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I. INTRODUCTION AND OPERATIONS

Introduction

This report covers the operations and research performed for D.O.E. by the University of Washington Geophysics Program on the seismicity and structure of eastern Washington for the past year. This contract covers the operation of a 40 station network covering the east side of the Cascades and all of eastern Washington with a higher than average density of stations in the Pasco Basin area. Data from this network is telemetered to the University for recording and analysis. Recorded earthquakes and blasts are analysed routinely for location and magnitude and catalogs are routinely produced. Larger events or unusual earthquake sequences are further analysed by producing fault plane solutions and other parameters of interest when possible. In addition to the routine analysis of the network data (which is reported on in section II of this report), other research projects are under way to assist in the evaluation of seismic hazards to large engineering structures in eastern Washington. The velocity structure of eastern Washington is being periodically modified as new data or techniques become available. Synthetic seismogram generation and ray tracing, as well as record section production, are such techniques covered in section III of this report. Section IV is a paper covering the development of a technique for automatically analysing well logs for major lithologic contacts by the use of Walsh transforms. Section V is a progress report on our surface-wave dispersion research which is attempting to determine the average shear wave velocity structure for the region and contrast it to the rest of the northwest.

Operations

The past year has seen quite a change in the general operations of the Eastern Washington seismic network as well as the entire state network. Analysis of data from all of the University of Washington seismograph networks has been integrated so that a common staff using uniform techniques can produce a single earthquake catalog covering the entire state. The data for over 100 stations is being simultaneously recorded on an online computer system and analysed using a series of computer programs for displaying and 'picking' the arrivals. Locations, maps, focal mechanisms, etc. can then be produced for interpretation. There is an online updated catalog of the earthquakes being processed by these routines which can be easily accessed by calling our computer. For details on the online system and the basic offline processing see the *Annual Technical Report, 1980.*

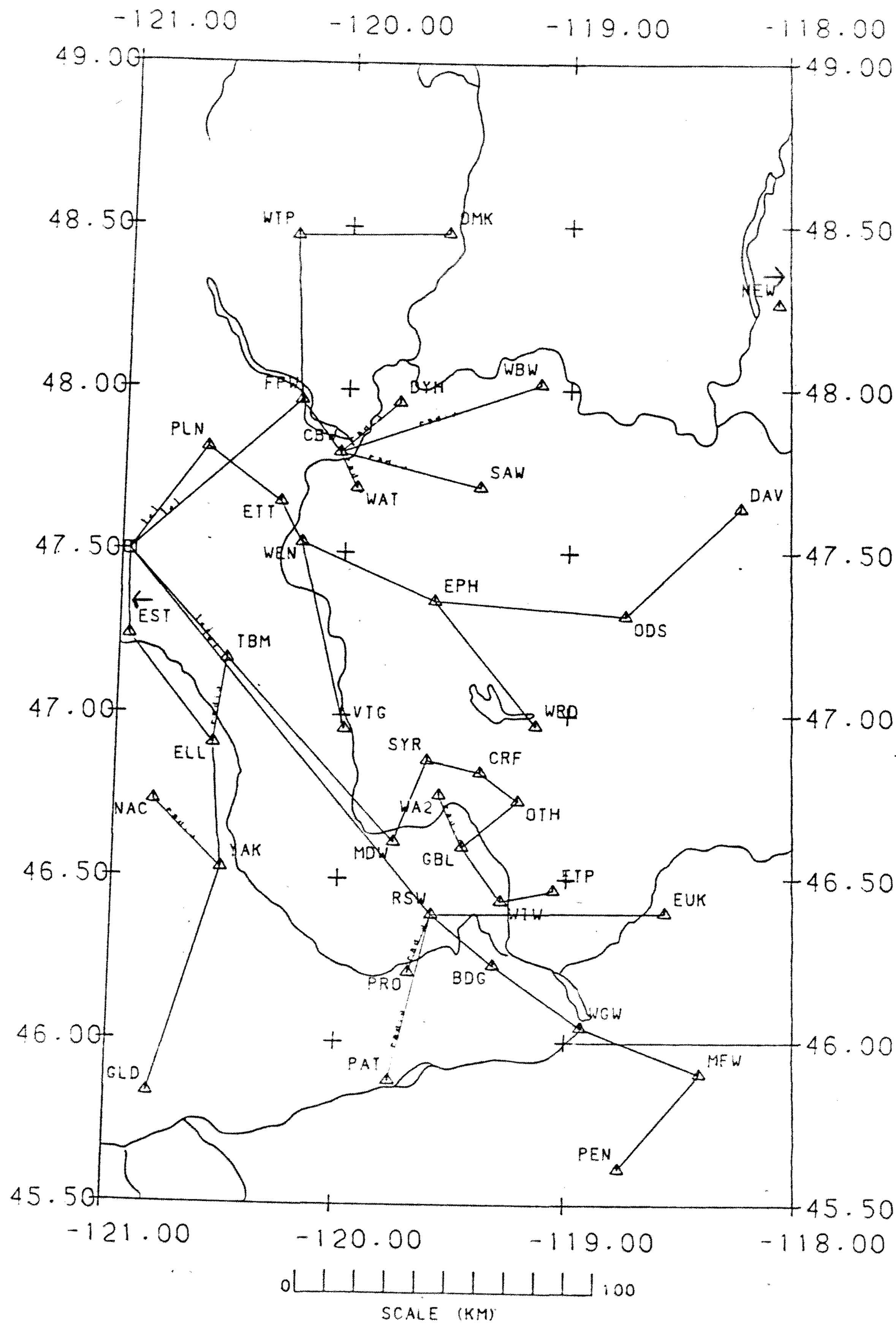
The routine processing is running smoothly, but continues to lag somewhat due to earthquake swarms associated with Mt. St. Helens' eruptions and the vigorous aftershock sequence which followed the 14 February Elk Lake earthquake. The data have been completely analysed from June 1, 1980 until March 15, 1981, and from May 1, 1981 through to the present. The six weeks from the middle of March through April has not been processed because of the large number of aftershocks from the Elk Lake earthquake. More than 250 locatable events occurred within 24 hours of the main Elk Lake shock, which itself was the largest tectonic earthquake in Washington in nearly 16 years. The data for the first quarter of 1980 have been processed by hand and are covered in the next section of this report. The data for the period March 20, 1980 through the end of May has not yet been analysed.

