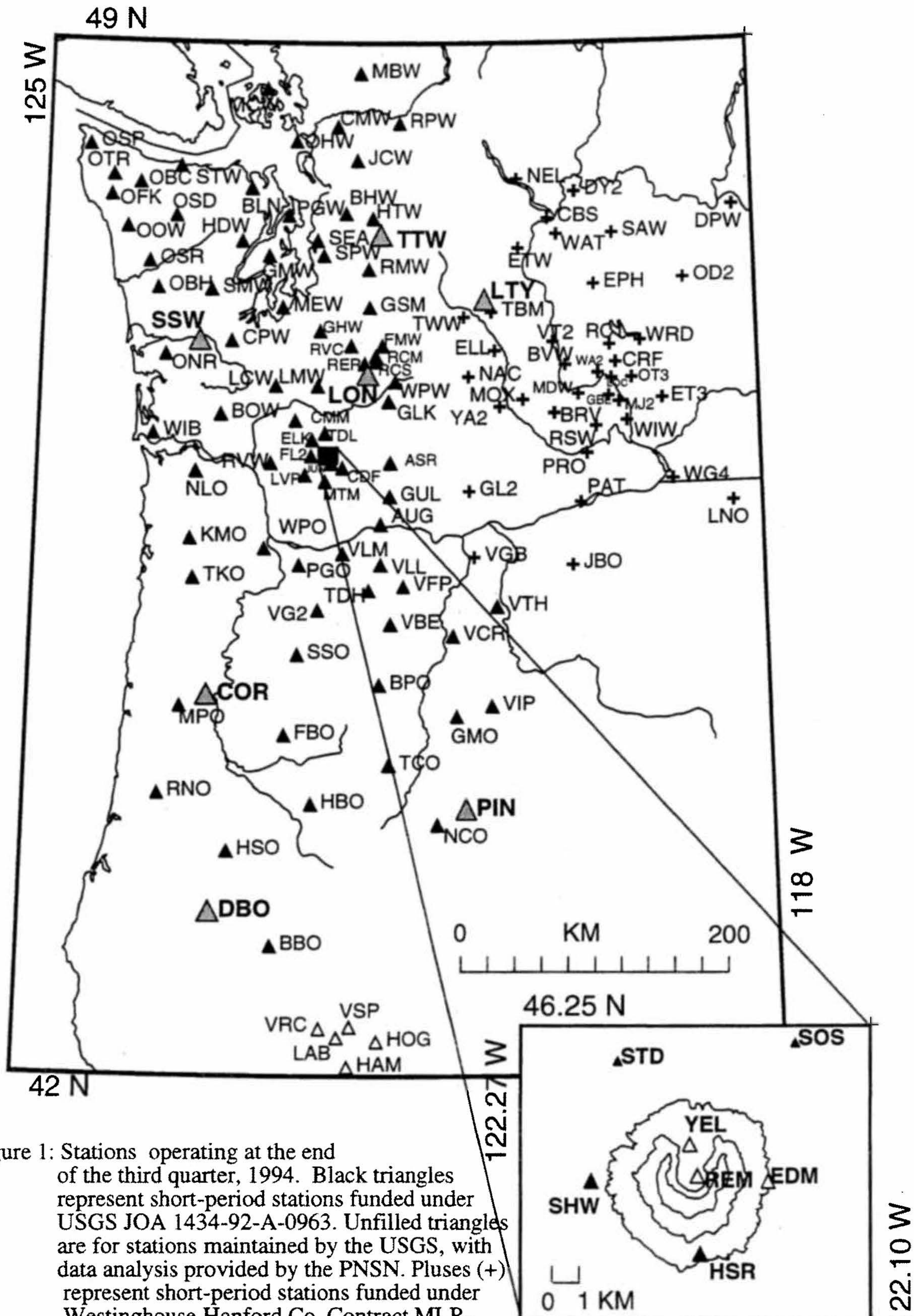

Figure 1: Stations operating at the end of the third quarter, 1994. Black triangles represent short-period stations funded under USGS JOA 1434-92-A-0963. Unfilled triangles are for stations maintained by the USGS, with data analysis provided by the PNSN. Pluses (+) represent short-period stations funded under Westinghouse Hanford Co. Contract MLR-SVV-666685, and large shaded triangles show the locations of broad-band three-component instruments, funded either via JOA 1434-92-A-0963, NSF EAR-9207181, or DOGAMI.

out in response to phone requests or distributed in the lab and at meetings. We also encourage others to reproduce and further distribute this sheet.

