FINAL TECHNICAL REPORT: 1985

Name of Contractor: University of Washington

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Summary

This is the final technical report for USGS contract 14-08-0001-21861 "Regional Seismic Monitoring in Western Washington" which covers network operation, routine data processing, and preparation of bulletins and reports. The objective of our work under this contract by to gather data for use in the evaluation of seismic hazards in western Washington, research carried out under contract 14-08-0001-22007 entitled "Earthquake Hazard Investigation in the Pacific Northwest", and by other projects. Since 1984, we have issued quarterly bulletins for all of Washington and the northern part of Oregon. These include catalogs of earthquakes and blasts located in Washington and Northern Oregon, and provide up-to-date coverage of seismic and volcanic activity. Appendix 1 comprises quarterly bulletins covering the contract period.

Final annual bulletins of seismicity for the years from 1980 through 1985 are being prepared for publication by the Washington State Department of Natural Resources. Each annual bulletin will include final event locations for all of Washington and the northern part of Oregon. as well as maps showing event locations and station coverage. A separate publication, also to be issued by the Dept. of Natural Resources, will cover technical aspects of data processing procedures, and will include descriptions of recently updated velocity models, and station corrections for each model.

Operations

The University of Washington records a total of 112 seismic stations, including WWSSN station LON and two Wood-Anderson seismometers at SEA and NEW. Twenty-seven key stations covering much of western Washington are supported under this contract, with a twenty-eighth station to be installed in 1986. Details of station operation for all stations are included in the Quarterly Reports in Appendix 1. A summary of station installation dates and outages from November 1984 through October 1985 is given in Table 1 for stations operated under this contract. Several stations which were inoperable for several months in winter were repaired as weather allowed. All stations under this contract were operating at the end of the contract period.

Three new stations were installed in 1985; one on McNeil Island in south Puget Sound (MEW), one near Port Gamble on the southern Kitsap Peninsula (PGW), and one in the Skagit Valley (RPW). RPW, in the Skagit Valley, permanently replaced temporary station BLS, installed earlier in the year. A new microwave link provided by Puget Power now provides the telemetry route. Site approval for an additional station in the Cultus Mountains just south of the Skagit Valley has been received, and the station will be installed in the spring of 1986, when the site is accessible.

TABLE 1
Western Washington Network
Major station outages and changes, November 1, 1984 - October 31, 1985

Station	Date	Comments
APW	11/04/84-04/12/85	Out
	07/10/85-08/30/85	Out
BLS	03/20/85	Temporary Station Installed
	08/08/85	Replaced by RPW
GHW	07/11/85-09/06/85	Out
HDW	01/01/85-06/30/85	Out
HTW	07/01/85-08/15/85	Out
	09/18/85-09/30/85	Out
MEW	03/05/85	Installed
NLO	01/20/85-08/15/85	Out
OSD	09/04/85-09/15/85	Out
PGW	-04/12/85	Installed
RMW	10/01/84-11/07/84	Out
RPW	08/22/85	Installed
RVW	11/16/84-04/12/85	Out
STW	10/01/84-03/16/85	Out

Data Processing

The seismographic network operated by the University of Washington consists of 110 short-period, vertical component, telemetered seismographic stations. Data is recorded by a DEC PDP 11/34 computer operating in an "event triggered" mode, recording data (at 100 samples per sec.) only when an event is detected. The digital recording system is closely modeled after the CEDAR system developed at the California Institute of Technology by Carl Johnson. Arrival times, first motion polarities, and signal durations are determined using interactive computer programs on a PDP 11/70 computer. Events are classified into the following categories: teleseisms (epicentral distance greater than 1000 km), regionals (distance less than 1000 km), and local events (epicenter within network). Most local events large enough to be well recorded on at least three stations are analyzed and located. The location program, based on the standard non-linear least-squares inversion scheme of Geiger (1912), has been optimized for use with Washington array data. The accuracy of locations determined with this program varies, and depends on the accuracy of the crustal model, the station distribution around the epicenter, station spacing, number of stations used, and quality of arrival time data.

Digital data is saved for all teleseisms, regional events, and all locatable local events. Each data file has a "pickfile" which includes arrival times, polarities, and coda lengths for each station read. Times are not routinely read for teleseisms or regional events, but the pickfile may list stations on which the signal is visible.

Prior to 1980, arrival time, polarity and coda length for each station were punched on a card, and a deck of cards was read into a computer to locate each event. Until recently, some pickfile data prior to 1980 was available only on computer cards. We are working to make all of this old data available in the current network format on disk or magnetic tape where it can be accessed conveniently. Maintenance of a consistent data base is essential to evaluation of seismic hazards. Data from June, 1975 through December 1979 are now available, and in current format. We are working on the translation of pickfiles from 1970-1975 for eastern Washington into our format, these events were picked from develocorder film at the USGS in Menlo Park. We will check eastern Washington pickfiles, 1970-June 1975, against available pickfiles for western Washington, generated here at the U.W.

Magnitude Threshold Analysis

An estimate of magnitude completeness levels statewide was presented in the 1984 Final Technical Report for contracts 04-01-00008-21861 and 04-01-0008-21862. The same type of analysis has now been done for three five-year periods, 1970-74, 1975-79, and 1980-84. These periods, besides being consistent in length, also delimit major changes in network coverage. Figures 1, 2, and 3 show the completeness estimates, while Tables 2, 3, and 4 give the data in tabular form.

TABLE 2
1970-1974

AREA	# OF EVENTS	COMPLETE AT	AREA	# OF EVENTS	COMPLETE AT
A1	0	-	E1	0	-
A2	2	-	E2	23	(2.5)
A3	1	-	E3	15	(1.8)
A4	0	-	E4	3	-
A5	0	-	E5	0	-
B1	33	2.1	F1	1	-
B2	37	1.8	F2	26	1.8
B3	10	(2.5)	F3	1112	.8
B4	1	-	F4	6	(2.0)
B5	0	-	F5	0	-
C1	91	2.1	G1	0	-
C2	582	1.7	G2	2	-
C3	93	1.9	G3	76	2.0
C4	6	(2.7)	G4	1	-
C5	0	-	G5	0	-
D1	22	(2.2)	H1	0	-
D2	177	2.2	H2	0	-
D3	78	2.1	H3	2	-
D4	2	-	H4	0	-
D5	0	-	H5	1	-

This analysis makes use of our recent effort to compile a consistent data set by reformatting, relocating, and thoroughly checking pick files from 1970-1979. The data sets for 1975-1979 and 1980-1984 are comprised of pickfiles relocated with our current models. From 1970-1974, only western Washington pickfiles were available for relocation and checking, as the eastern Washington data was recorded and located by the USGS in Menlo Park. Existing summary cards located with previous velocity models were therefore used for eastern Washington events, with a few obvious duplicate (eastern and western pickfiles for the same event) summary cards omitted.