We have just installed an automated P-wave picker provided by the U.S. Geological Survey which should noticeably speed up the routine processing of events. All incoming seismic signals are examined by a series of microprocessers which are programed to recognized typical P-wave signals and report these 'picks' to a supervisor microprocessor. This computer determines what sequence of picks could be a legitimate earthquake and discards those picks which fall outside the allowable range of times. It then reports the sequence of picks as phase data to our main offline computer where routines can automatically run a location. When this system is fully operational we should have fairly accurate locations within three minutes of the occurrence of an earthquake. There are still minor adjustments which must be made to the equipment and software.

The new network manager, Jim Zollweg, began work in March of this year and has now taken over most of the management of the routine operations of the network. Jim supervises the technicians, data managers, and seismic analysts as well as providing quality control of both the equipment and data. We are training two new analysts to help with the routine processing.

The field maintenance of the eastern Washington stations has been taken over by a subcontractor, the Stanwyck corporation. Some time has been spent training their field technician, who is stationed in the tri-cities and can respond rapidly to technical problems as we find them. This service has eased some of our workload, and has significantly improved our percentage of "up" time. This situation should improve even further as the technician become more familiar with the equipment and stations and works out some of the basic problems which have plaged some of our stations..

A new station was installed last spring in the Horse Heaven Hills near Paterson (PAT). This station has better than average noise characteristics and fills in an important part of the western plateau. Table I-1 lists the stations in the Eastern Washington network which are currently operating. Figure I-1 shows all of the active stations in Washington and northern Oregon which are being recorded at the University of Washington. Figure I-2 shows the Eastern Washington network in more detail with lines showing the telemetry paths. Additional stations are planned in northern Oregon as part of a recent N.R.C. contract to monitor the seismicity of the Pacific Northwest.