Educating media providers and giving them accurate and timely information is our most effective tool for reaching the public, and often generates additional interest. Requests for information this quarter were numerous - we responded to 50 calls from the media, 23 calls from the emergency management community, 18 calls from educators, and over 300 calls from the public and business community requesting information.

In addition to providing background and information on current seismicity, PNSN staff at the UW gave more than twenty interviews that were broadcast on television or radio stations, and cooperated in the production of two programs broadcast on Community Access TV (CATV) in Bremerton; one addressing seismic hazards and the other with a panel of emergency response and management personnel. A workshop on Pacific Northwest geologic hazards was held at U.W. for Red Cross Volunteer Trainers. Presentations were also made to approx. 50 King Co. planners, engineers, and staff, and to 60 members of the Ballard Rotary Club.

During the third quarter, 3 school groups, with a total of 75 students and accompanying adults toured our lab, including 18 physically challenged "Do It" scholars. Staff also participated in 4 workshops for elementary school teachers developing earth sciences curriculum, provided tours and workshops for two other teacher groups, and presented a lecture to 45 U.W. Geography students.

We have several computer-accessible information services. The most widely used of these is

"finger quake@geophys.washington.edu".

This is based on the UNIX "finger" utility, which returns information about a login user name. By placing a brief summary of current local earthquake activity greater than magnitude 2.0 in a specific file (.plan) under the login name "quake", any UNIX user with access to Internet can view the information. This use of the "finger quake" utility has been adopted by many regional seismic networks. For computer users without direct access to Internet, the same information is available via e-mail

(by sending e-mail to "quake@geophys.washington.edu") or

modem ((206) 685-0889; Modem setting: 8 bits, 1 stop bit, No parity; login as "quake"; password: "quake")

Additional PNSN information, such as catalogs and station information is available over the Internet via

"anonymous ftp" in the subdirectory ~ftp/pub/seis_net.

Another service we provide is a World-Wide-Web (WWW) information server which provides text and graphics for anyone connected to the Internet running a version of "Mosaic" (available for workstations, PC-Windows, and Macintoshes via anonymous ftp at ftp.ncsa.uiuc.edu). Our WWW server contains text about earthquakes in the Pacific Northwest, maps of stations, catalogs and maps of recent earthquake activity, and maps and text about recent interesting sequences. It also contains links into other sources of earthquake information around the country and world. To access it use **"mosaic http://www.geophys.washington.edu".**

STATIONS USED FOR LOCATION OF EVENTS

Table 2A lists short-period, mostly one-component stations used in locating seismic events in Washington and Oregon. Table 2B lists broad-band, three-component stations operating in Washington and Oregon that provide data to the PNSN. The first column in the table gives the 3-letter station designator, followed by a symbol designating the funding agency; stations marked by a percent sign (%) were supported by USGS joint operating agreement 1434-92-A-0963, and (+) indicates support under Westinghouse Hanford Company Contract MLR-SVV-666685. Other stations were supported from other sources. Additional columns give 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 2A