1970-1974

2403 EVENTS

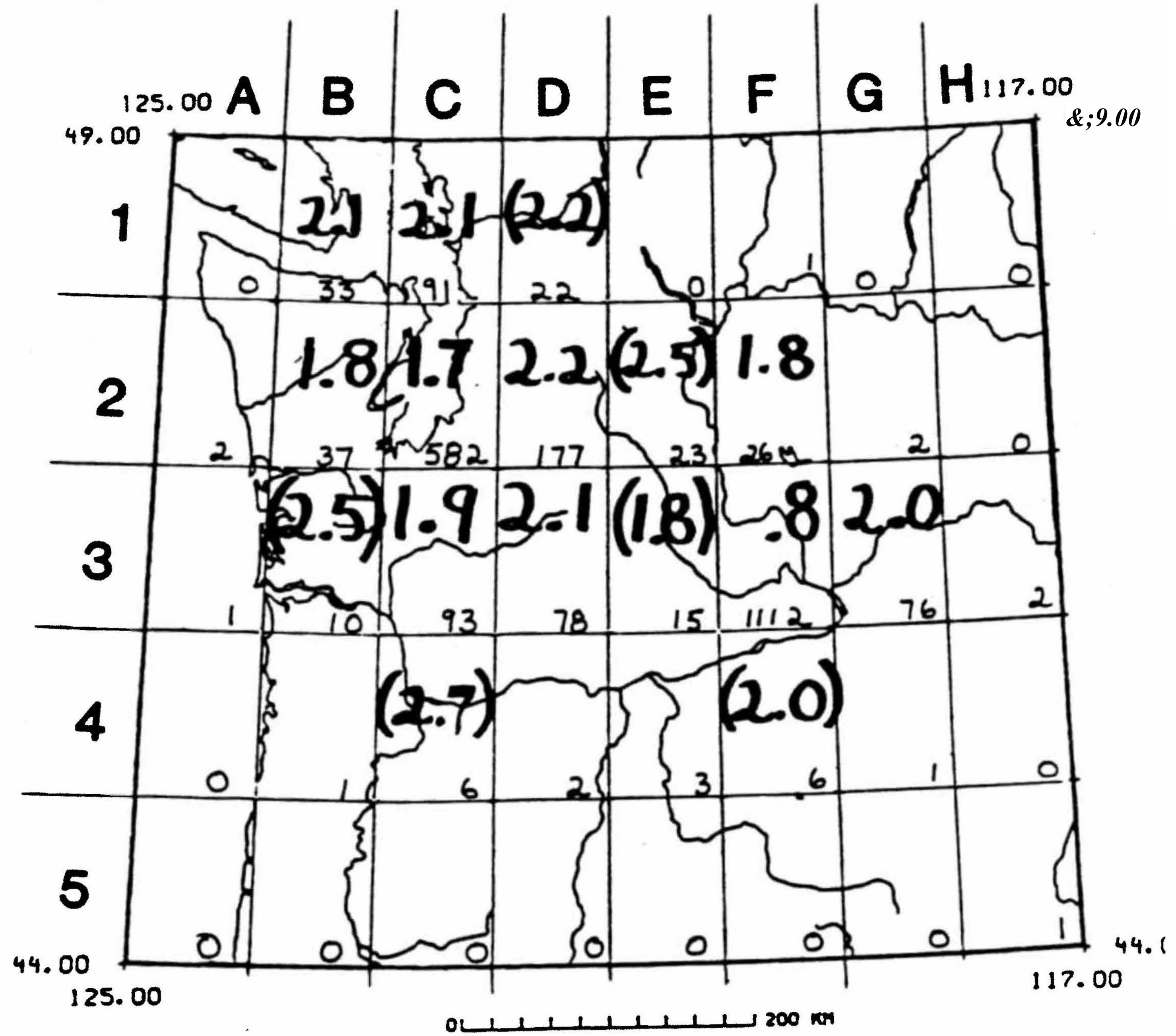

Figure 1. Estimated magnitude completeness levels (large numbers), and number of located events 1970-1974 (small numbers). Magnitude completeness levels were estimated on the basis of log N vs. M plots when 25 or more events were located in an area. Where fewer than 25 events occurred 1.0 magnitude unit was added to the smallest located event in the area, and the magnitude completeness level is shown in parenthesis. The value of 1.0 magnitude unit is an average from the areas with 25 or more events, representing the difference between the smallest event located, and completeness magnitude.

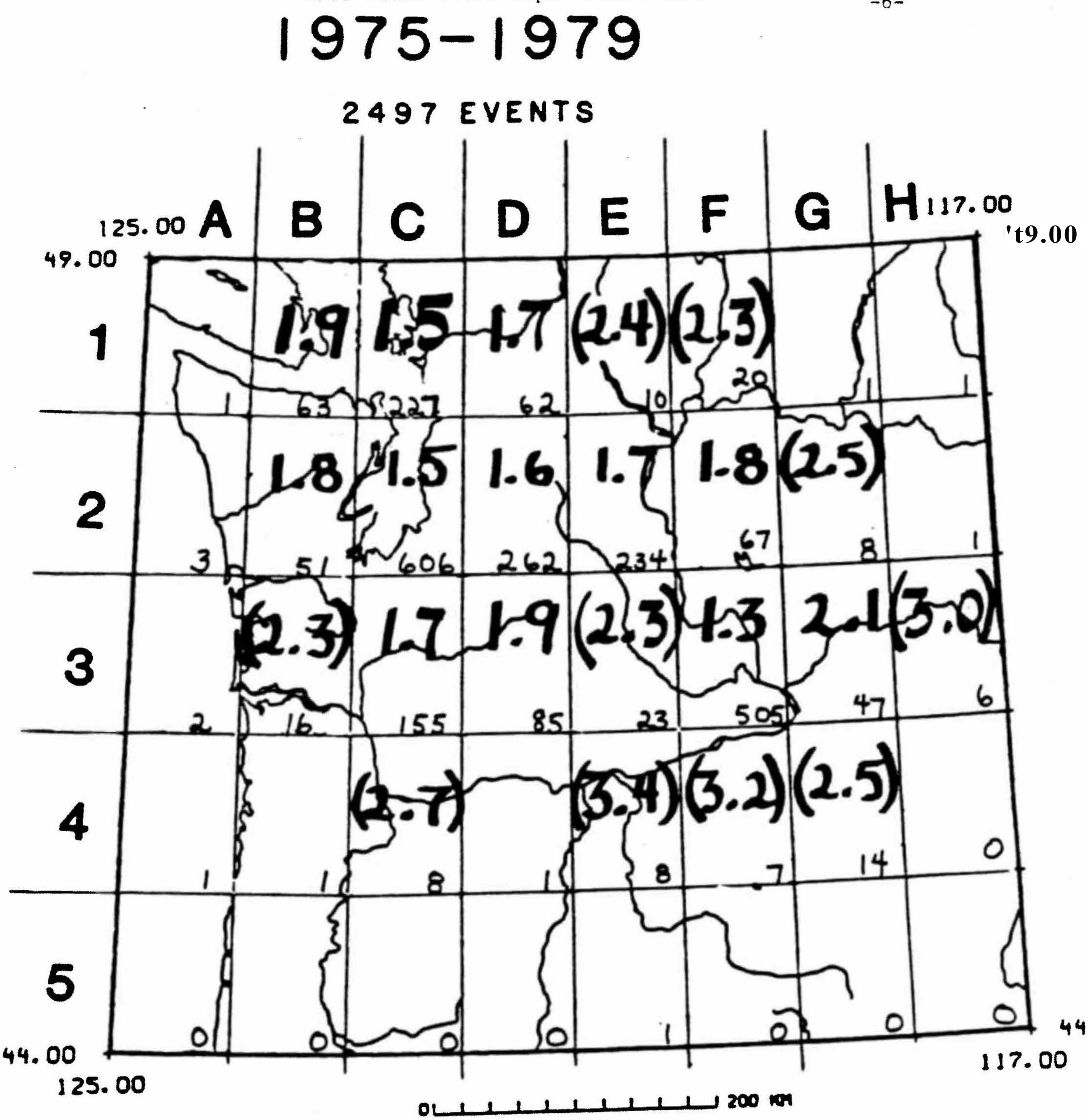

Figure 2. Estimated magnitude completeness levels (large numbers), and number of located events 1974-1979 (small numbers). Magnitude completeness levels were estimated on the basis of log N vs. M plots when 25 or more events were located in an area. Where fewer than 25 events occurred 1.3 magnitude units were added to the smallest located event in the area, and the magnitude completeness level is shown in parenthesis. The value of 1.3 magnitude units is an average from the areas with 25 or more events, representing the difference between the smallest event located, and completeness magnitude.