I-2 Eastern Washington Seismograph Network
Showing Telemetry Interconnections

TABLE I-1 EASTERN WASHINGTON SEISMIC STATIONS

STA	LAT	LONG	TIME	NAME
ALD	45 49.17	120 04.00	1/77-	(PGE-local)
BDG	46 14.08	119 19.05	7/75-	Badger
CBW	47 48.42	120 01.960	7/75-	Chelan B
CRF	46 49.51	119 23.09	7/75-	Corfu
DAV	47 38.30	118 13.56	7/75-	Davenport
DYH	47 57.63	119 46.16	7/75-	Dyer Hill
ELL	46 54.58	120 34.10	7/79-	Ellensburg
EPH	47 21.13	119 35.77	7/75-	Ephrata
EST	47 14.28	121 12.53	7/79-	Easton
ETP	46 27.89	119 03.54	7/75	Eltopia
ETT	47 39.30	120 17.60	6/77	Entiat
EUK	46 23.75	118 33.72	7/75-	Eureka
FMC	45 37.47	120 01.70	1/77-	(PGE-local)
FPW	47 58.00	120 12.77	7/75-	Fields Pt.
GBL	46 35.86	119 27.59	7/75-	Gable
GLD	45 50.33	120 48.85	8/77-	Goldendale
MDW	46 36.80	119 45.65	7/75-	Midway
MFW	45 54.18	118 24.35	7/75-	Milton-Free.
NAC	46 43.98	120 49.47	8/79-	Naches
NEW	48 15.83	117 07.22	/77-	(USGS)
ODS	47 18.40	118 44.70	7/75-	Odessa
OMK	48 28.82	119 33.65	7/75-	Omak
OTH	46 44.34	119 12.99	7/75-	Othelo
PAT	45 52.85	119 45.68	6/81-	Paterson
PEN	45 36.72	118 45.78	7/75-	Pendleton
PLN	47 47.08	120 37.97	6/77-	Plain
PRO	46 12.76	119 41.15	7/75-	Prosser
RPK	45 45.70	120 13.83	1/77-	(PGE-local)
RPW	48 26.90	121 30.82	8/77-	Rockport
RSW	46 23.47	119 35.322	7/75	Rattlesnake
SAW	47 42.10	119 24.06	7/75-	St. Andrews
SYR	46 51.78	119 37.07	7/75-	Smyrna
TBM	47 10.17	120 31.00	7/79-	Table Mt.
VTG	46 57.48	119 59.24	7/75-	Vantage
WA2	46 45.40	119 33.76	5/78-	Wahluke2
WAT	47 41.92	119 57.25	11/76-	Waterville
WBW	48 1.07	119 08.23	7/75-	Wilson B
WEN	47 31.77	120 11.650	7/75-	Wenachee
WGW	46 2.68	118 55.96	7/75-	Wallula Gap
WIW	46 25.93	119 17.29	7/75-	Wooded Is.
WPW	46 41.92	121 32.42	4/80-	White Pass
WRD	46 58.19	119 08.60	7/75-	Warden
WTP	48 28.27	120 14.87	8/77-	Winthrop
YAK	46 31.73	120 31.22	7/79-	Yakama

II. SEISMICITY 1980 - 1981

Introduction

The patterns of Washington state seismicity east of Puget Sound have changed profoundly with respect to both location and rate of occurrence since early 1980. The most striking change has unquestionably been the emergence of the south Cascades region as the state's most seismically active area. While the majority of the located events in the south Cascades have been directly associated with eruptive activity at Mt. St. Helens, two significant sequences of tectonic earthquakes were recorded in the first half of 1981, each with a main shock in the magnitude 5 - 5.5 (M_L) range. These earthquakes, the Elk Lake Earthquake of 14 February 1981 and the Goat Rocks Wilderness Earthquake of 28 May 1981 are the largest tectonic earthquakes to occur in Washington in more than a decade.

Data

The data base is not complete for the time period discussed in this report, 1 January 1980 to 30 June 1981. Digital methods of recording and processing the seismic data using on- and off-line computers were being initiated at about the time the Mt. St. Helens eruption swarm began. Since that time, overall state seismicity has been very high. Roughly 4600 events have been located in the 18-month time frame, representing a several-fold increase over normal activity. Because of these factors, the catalogs of processed data are uneven in quality and contain some obvious gaps.

The on-line, triggered digital system became operational in early 1980. For the first quarter of 1980, therefore, processing of eastern Washington seismic data has been carried out in a rather traditional manner. Data was recorded on 16mm film on two Develocorders (the C or Central and the H or Hanford). Films were scanned manually for seismic events. Those that were noted were copied. The arrival times for C Develocorder events have been read for the entire quarter and the events located. Only the January 1980 H Develocorder events have been located; those of February and March 1980 are presently being read.

After the on-line system's advent, the C and H films were scanned as before, but only events that did not trigger the digital system were copied and read. Scanning, reading and location of non-triggering eastern Washington events is complete from 1 April 1980 to date. At present, we are only using one Develocorder to record a representative selection of eastern and central Washington stations; the overall high performance of the digital system was a major factor in our decision to reduce our volume of film recording.