Short-period Stations Operating at the End of the Third Quarter 1994

STA	F	LAT	LONG	EL	NAME
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
BBO	%	42 53 12.6	122 40 46.6	1.671	Butler Butte, Oregon
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 28.2	0.920	Black Rock Valley
BVW	+	46 48 39.6	119 52 59.4	0.670	Beverly
CBS	+	47 48 17.4	120 02 30.0	1.067	Chelan Butte, South
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.
CPW	%	46 58 25.8	123 08 10.8	0.792	Capitol Peak
CRF	+	46 49 30.0	119 23 13.2	0.189	Corfu
DBO	%	43 07 09.0	123 14 34.0	0.984	Dodson Butte, Oregon
DPW	+	47 52 14.3	118 12 10.2	0.892	Davenport
DY2	+	47 59 06.6	119 46 16.8	0.890	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 34.8	120 33 58.8	0.789	Ellensburg
EPH	+	47 21 22.8	119 35 45.6	0.661	Ephrata
ET3	+	46 34 38.4	118 56 15.0	0.286	Eltopia (replaces ET2)
ETW	+	47 36 15.6	120 19 56.4	1.477	Entiat
FBO	%	44 18 35.6	122 34 40.2	1.080	Farmers Butte, Oregon
FL2	%	46 11 47.0	122 21 01.0	1.378	Flat Top 2
FMW	%	46 56 29.6	121 40 11.3	1.859	Mt. Fremont
GBL	+	46 35 54.0	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	Grizzly Mountain, Oregon
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.
GUL	%	45 55 27.0	121 35 44.0	1.189	Guler Mt.
HAM	#	42 04 08.3	121 58 16.0	1.999	Hamaker Mt., Oregon
HBO	%	43 50 39.5	122 19 11.9	1.615	Huckleberry Mt., Oregon
HDW	%	47 38 54.6	123 03 15.2	1.006	Hoodsport
HOG	#	42 14 32.7	121 42 20.5	1.887	Hogback Mtn., OR
HSO	%	43 31 33.0	123 05 24.0	1.020	Harness Mountain, Oregon
HSR	%	46 10 22.2	122 10 58.2	1.774	South Ridge, Mt. St. Helens
HTW	%	47 48 14.2	121 46 03.5	0.833	Haystack Lookout
JBO	+	45 27 41.7	119 50 13.3	0.645	Jordan Butte, Oregon
JCW	%	48 11 42.7	121 55 31.1	0.792	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
LAB	#	42 16 03.3	122 03 48.7	1.774	Little Aspen Butte, Oregon
LCW	%	46 40 14.4	122 42 02.8	0.396	Lucas Creek
LMW	%	46 40 04.8	122 17 28.8	1.195	Ladd Mt.
LNO	+	45 52 18.6	118 17 06.6	0.771	Lincton Mt., Oregon
LOC	+	46 43 01.2	119 25 51.0	0.210	Rohay Station
LON	*	46 45 00.0	121 48 36.0	0.853	Longmire (SPZ 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 47.4	119 45 39.6	0.330	Midway
MEW	%	47 12 07.0	122 38 45.0	0.097	McNeil Island
MJ2	+	46 33 27.0	119 21 32.4	0.146	Rockwell Station
MOX	+	46 34 38.4	120 17 53.4	0.501	Moxie City
MPO	%	44 30 17.4	123 33 00.6	1.249	Mary's Peak, Oregon
MTM	%	46 01 31.8	122 12 42.0	1.121	Mt. Mitchell
NAC	+	46 43 59.4	120 49 25.2	0.728	Naches
NCO	%	43 42 14.4	121 08 18.0	1.908	Newberry Crater, Oregon
NEL	+	48 04 12.6	120 20 24.6	1.500	Nelson Butte
NLO	%	46 05 21.9	123 27 01.8	0.826	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
OD2	+	47 23 15.6	118 42 34.8	0.553	Odessa site 2
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
ONR	%	46 52 37.5	123 46 16.5	0.257	Olympics - North River