1980-1984

9997 EVENTS

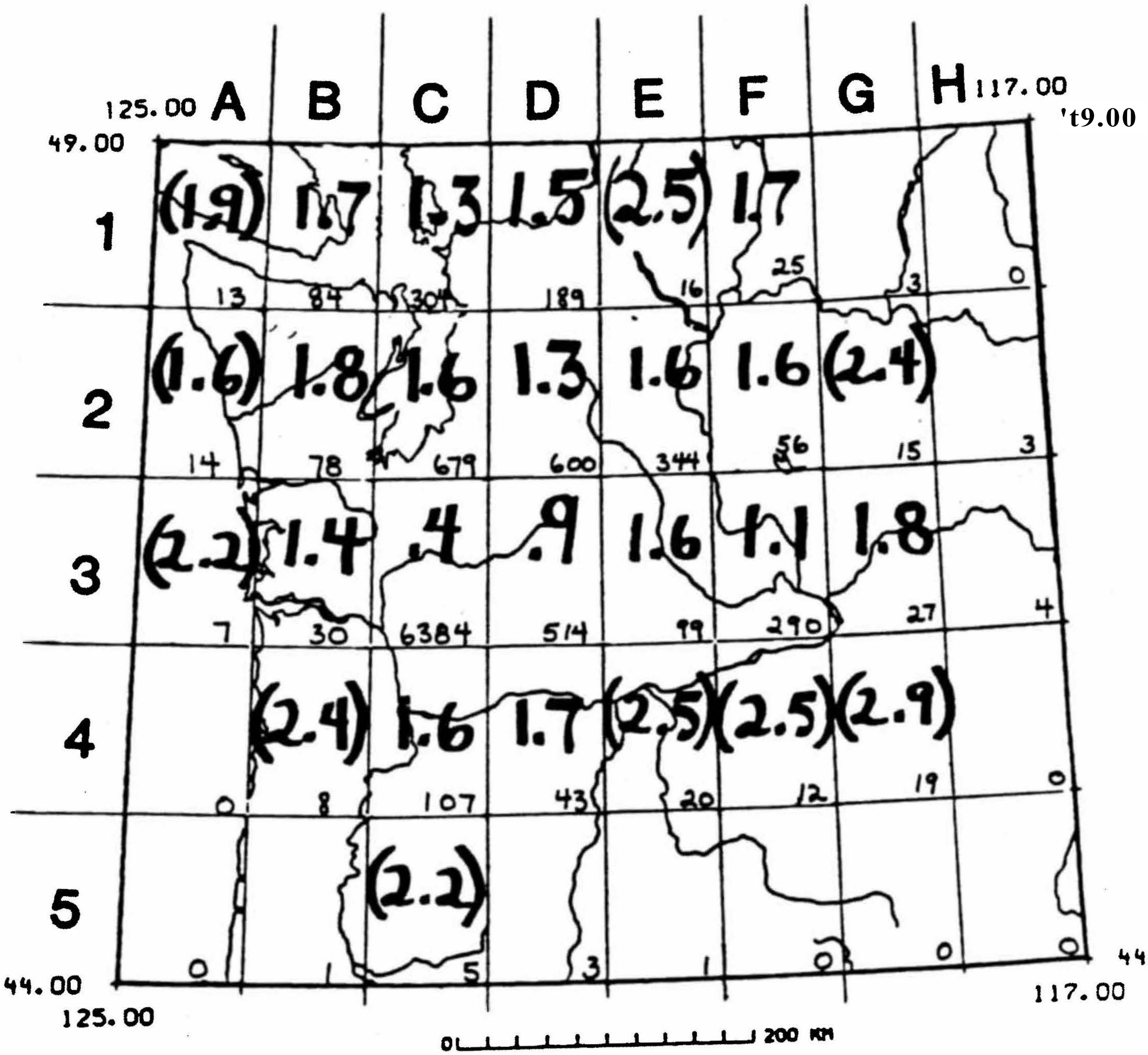

Figure 3. Estimated magnitude completeness levels (large numbers), and number of located events 1980-1984 (small numbers). Magnitude completeness levels were estimated on the basis of log N vs. M plots when 25 or more events were located in an area. Where fewer than 25 events occurred 1.4 magnitude units were added to the smallest located event in the area, and the magnitude completeness level is shown in parenthesis. The value of 1.4 magnitude units is an average from the areas with 25 or more events, representing the difference between the smallest event located, and completeness magnitude.

TABLE 3
1975-1979

AREA	# OF EVENTS	COMPLETE AT	AREA	# OF EVENTS	COMPLETE AT
A1	1	-	E1	10	(2.4)
A2	3	-	E2	234	1.7
A3	2	-	E3	23	(2.3)
A4	1	-	E4	8	(3.4)
A5	0	-	E5	1	-
B1	63	1.9	F1	20	(2.3)
B2	51	1.8	F2	67	1.8
B3	16	(2.3)	F3	505	1.3
B4	1	-	F4	7	(3.2)
B5	0	-	F5	0	-
C1	227	1.5	G1	1	-
C2	606	1.5	G2	8	(2.5)
C3	155	1.7	G3	47	2.1
C4	8	(2.7)	G4	14	(2.5)
C5	0	-	G5	0	-
D1	62	1.7	H1	1	-
D2	262	1.6	H2	1	-
D3	85	1.9	H3	6	(3.0)
D4	1	-	H4	0	-
D5	0	-	H5	0	-

TABLE 4
1980-1984

AREA	# OF EVENTS	COMPLETE AT	AREA	# OF EVENTS	COMPLETE AT
A1	13	(1.9)	E1	16	(2.5)
A2	14	(1.6)	E2	344	1.6
A3	7	(2.2)	E3	99	1.6
A4	0	-	E4	20	(2.5)
A5	0	-	E5	1	-
B1	84	1.7	F1	25	(1.7)
B2	78	1.8	F2	56	1.6
B3	30	1.4	F3	290	1.1
B4	8	(2.4)	F4	12	(2.5)
B5	1	-	F5	0	-
C1	304	1.3	G1	3	-
C2	679	1.6	G2	15	(2.4)
C3	6384	.4	G3	27	1.8
C4	107	1.6	G4	19	(2.9)
C5	5	(2.2)	G5	0	-
D1	189	1.5	H1	0	-
D2	600	1.3	H2	3	-
D3	514	.9	H3	4	-
D4	43	(1.7)	H4	0	-
D5	3	-	H5	0	-

The region between 44° and 49° N latitude and between 117° and 125° W longitude was divided into one degree quadrangles, and a magnitude completeness level was determined for each quadrangle for each of the three five-year periods. Two methods were used to evaluate magnitude completeness, depending on number of located events. In areas where at least 25 events occurred the linear relation;

$$\log N = A - bM$$

where N is the number of earthquakes of magnitude M or greater (A and b are constants) was used. Reduced network sensitivity to events of small magnitude results in a departure from linearity. By plotting log N versus M; the magnitude level of completeness is determined empirically to be the point where the linear relation no longer holds. Where 25 or fewer events occurred the linear relation is difficult to determine, and another method was used.

Using regions where the first method applies, the average difference between the magnitude completeness level and the smallest event located in an area was determined. In the second method, this value was added to the magnitude of the smallest located event in sub-regions where 25 or fewer events occurred to give an estimate of completeness.

Where 25 or fewer events were located, the magnitude completeness is in parenthesis, and was determined by the second method. No completeness-level estimates are given for areas with less than 5 events.

From 1969 through 1974, the USGS operated a small, dense network in eastern Washington, near Hanford. In 1975 responsibility for operating this network was transferred to the University of Washington. Station coverage in the immediate Hanford area become somewhat less dense, and equipment was relocated to provide better over-all coverage of eastern Washington. This shift is visible in the changes in magnitude detection levels between Figures 1 and 2.

In 1980, the UW Network changed to a digitally recorded, triggered system. Also in early 1980, Mt. St. Helens became active. Over six thousand events were located in the Mt. St. Helens