Between April and June 1980, processing of all Washington events is incomplete. More than ten thousand events triggered on the 11/34 between 20 March and 30 June. During this time period, events were picked by hand from computer plots of the digital data, and only events having a magnitude of about 3.2 or greater were analyzed. While over 1000 events were located, this represents only a fraction of the recorded events and is heavily biased toward the Mt. St. Helens area. Only limited data from this period is included in the catalog in this report.

Since 1 July 1980, every effort has been made to keep the processing completely up to date in all regards. This effort has already failed us once, after the 14 February 1981 Elk Lake earthquake. The heavy aftershock sequence put analysts so far behind in their work that ultimately we were forced to skip one time segment so that we could remain current. Lately, we have been able to make some progress on the 1981 backlog, and currently only about six weeks of data (16 March to 30 April 1981) is incompletely processed. We have consistently kept within a few days of current since 1 May 1981.

To summarize the state of the eastern and central Washington data processing, then, we feel it is complete from 1 July 1980 through 15 March 1981 and 1 May

1981 to date. Northeastern and central Washington is also complete for January through March of 1980 and southeastern Washington is complete for January 1980. All events that did not trigger the 11/34 are complete from 1 April 1980 to date. However, errors and inconsistencies may arise in our compilations of the information given in this report.

Larger events (magnitude 3 to 5.5)

1980 and 1981 were years of exceptional seismicity in Washington. Figures II-1 and II-2 show the numbers of events statewide with magnitudes of 4 or greater and 3 or greater, respectively. The larger events were almost completely confined to the Cascades, and the Mt. St. Helens eruption swarms account for approximately 95% of the catalogued events of magnitude 4 or greater.

Two earthquakes with magnitudes of 5 or greater occurred during the time period, both in the first half of 1981. The first, the magnitude 5.5 Elk Lake Earthquake of 14 February 1981, is the largest Washington earthquake to occur since 1965. It was located about 15 km north of Mt. St. Helens near the north edge of the zone devastated by the blast of 18 May 1980, at a depth of about 7 kilometers. While the proximity in time and space to a volcanic eruption is clearly more than coincidental, it is important to realize that the Elk Lake earthquake was a relatively normal event involving the release of tectonic stress rather than an event directly related to the movement of magma to the surface at Mt. St. Helens. Aftershock activity has been vigorous and more than 600 aftershocks have been located. Most cluster along a nearly vertical plane some 6 to 8 kilometers long at the surface and striking slightly west of north. Focal mechanisms for the main shock and most of the aftershocks for which solutions could be obtained indicate right-lateral strike-slip along a plane closely corresponding in strike to the aftershock zone. Figure II-3a shows the preferred solution for the main shock.

The earthquake occurred along a trend of post-1969 epicenters that extends some 50 kilometers from south of Mt. St. Helens to about the Riffe Lake area. The aftershock zone is a segment of the larger zone and the main shock fault plane solution is consistent with horizontal movement along the zone. Thus, there is the implication that a larger earthquake could occur at shallow depth in western Washington. While the Elk Lake shock caused only a few instances of superficial damage, a magnitude 6+ shock would now seem to be possible anywhere along the zone. Such an earthquake could potentially cause significant damage in southwestern Washington.

The Goat Rocks Wilderness earthquake of 28 May 1981 had a magnitude of about 5.0 M_L. It was preceded by 15 minutes by a magnitude 4 foreshock, but none of the more than 200 aftershocks yet recorded has had a magnitude in excess of 3. While the main shock was perceptible over a wide area, no damage is known to have occurred. This is unquestionably due to the location of the sequence in one of the least-populated areas of the state: the nearest permanent habitation is about 15 km from the epicentral region and the nearest town about 20 km.

There were few seismometers operating within 50 kilometers of the epicenter. Portable seismographs were operated within 10 to 15 kilometers of the epicenter on a few occasions between May and July, but it was not possible to get closer or deploy more than two portable stations at any given time. Consequently, our locations for events in the sequence are not very accurate. All of the better-located events occurred at depths less than 5 km. The better-located aftershocks define a linear zone about 5 km long and striking NW. Fault-plane solutions for the largest foreshock and the main shock (Figures II-3b and II-3c) are well-constrained and indicate right-lateral strike-slip is occurring along a plane coincident with the aftershock zone.

Two Cascade earthquakes in the magnitude 4.0 - 4.2 range occurred in February 1981 in addition to the Elk Lake sequence. These were the Toppenish Ridge earthquake of 02 February and the Cle Elum earthquake of 18 February. The Toppenish Ridge earthquake (M_L 4.0) was located in a remote part of the Yakima Indian Reservation and is not known to have been felt. Its fault plane solution (Figure II-3d) is well-constrained and is intriguing in its similarity to the solutions for the Goat Rocks Wilderness earthquakes. Yet more interesting is the fact that the Toppenish Ridge and Goat Rocks earthquakes can be joined by a line with about the same strike as one of the common nodal planes.