Table 2, continued

STA	F	LAT	LONG	EL	NAME
OOW	%	47 44 12.0	124 11 22.0	0.743	Octopus West
OSD	%	47 48 59.2	123 42 13.7	2.008	Olympics - Snow Dome
OSP	%	48 17 05.5	124 35 23.3	0.585	Olympics - Sooes Peak
OSR	%	47 30 20.3	123 57 42.0	0.815	Olympics Salmon Ridge
OT3	+	46 40 08.4	119 13 58.8	0.322	New Othello (replaces OT2 8/26/94)
OTR	%	48 05 00.0	124 20 39.0	0.712	Olympics - Tyee Ridge
PAT	+	45 52 55.2	119 45 08.4	0.262	Paterson
PGO	%	45 27 42.6	122 27 11.5	0.253	Gresham, Oregon
PGW	%	47 49 18.8	122 35 57.7	0.122	Port Gamble
PRO	+	46 12 45.6	119 41 08.4	0.553	Prosser
RC1	+	46 56 42.6	119 26 39.6	0.485	Royal City
RCM	%	46 50 08.9	121 43 54.4	3.085	Mt. Rainier, Camp Muir
RCS	%	46 52 15.6	121 43 52.0	2.877	Mt. Rainier, Camp Schurman
REM	#	46 11 57.0	122 11 03.0	2.102	Rembrandt (Dome station)
RER	%	46 49 09.2	121 50 27.3	1.756	Mt. Rainier, Emerald Ridge
RMW	%	47 27 35.0	121 48 19.2	1.024	Rattlesnake Mt. (West)
RNO	%	43 54 44.0	123 44 26.0	0.875	Roman Nose, Oregon
RPW	%	48 26 54.0	121 30 49.0	0.850	Rockport
RSW	+	46 23 40.2	119 35 28.8	1.045	Rattlesnake Mt. (East)
RVC	%	46 56 34.5	121 58 17.3	1.000	Mt. Rainier - Voight Creek
RVW	%	46 08 53.2	122 44 32.1	0.460	Rose Valley
SAW	+	47 42 06.0	119 24 01.8	0.701	St. Andrews
SEA		47 39 18.0	122 18 30.0	0.030	Seattle (Wood Anderson)
SHW	%	46 11 50.6	122 14 08.4	1.399	Mt. St. Helens
SMW	%	47 19 10.7	123 20 35.4	0.877	South Mtn.
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
SSO	%	44 51 21.6	122 27 37.8	1.242	Sweet Springs, Oregon
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
TBM	+	47 10 12.0	120 35 52.8	1.006	Table Mt.
TCO	%	44 06 21.0	121 36 01.0	1.975	Three Creek Meadows, Oregon.
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
TKO	%	45 22 16.7	123 27 14.0	1.024	Trask Mtn, Oregon
TWW	+	47 08 17.4	120 52 06.0	1.027	Teanaway
VBE	%	45 03 37.2	121 35 12.6	1.544	Beaver Butte, Oregon
VCR	%	44 58 58.2	120 59 17.4	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
VRC	#	42 19 47.2	122 13 34.9	1.682	Rainbow Creek, Oregon
VSP	#	42 20 30.0	121 57 00.0	1.539	Spence Mtn, Oregon
VT2	+	46 58 02.4	119 59 57.0	1.270	Vantage2
VTH	%	45 10 52.2	120 33 40.8	0.773	The Trough, Oregon
WA2	+	46 45 19.2	119 33 56.4	0.244	Wahluke Slope
WAT	+	47 41 55.2	119 57 14.4	0.821	Waterville
WG4	+	46 01 49.2	118 51 21.0	0.511	Wallula Gap
WIB	%	46 20 34.8	123 52 30.6	0.503	Willapa Bay (3 components)
WIW	+	46 25 45.6	119 17 15.6	0.128	Wooded Island
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 12.0	119 08 41.4	0.375	Warden
YA2	+	46 31 36.0	120 31 48.0	0.652	Yakima
YEL	#	46 12 35.0	122 11 16.0	1.750	Yellow Rock, Mt. St. Helens

TABLE 2B

Broad-band three-component stations operating at the end of the third quarter 1994

STA	F	LAT	LONG	EL	NAME
COR		44 35 08.5	123 18 11.5	0.121	Corvallis, Oregon (IRIS station, Operated by OSU)
DBO	%	43 07 09.0	123 14 34.0	0.984	Dodson Butte, Oregon (Operated by UO)
LON	*	46 45 00.0	121 48 36.0	0.853	Longmire, WA (operated by UW)
LTY	*	47 15 21.2	120 39 53.3	0.970	Liberty, WA (operated by UW)
SSW	*	46 58 20.4	123 26 01.8	0.120	Satsop, WA (operated by UW)
TTW	*	47 41 40.7	121 41 20.0	0.542	Tolt Res, WA (operated by UW)
PIN		43 48 40.0	120 52 19.0	1.865	Pine Mt. Oregon (operated by UO)