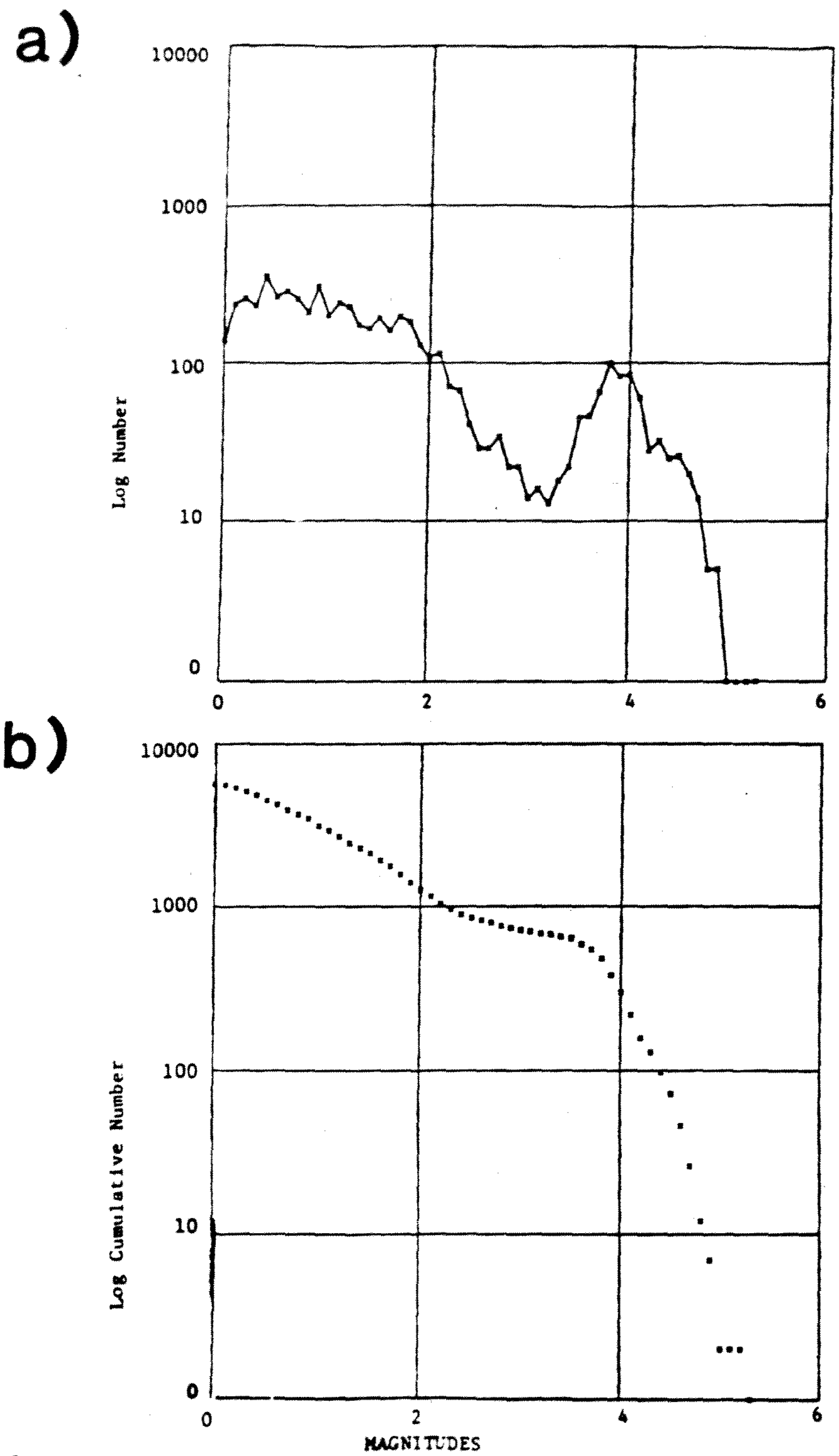

Figure 4. a) Log Number versus Magnitude plot for the area called 'B3' in Fig. 3 and Table 4; between 122° and 123° W longitude, and between 46° and 47° N latitude. This area includes Mt. St. Helens, which erupted violently in 1980, and is currently active. Over six thousand earthquakes and blasts were located in this quadrangle from 1980 through 1984 by the Seismographic Network of the University of Washington. b) Log Cumulative Number versus Magnitude for the same area.

region between 1980 and 1984. About 15 stations were installed in the vicinity during 1980, with additional data provided by about 9 temporary 5-day stations run by the USGS between March and July, 1980. We can detect and reliably locate extremely small events in this region. However, during eruptions; and especially in 1980; earthquakes often occurred nearly continuously. During these intervals, the network is frequently de-sensitized so that only larger events trigger the on-line recording system. During 1980, in the period of intense activity which preceded the catastrophic eruption of May 18th, only events of magnitude 4 or larger have been located. These changes in sensitivity and location are clearly visible in the b-value and log number (not cumulative) versus magnitude graphs shown in Fig. 4.

Calibrated stations

The U.W. seismic network contains about 35 stations which are calibrated. About half of these are composed of calibrated S-13 seismometers with SLU VCOs, while the others have L4 seismometers with either a J402, J302, or 6202 VCO. Damping values range from .668 to .888, at least six different discriminator types are in use, and some stations have an additional anti-aliasing filter. Adding to the complexity, any one of the components may be changed over the course of time. A program to calculate the response curve for any combination of components has been developed under another contract, and a feature to keep track of changes in components through time is also being incorporated. Rob Leet, a graduate student, empirically measured the response of the discriminators and VCOs, and wrote the software with guidance from Tony Qamar, a Senior Research Associate. Table 5 gives counts per meter of ground motion at 1 Hz on the PDP 11/34 used for seismic processing, and the magnification at 1 Hz on our standard hard-copy graphics output ('punt') at unit attenuation. One check of the magnifications has been done using teleseismic arrivals, which may be assumed to have a nearly constant amplitude across the network. Some discrepancies in amplitudes were noted, and amplitudes of additional teleseismic arrivals will be measured to determine the cause.

TABLE 5
Calibrated Stations

Station	Counts/Meter	Punt Magnification
APW	0.31791E+09	40533.445
BHW	0.15933E+09	20314.861
BLN	0.12807E+10	163287.688
RPW	0.25384E+10	323650.531
BOW	0.12569E+10	160255.750
CDF	0.63357E+09	80780.680
ETT	0.44683E+09	56970.555
FMW	0.14704E+10	187476.844
FOR	0.44006E+09	56107.789
GBL	0.44902E+09	57249.871
GHW	0.79855E+08	10181.542
GL2	0.41973E+09	53516.027
GMW	0.12719E+10	162163.734
GSM	0.63745E+09	81274.352
HDW	0.12654E+10	161332.125
HTW	0.62995E+09	80318.102
JCW	0.12719E+10	162163.734
KMO	0.54730E+09	69780.477
LMW	0.64205E+09	81860.828
MBW	0.20164E+09	25708.502
MCW	0.12719E+10	162163.734
MDW	0.57895E+08	7381.583
MEW	0.40232E+08	5129.523
NLO	0.31572E+09	40254.441
OBC	0.66896E+10	852919.375
OHW	0.79306E+08	10111.460
OSD	0.12812E+10	163348.828
PGW	0.11750E+09	14981.272
RMW	0.12719E+10	162163.734
RVW	0.31791E+09	40533.445
SMW	0.31750E+09	40481.031
STW	0.63745E+09	81274.352
TDL	0.34986E+09	44607.594
WA2	0.21378E+09	27257.059

Publications

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

Acknowledgements

Laurens Engel is to be especially commended for his work maintaining and installing seismic stations, and telemetry and other network equipment in every kind of weather. Rick Benson, Pandy Rathbun, Chris Jonientz-Trisler, and Cindy Roe helped compile data for the quarterly reports, which were written by Ruth Ludwin and Tony Qamar.

APPENDIX 1

U. W. Seismic Network Quarterly Reports

84-D, **85-A, 85-B, 85-C**

QUARTERLY NETWORK REPORT 84-D
on
Seismicity of Washington and Northern Oregon

October 1 through December 31, 1984

Geophysics Program
University of Washington
Seattle, Washington

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

U.S. GEOLOGICAL SURVEY
CONTRACT NO. 14-08-0001-21861
and
CONTRACT NO. 14-08-0001-21862
and
CONTRACT NO 14-08-0001-19848

and

U.S. DEPARTMENT OF ENERGY
CONTRACT NO. EY-76-S-06-2225
TASK AGREEMENT NO. 39

and

U.S. NUCLEAR REGULATORY AGENCY
UNDER CONTRACT NO. NRC-04-81-177

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INTRODUCTION

This is the fourth quarterly report of 1984 from the University of Washington Geophysics Program covering seismicity of all of Washington and northern Oregon. From 1975 through 1983 seismicity in eastern Washington has been covered in quarterly and annual reports. Quarterly reports for western Washington and the northern Cascades have been produced since 1983, and annual catalogs covering western Washington since 1969. This report discusses network operations, seismicity of the area, and any unusual events or findings. These reports are preliminary, and not a substitute for detailed technical reports, a regional catalog, or technical papers. In particular, event magnitudes are preliminary, and subject to revision. Some earthquake locations may be revised if new data become available, such as P and S readings from Canadian seismic stations. Findings mentioned in these quarterly reports should not be cited for publication. Figure 1 shows the major geographical features in the state of Washington and northern Oregon and the seismograph stations currently in operation.

NETWORK OPERATIONS

Table 1 shows station outages during the fourth quarter. Brief outages are not shown. Teleseismic arrivals are checked to determine when outages start, and repair records to determine repair date. Because many stations are in the Olympic and Cascade Mountains, where winter conditions are extremely severe, stations cannot be serviced in the winter. Outages and intermittent operation are sometimes caused by snow and ice covering telemetry equipment. Table 3 on page 21 gives location information for stations.