In contrast to the Toppenish Ridge event, the 18 February magnitude 4.2 Cle Elum earthquake was felt by most people in the epicentral region. As if to break the monotony of well-determined strike-slip fault plane solutions, the Cle Elum earthquake first motions determine one nearly vertical east-west-striking plane very well, while the other nodal plane is constrained only in the sense that it must be nearly horizontal. One of a variety of acceptable orientations for it is shown in Figure II-3e.

In the magnitude 3 to 4 range, four earthquakes that are of interest occurred in the Cascades and the eastern part of the state. A magnitude 3.0 event was felt near Omak on 18 June 1980. Since it occurred near the periphery of the network, the epicenter and focal depth are not very well-controlled, and a fault-plane solution was not attempted.

A magnitude 3.3 earthquake occurred a few kilometers southwest of Potholes Reservoir on 19 November 1980. This is a rather large event for this region, although certainly not unique. Too few good first motions were recorded to permit an attempt at a fault plane solution, as is typical for shallow events in the central basin.

A felt event of magnitude 3.5 occurred in the central Cascades near Monte Cristo on 15 March 1981. It was followed by more than 20 aftershocks over the following two weeks, many of which occurred as double shocks a few seconds apart.

A magnitude 3.3 event occurred near Goldendale in the south Cascades on 14 June 1981. It is not known to have been felt. An attempt at a fault-plane solution (Figure II-3f) yields a poor quality thrust-type solution if one places the most confidence on the sharper first motions. This event was the deepest of the larger events discussed herein, having a calculated depth of about 14 km. This is twice the focal depth of the next-deepest event discussed, the Elk Lake earthquake.

Explosions and small earthquakes (magnitude less than 3)

626 seismic events were located east of 121.5 degrees west longitude during the time periods for which our catalogs are complete. 358 were known or suspected explosions. Many more explosions occurred than we have attempted to locate. Long sequences of large explosions have been identified near Gable Mountain and near Ice Harbor Dam, both in the Pasco Basin - Saddle Mountains area. Figure II-4 shows these as well as other known and suspected explosions. It is possible that some of these are earthquakes; most of the earthquakes in the area are quite shallow and it is occasionally difficult to distinguish them from new blasting sources unless more information is available than the seismograms alone. Conversely, many of the earthquakes shown in Figure II-5 occur in the Gable and Ice Harbor blast areas, and may have been misidentified by the analysts. The problem is compounded somewhat because the earthquake and explosion areas overlap, particularly in the Gable Mountain area.

Four clusters of earthquake activity are evident. The two westernmost clusters represent the Cle Elum and Goat Rocks earthquakes with their aftershocks. There is diffuse activity throughout the Pasco Basin area, and there is a strong concentration of epicenters in the Saddle Mountains near latitude 46.8 degrees North. This area and the one to the south of Lake Chelan are areas which have been typically active in the past. None of this activity stands out as being particularly unusual as compared to the previous ten years.

Two of the earthquakes in the south Lake Chelan area are known to have been felt. Both events were about magnitude 2.5 M_L. Some blasts have also been detected from the nearby Waterville area, and it is possible that some of these have been mistakenly identified as earthquakes.

The appendix to this report is a catalog of the located events since Jan 1980. There are periods, as mentioned above, for which the catalog is incomplete. The locations reported in this catalog have been determined using a location routine obtained from Dr. Bob Herrmann at St. Louis University. It has a number of deficiencies for our set of earthquakes. In particular, shallow events have poorly determined depths; often the depth is fixed at 0.10 km. Azimuthal weighting is not used and there is no way to automatically down-weight obviously bad readings. We are presently doing a major rewrite of this program and will rerun all the data for the past two years as soon as this is completed and thoroughly tested.