EARTHQUAKE DATA

There were 1,664 events digitally recorded and processed at the University of Washington between July 1 and September 31, 1994. Locations in Washington, Oregon, or southernmost British Columbia were determined for 821 of these events; 656 were classified as earthquakes and 165 known or suspected blasts. The remaining 843 processed events include teleseisms (155 events), regional events outside the PNSN (103), and unlocated events within the PNSN. Unlocated events within the PNSN include very small earthquakes and some known blasts. For example, only a few of the frequent mine blasts at Centralia are routinely processed.

Activity in the Klamath Falls area continued to decline in the third quarter of 1994. In September of *1993*, a pair of damaging earthquakes (Sept. 21, 03:29 and 05:45 UCT; M_c 5.9 and 6.0 respectively), occurred in the area, and were followed by a vigorous aftershock sequence. Activity has declined from 1,215 locatable earthquakes in the first quarter of 1994, to 354 in the second quarter and 197 in the third quarter. Table 4, located at the end of this report, is the catalog of earthquakes and blasts located within the network for this quarter. For the Klamath Falls area, only earthquakes of magnitude 1.6 and larger have been included in Table 4.

Fig. 2 shows all earthquakes with magnitude greater than or equal to 0.0 ($M_c \geq 0.$) Fig. 3 shows blasts and probable blasts ($M_c \geq 0.$) Fig. 4 shows earthquakes located near Mt. Rainier ($M_c \geq 0$). Fig. 5 shows earthquakes located at Mt. St. Helens ($M_c \geq 0$).

MOMENT TENSOR FOCAL MECHANISM SOLUTIONS

Moment-tensor focal mechanisms for earthquakes with $M_w > 3.5$ in the Pacific Northwest are included in this report. These solutions were computed under other support (USGS NEHRP Grant 1434-93-G-2326), at the Oregon State University under the direction of Dr. John Nabelek. The operation of broadband stations in Oregon (COR, DBO and PIN) was in part supported by a grant from the Oregon Department of Geology and Mineral Industries.

Moment-tensor solutions use data from 3-component broad-band stations in Washington, Oregon, California and British Columbia and from US National Seismic Network stations in the western US (Figure 6). The inversions are performed in the 0.01 - 0.1 Hz range, with the frequency band adjusted according to earthquake magnitude and station epicentral distance.

Moment tensors, best-fit double-couple mechanisms, M_w, seismic moments, and depths are given in Table 3. The coordinate conventions of Aki and Richards (Quantitative Seismology: Theory and Methods, W. H. Freeman, San Francisco, 1980) are followed. Figure 7 shows locations and focal mechanisms for the events listed in Table 3. Events 3,4,5,7, and 9 were relocated and are marked with R. Events 1 through 4 which occurred in February, were analyzed since the last quarterly report.

OREGON SEISMICITY

During the third quarter of 1994, 208 earthquakes were located in Oregon between 42.0° and 45.5° north latitude and between 117° and 125° west longitude. Of these, 11 were located outside the Klamath Falls area. Activity in the Klamath Falls area continued to fall off, and no events larger than magnitude 2.5 occurred there during the third quarter. Magnitude 2.5 earthquakes on July 5 at 18:05 UCT and on August 8 at 03:17 UCT were not reported felt.

A special issue of **Earthquakes and Volcanos** (Vol. 24, No. 3, 1993) with several articles on the Klamath Falls sequence is available. Subscriptions to **Earthquakes and Volcanos** are available from the Supt. of Documents, US Government Printing Office, Washington, DC 20402. Individual issues can be ordered from the USGS Map Distribution, Box 25286, Bldg. 810, Denver Federal Center, Denver, CO 80225.