Western Washington and Northern Oregon

Seismographs in western Washington generally operated well in the fourth quarter. The Snow Dome station on Mount Olympus (OSD) which was installed last

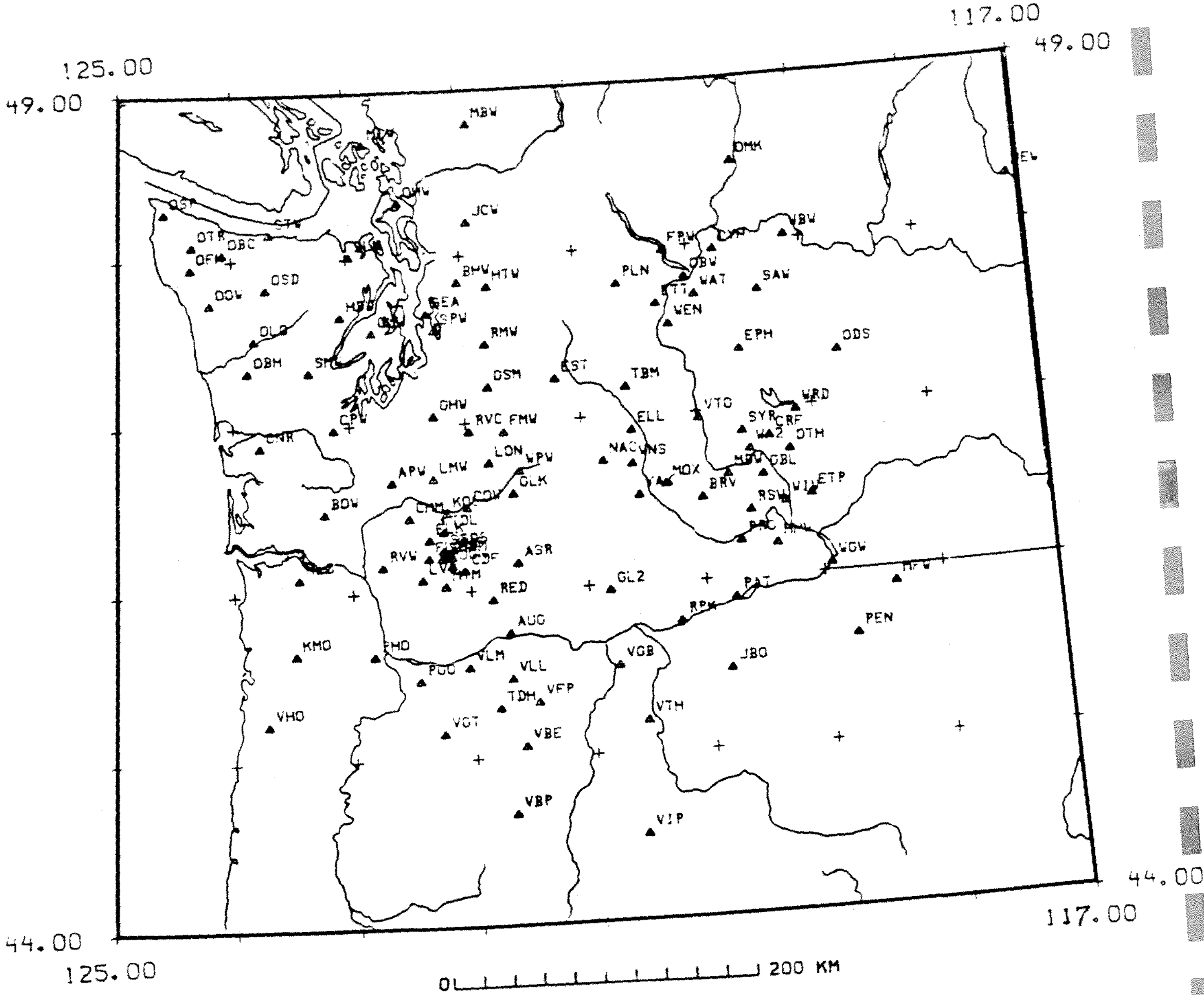

Figure 1. Seismograph stations operating during the fourth quarter 1984.

TABLE 1
Western Washington Network
Major station outages and changes, October 1, 198~~3~~4 - December 30, 1984

Station	Outage Dates	Comments
	Western Washington	
APW	11/04/84-12/31/84	Dead
STW	10/01/84-12/31/84	Destroyed by machinery in August
RMW	10/01/84-11/07/84	Repaired, VCO
RVW	11/16/84-12/31/84	Dead
	Olympic Peninsula	
OBC	10/01/84-12/31/84	Intermittent
OSD		Installed 9/14/84, Began Operation
OSP	10/01/84-12/31/84	Intermittent
ONR	10/01/84-11/10/84	Repaired, VCO
	Mt. St Helens	
ASR	10/01/84-12/31/84	Intermittent Entire Quarter
ELK	10/01/84-10/09/84	Repaired, VCO
KOS	10/01/84-12/31/84	Intermittent Entire Quarter
LVP	10/01/84-12/31/84	Dead Entire Quarter
RED	10/01/84-12/31/84	Dead Entire Quarter
	Northern Oregon	
AUG	10/01/84-12/02/84	Repaired
KMO	10/01/84-12/31/84	Intermittent
PGO	10/01/84-11/20/84	Repaired, VCO
PHO	10/01/84-11/20/84	Repaired, Seismometer
TDH	10/01/84-12/31/84	Intermittent Entire Quarter
VIP	10/01/84-12/31/84	Intermittent Entire Quarter
VTH	10/01/84-12/31/84	Intermittent Entire Quarter
VBE	10/01/84-12/31/84	Dead Entire Quarter
VBP		Discontinued Permanently in Oct.
VFP	10/01/84-12/31/84	Equipment Removed
VGT	10/01/84-12/31/84	Discontinued
VHO	10/01/84-12/31/84	No Telemetery Path
VLL	10/01/84-12/31/84	Dead Entire Quarter
VLM	10/01/84-12/31/84	Discontinued
VLO		Discontinued Permanently
	Eastern Washington	
DYH	10/01/84	Seismometer replaced
ODS	10/01/84-10/30/84	Repaired, Tx
PEN	11/01/84-11/08/84	Batteries
VTG	12/09/84-12/21/84	Batteries
WRD	10/01/84-10/16/84	Batteries

quarter began operation in October, enhancing coverage of the northern Olympic Peninsula. A site has been selected for a new station on McNeil Island in the south Puget Sound area. Site approval is being sought, and radio frequencies have been requested for this site and another new site to be situated near Port Gamble on the Kitsap Peninsula. Station BLS in the Skagit Valley, which was installed in 1983 to replace RPW but never activated, is now operable and awaiting installation of a telemetry link at the Puget Power microwave site on Mt. Erie near Anacortes. Signals from Mt. Erie will be transmitted through Redmond to the University of Washington. A new site is being sought for station LYW lost with RPW in 1982 through termination of a phone line. In southwestern Washington, several stations were inactive or intermittent during the quarter. Most of these were continuing problems from previous quarters, but Alpha Peak station (APW), east of Chehalis, ceased functioning at the beginning of November (probably due to vandalism), RVW also lost function in November, and ELK was repaired in early October. Station STW, on the northern Olympic peninsula, remained out. Several other stations on the Olympic Peninsula were intermittent, and ONR was repaired.

The U.S.G.S. and the D.O.E. have signed a joint use agreement with the Bonneville Power Administration (B.P.A.). Under the agreement, most existing telephone data lines from Washington and northern Oregon will be replaced by microwave links. The new system should be available in summer of 1985. An additional description of planned links is contained in the *Annual Technical Report, 1984, on Earthquake Monitoring of Eastern and Southern Washington, prepared for he U.S. D.O.E. under contract no. EY-76-S-06-2225 and U.S. N.R.C. contract no. NRC-04-81-177, Geophysics Program, University of Washington.* This new system will facilitate a revamping of seismic coverage of northern Oregon, as well as providing an improvement in dynamic range. Because of the planned realignment of stations in northern Oregon to take advantage of microwave transmission and personnel limitations, little maintenance was done in 1984. Three stations in northern Oregon were inoperative for the entire quarter, five others have been discontinued either permanently or temporarily, and four were intermittent during the fourth quarter. The new transmission equipment should dramatically improve data quality for northern Oregon during the next year.. On the positive side, repairs were made to stations AUG and PGO in northern Oregon during this quarter, and a bottoming seismometer at PHO was replaced.

Eastern Washington

The maintenance contract with Stanwyck Corporation covering seismic stations in eastern Washington expired in mid-December. The University of Washington is in the process of hiring a technician who will be based in eastern Washington to maintain these stations. Eastern Washington will also be affected by the shift from phone-line to microwave transmission using Bonneville Power Administration equipment. Equipment changeover will create an extra workload for the technicians. Outages were minimal, and stations in eastern Washington operated well during the fourth quarter.

EARTHQUAKE DATA

There were 427 events processed by the University of Washington seismic network between October 1 and December 31, 1984. We determined locations for 291 of these in Washington and Northern Oregon; 209 were classified as earthquakes and 82 as known or suspected blasts. The remaining unlocatable events were regional events outside the U. W. network, or teleseisms. Routine scanning of film records was discontinued this quarter because film recording is being phased out. As a result only 7 earthquakes were hand-picked from film records. The few events which were hand-picked did not trigger the on-line system, but were detected on helicorder records. Helicorder records are scanned daily to ensure that significant events are not missed by the online system. Table 2 is the event catalog for this quarter. Figure 2 shows all earthquakes greater than magnitude 1.0. Figure 3 shows blasts and probable blasts. Figure 4 shows all earthquakes located in western Washington. Figure 5 shows all earthquakes located in eastern Washington.