Most of the columns in the appendix are self explanatory. Times are in coordinated universal time (PST + 8hr). The * sometimes following the depth means that the depth has been fixed. NS/NP is the number of stations and the number of phases used in the location determination, and the model code matches the models given in table II-1. The *types* listed in table II-1 are as follows:

X- Known explosion

P- Probable explosion (based on seismogram character)

F- Earthquake reported to have been felt

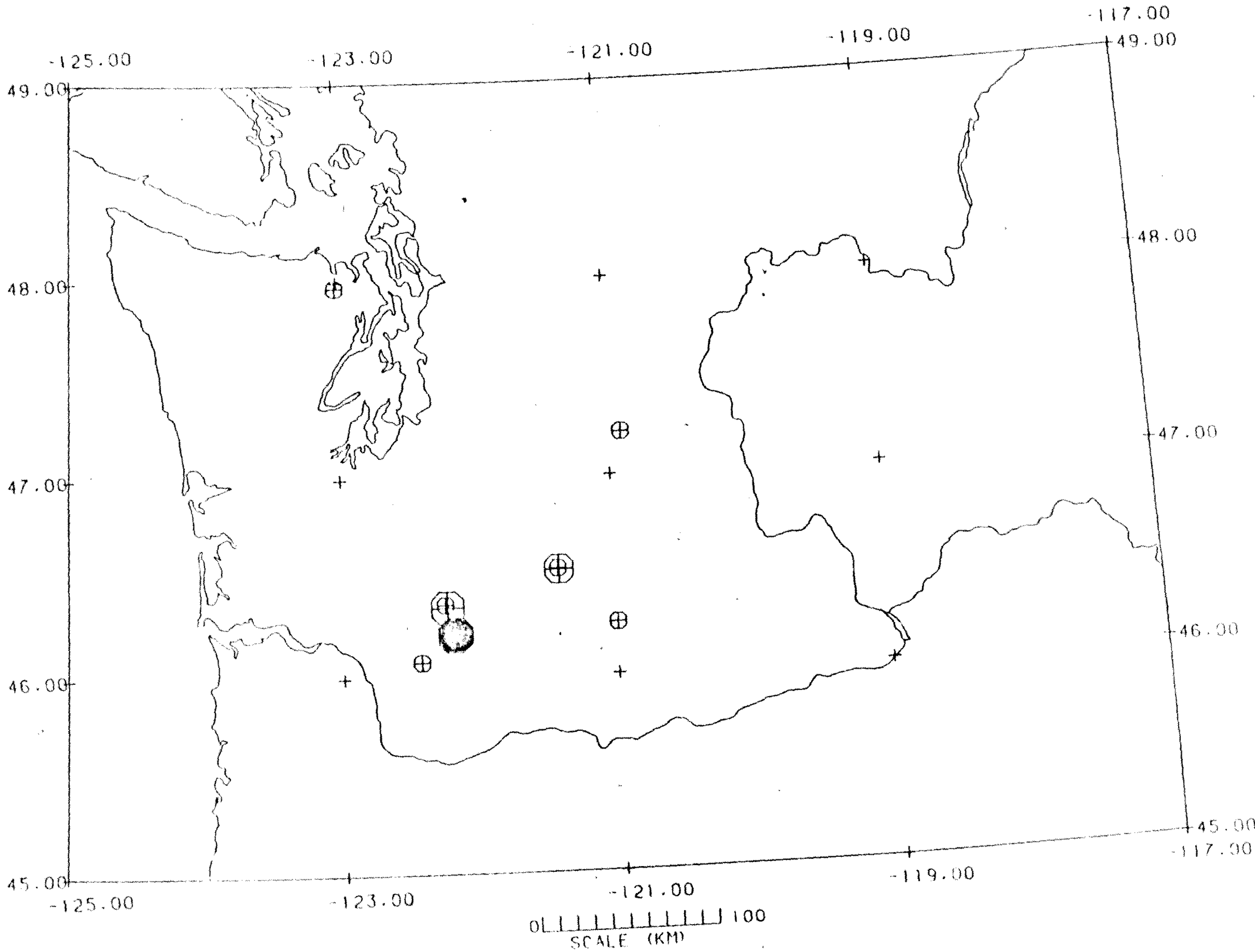
H- Hand picked event from film records (Computer recording not available)

This catalog is a subset of the state-wide catalog which has 2549 entries for 1980 and 2596 for 1981 thus far. This includes some 1274 regional and teleseismic events which are not located or processed other than saving the trace data. This complete catalog is kept nearly up to date including the addition of new events as they are analyzed and the corrections to older events as they are made. It is a complete catalog from 1969 to within a few days of the present excluding those periods of time mentioned above.