Figure 6 shows earthquakes located at Mount St. Helens.

Western Washington and Oregon

During the fourth quarter of 1984 171 events were located between 44° and 49° latitude and between 121° and 125° longitude. The most significant sequence included two felt earthquakes, magnitudes 3.1 and 3.2, which occurred near Concrete in Whatcom County on Dec. 2 and Dec. 3. Five other events were located during the quarter in a tight cluster at the same spot, including a magnitude 2.9 on Dec. 23. A preliminary focal mechanism solution for the December 2nd event indicates thrust faulting with a NW-SE P axis.

On November 17, a low-frequency event of M_C = 3.1 was located near Mt. Rainier. This event was well recorded on only four stations, and had a lower peak amplitude than would normally be expected for an earthquake with a long coda, suggesting a landslide or rockfall, which would account for these characteristics. During the quarter, 17 events greater than or equal to magnitude 1.0 occurred in the vicinity of Mt. Rainier, although none were reported felt. The highest activity rate was 15 countable events per month. This can be compared to other swarms in the same area, such as the one in Dec. 82 - Jan. 83. Within three months, 12 earthquakes above M_C 1.0 occurred, with activity rates as high as 50 countable earthquakes per month.

Scattered activity continued as usual in the Puget lowland and Cascades. The largest earthquake in the Puget Basin was a M_C = 3.2 event on December 17 located at a depth of 45 km near Henderson Bay on the southeastern part of the Kitsap Peninusla. A preliminary focal mechanism indicates a NE-SW P axis. In the Cascades, there was a clear concentration of earthquakes along a zone extending NNW from Mount St. Helens.

Two unusual deep earthquakes were located in south-western Washington dur-

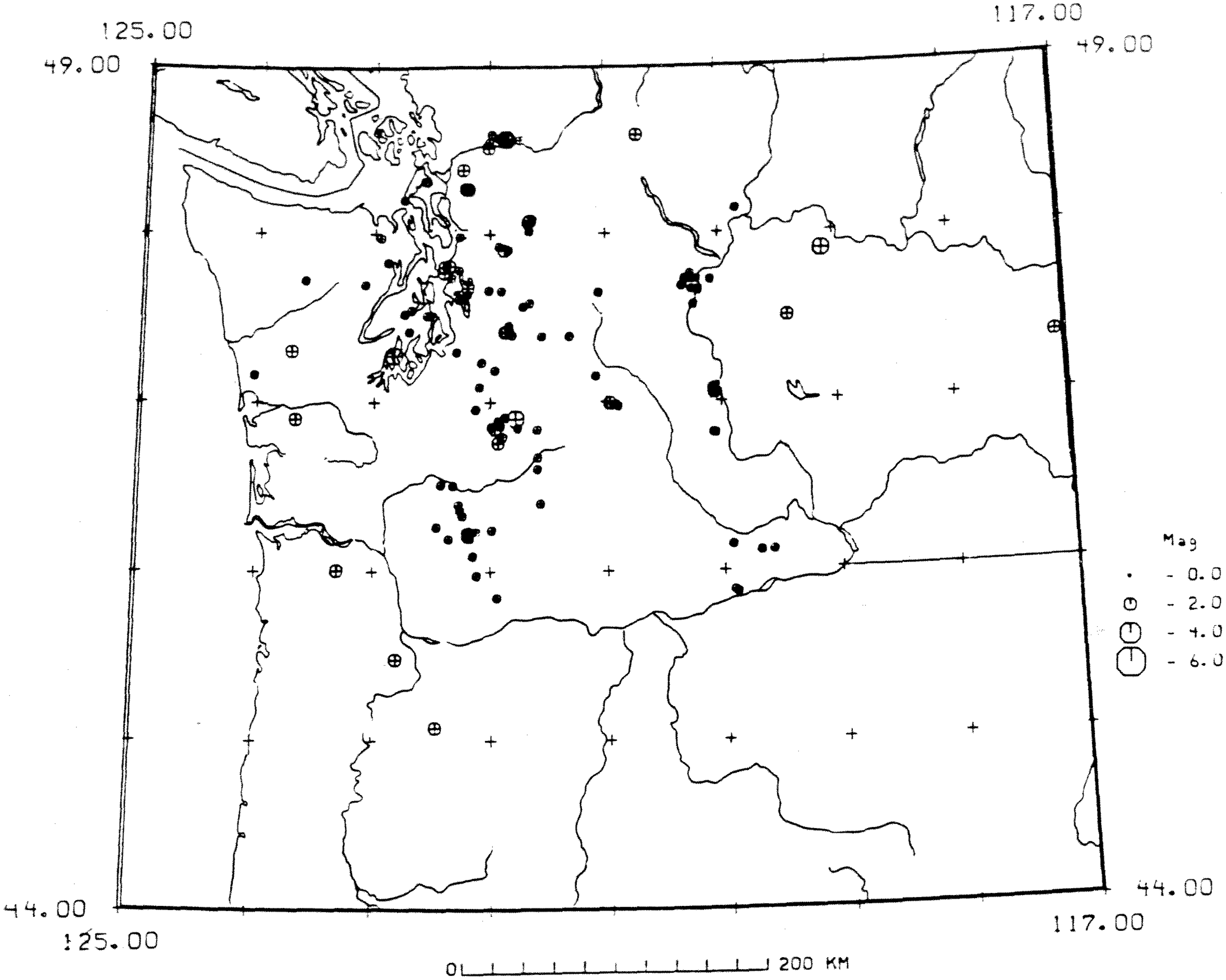

Figure 2. Earthquakes located in the state of Washington and northern Oregon with magnitudes greater than 1.0 from October 1 through December 31, 1984.

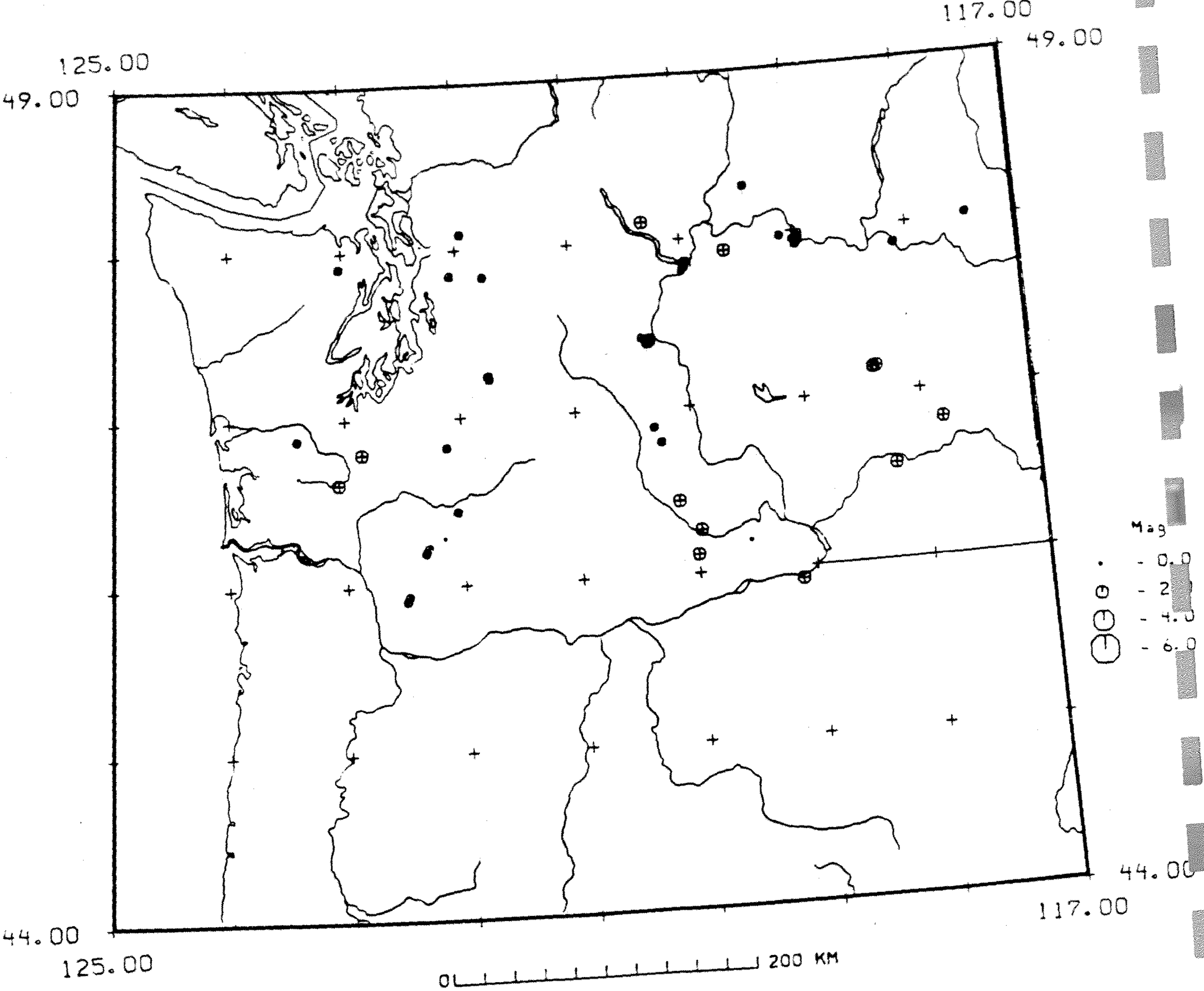

Figure 3. Blasts and probable blasts October 1 through December 31, 1984.

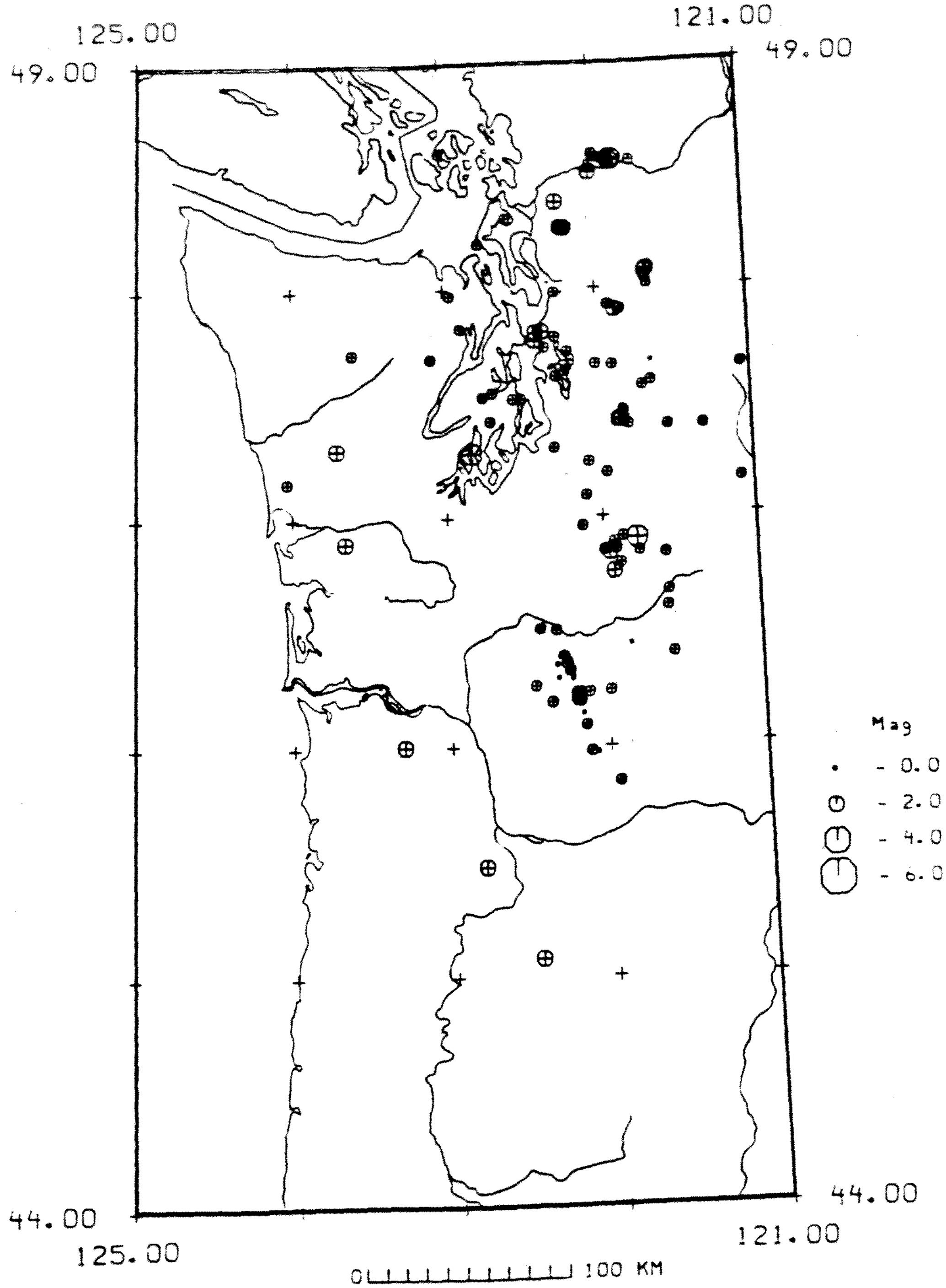

Figure 4. All earthquakes located in western Washington. October 1 through December 31, 1984.

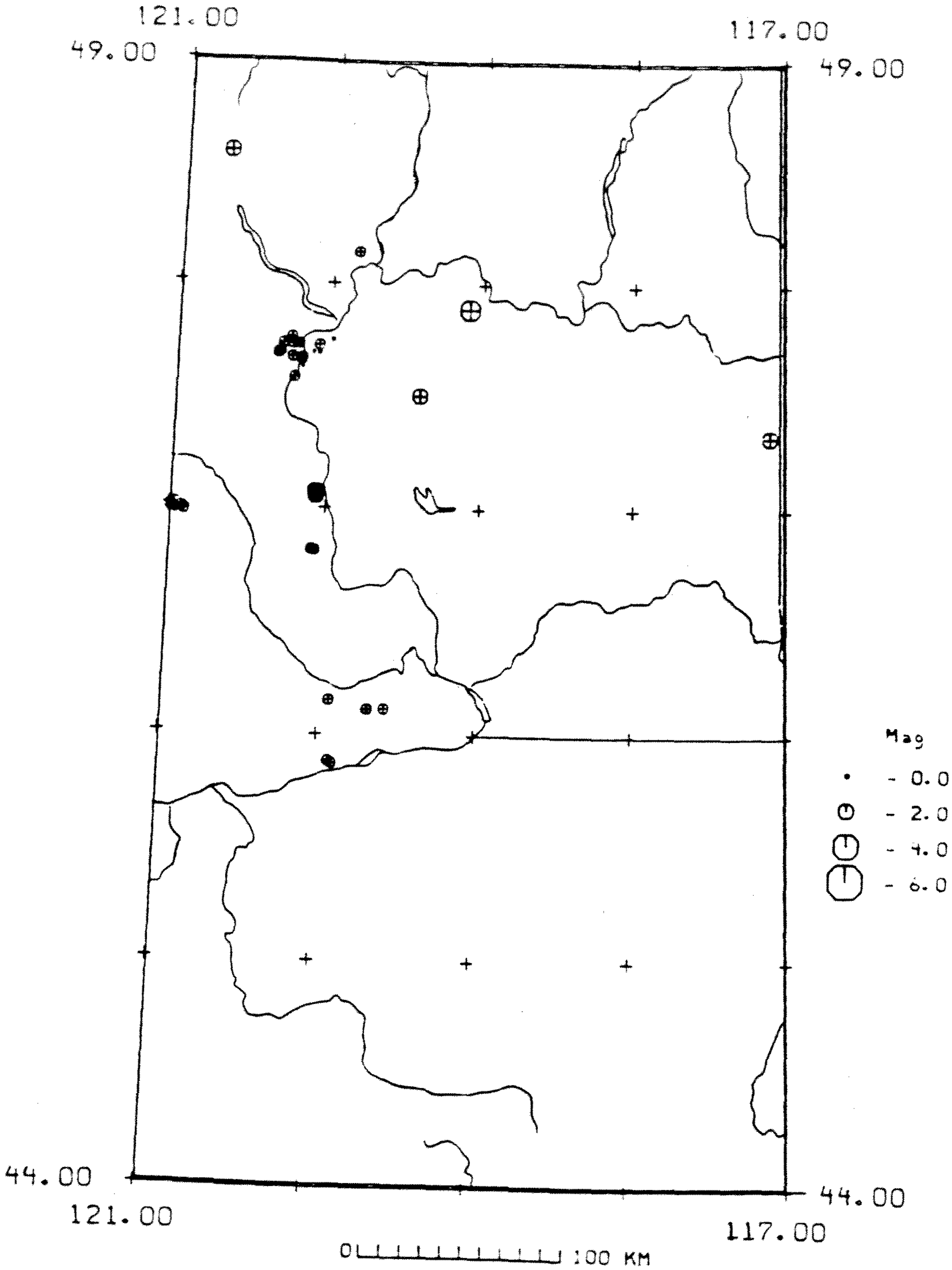

Figure 5. All earthquakes located in eastern Washington. October 1 through December 31, 1984.