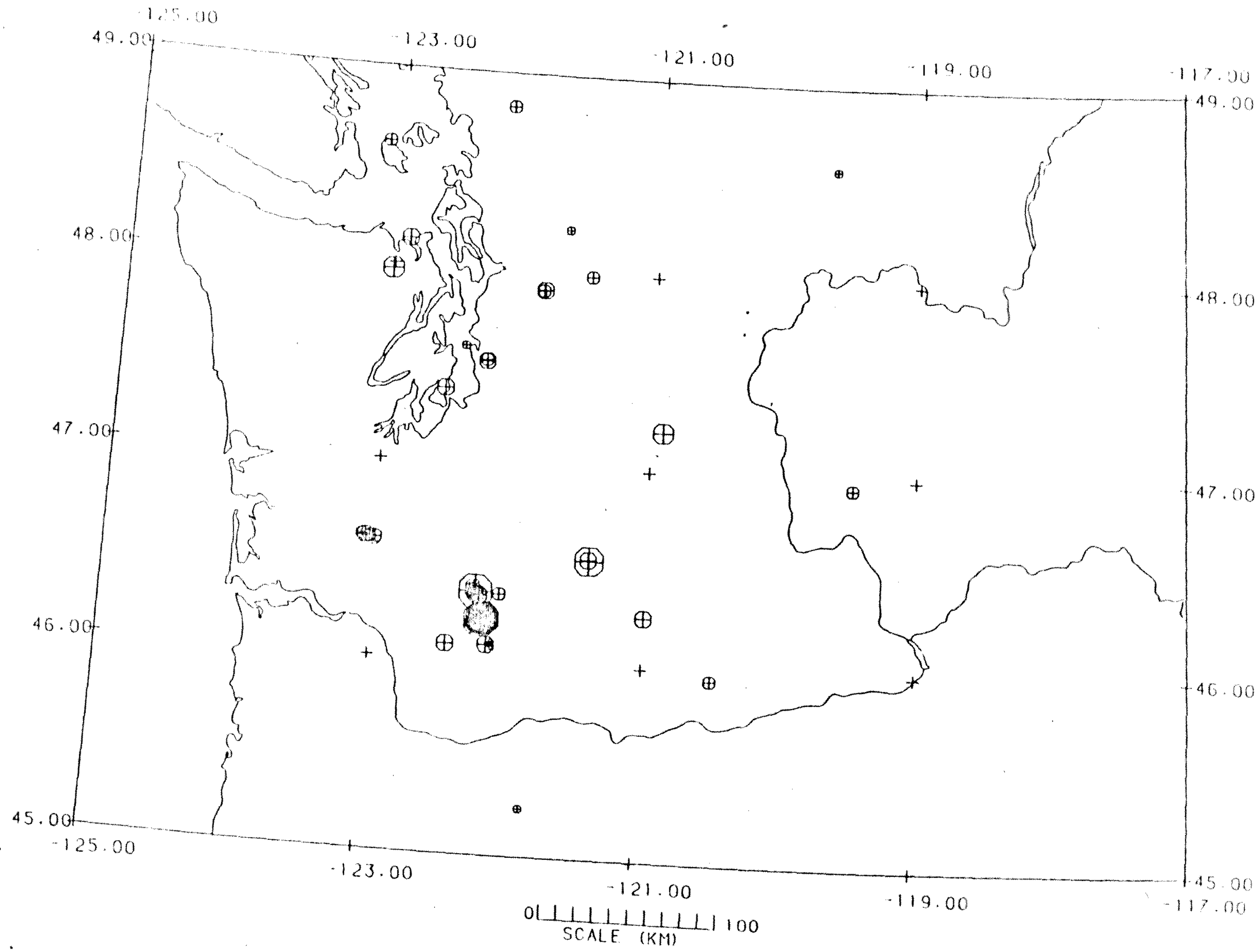
Table II-1 gives the velocity models currently being used for locating events in eastern Washington. In addition to these models there are models for the Puget Sound (P1), the Mount St. Helens area (S1), and the Olympic Penensula (O1).