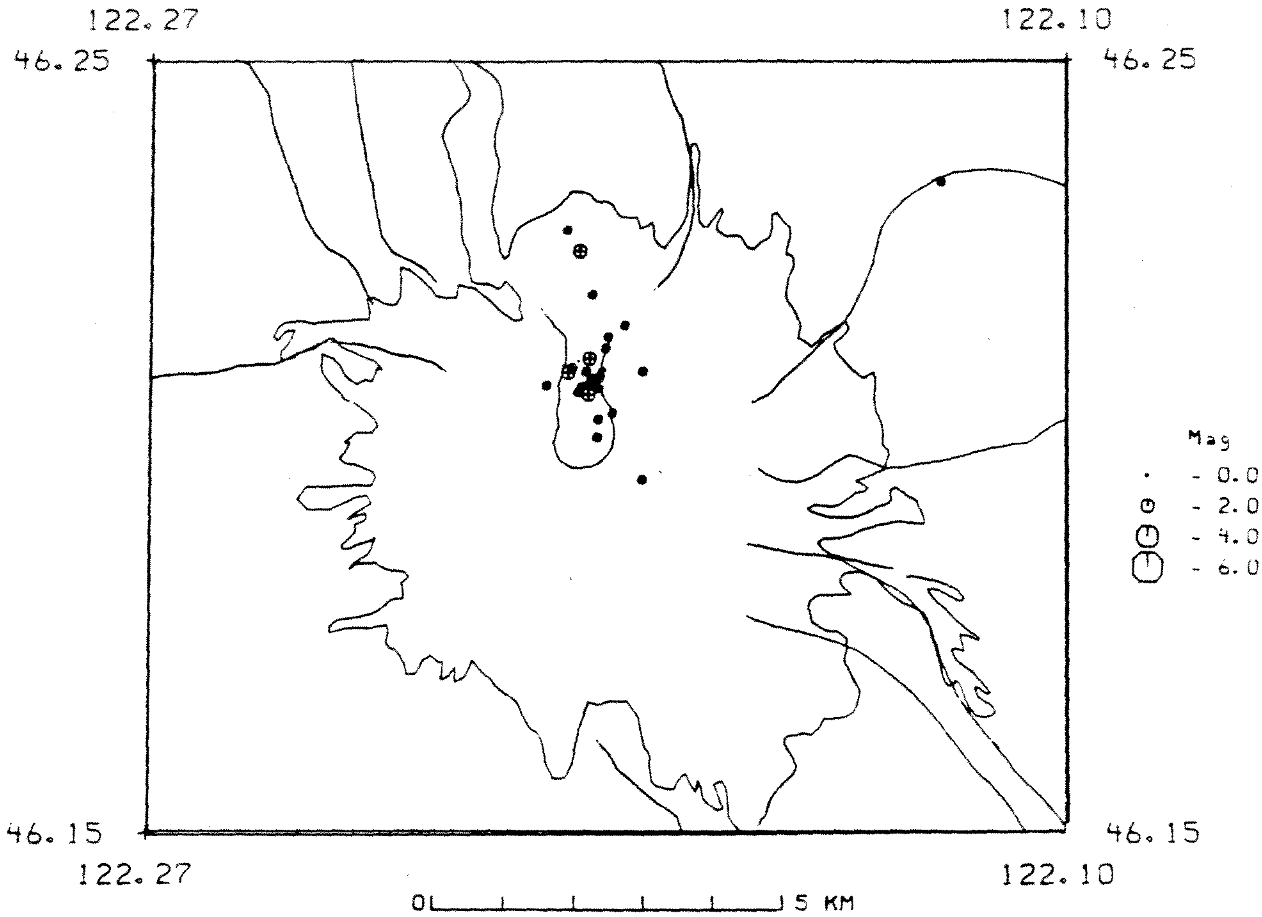

Figure 6. Earthquakes located in the Mt. St. Helens area.
October 1 through December 31, 1984.

ing the quarter. One was a M_C = 2.8 earthquake at about 35 km depth located on the Olympic Peninsula south of Aberdeen on November 21. Deep events are rare this far south of the Puget Basin. The second event, on October 20, was located at a depth of 50 km near Mist, Oregon (south of Clatskanie, Oregon) with a M_C of 2.0. This event is extremely unusual. South of a line extending from Mt. Rainier to the mouth of the Columbia River, no earthquakes at depths greater than 35 km were located prior to June 1984, when a well located deep event was felt in the Longview-Kelso area. The seismogram for the October 20 event does not resemble seismograms from other deep events; in that first arrivals are less impulsive and th coda frequency appears lower.

An event of M_C 2.5 occurred at a depth of 23 km near Portland, OR on December 11, 1984. It was felt in the western part of Portland. No other earthquakes were detected in the vicinity.

Eastern Washington and Oregon

A very interesting cluster of activity just northwest of Vantage, on the Columbia River began at the end of October, and is continuing into 1985. Eight events of M_C between 1.7 and 2.6 occurred in the fourth quarter of 1984, and several larger events occurred during the first week of 1985. Hypocenters for these events are very tightly grouped.

An earthquake of M_C = 3.0 was felt at Grand Coulee Dam and Elmer City on October 10, 1984. This event was located with a depth of approximately 9 km, deeper than is usual in this area. Earthquakes in the southern Lake Chelan-Entiat area continued at their normal background level during this quarter.

Mount St. Helens Area

The fourth quarter was seismically quiet at Mt. St. Helens. By October 1 seismicity associated with the dome-building eruption in September had ceased, and activity continued at a background level. In the quadrangle shown in Figure 6, 35 locatable earthquakes occurred during the quarter.

Catalog

Table 2 is a catalog of located events between October 1, 1984 and December 31, 1984 in the state of Washington and northern Oregon. The columns are generally self-explanatory except that the following features should be noted:

a) The origin time listed is that calculated for the earthquake on the basis of multistation arrival times. It is given in Coordinated Universal Time (UTC), identical to Greenwich Civil Times; in hours:minutes (TIME); and seconds (SEC). To convert to Pacific Standard Time (PST), subtract eight hours.

b) The epicenter location is given in north latitude (LAT) and west longitude (LONG) in degrees and minutes.

c) In most cases the DEPTH, which is given in kilometers, is freely calculated by computer from the arrival-time data. In some instances, the depth must be fixed arbitrarily to obtain a convergent solution. Such depths are noted by an asterisk (*) in the column immediately following the depth. A $ or a # following the depth mean that the maximum number of iterations has been exceeded without meeting convergence tests and both the location and depth have been fixed.

d) MAG is an estimate of local Richter magnitude as calculated using the coda length-magnitude relationship determined for Washington. Where blank, data were insufficient or impossible to obtain for a reliable magnitude determination. Normally, the only earthquakes with undetermined magnitudes are those with very small magnitudes. These magnitudes are preliminary only and may be revised as we improve our analysis procedure.

e) NS/NP is the number of station observations and the number of P or S phases used to calculate the earthquake location. A minimum of three stations and four phases are required. Generally the greater the number of observations used, the better the quality of the solution.

f) The root mean square (RMS) is taken about the mean of the station first-arrival residuals. It is only meaningful as a general statistical measure of the goodness of the solution when 5 or more well distributed stations are used in the solution. Good solutions are normally characterized by RMS values less than about 0.3 sec.

g) QUALITY of the hypocenter indicates the general reliability of the solution. The first quality is rated by a statistical measure of the solution based on travel time residuals. The second quality is rated according to the spatial distribution of stations around the epicenter. Similar quality factors are used by the USGS for events located with the computer program HYPO71.

h) MODEL refers to the crustal velocity model used in the location calculations.

P1 is the Puget Sound model
C1 is the Cascade model
S1 is for the Mt. St. Helens region outside the crater, incl. Elk Lake
S2 is used for events at Mt. St. Helens since February 1, 1984.
O1 is the Olympic model
N1 is the northeastern model
E1 is the southeastern model

i) TYPE of events flagged in Table 2 use the following code:

F - earthquakes reported to have been felt
P - probable explosion
L - low frequency earthquakes
H - handpicked from film records
X - known explosion