TABLE II-1 VELOCITY MODELS

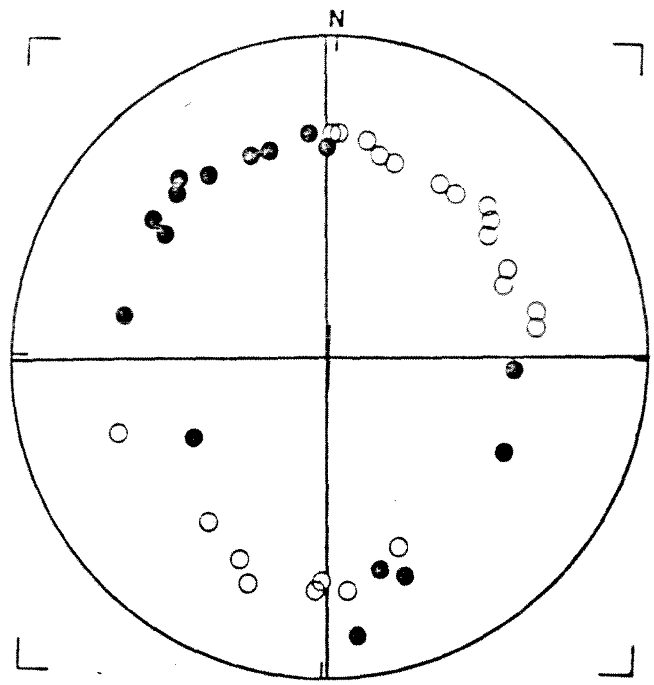
Model	velocity	depth(km)
E1	3.70	0.0
	4.70	0.8
East	5.15	1.2
	6.05	7.5
	7.20	19.
	8.00	28.0
N1	5.10	0.0
North-	6.05	0.5
East	7.2	19.0
	8.0	24.5
C1	5.1	0.0
	6.0	1.0
Cascades	6.6	10.0
	6.8	18.0
	7.1	25.0
	7.9	35.0



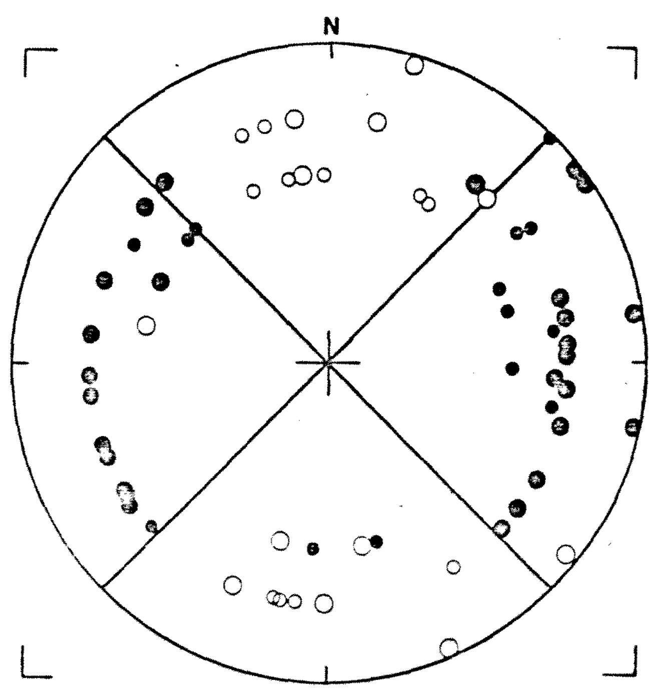
II-1 Washington State Seismicity 1980-1981
Magnitude (M_L) > 4



II-2 Washington State Seismicity 1980-1981
Magnitude (M_L) > 3

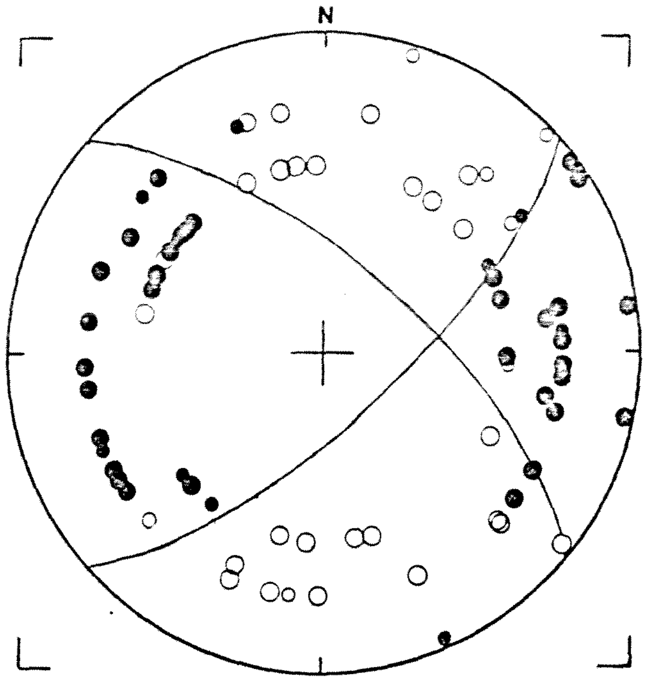


a. Feb. 14, 1981 Elk Lake Event M = 5.5

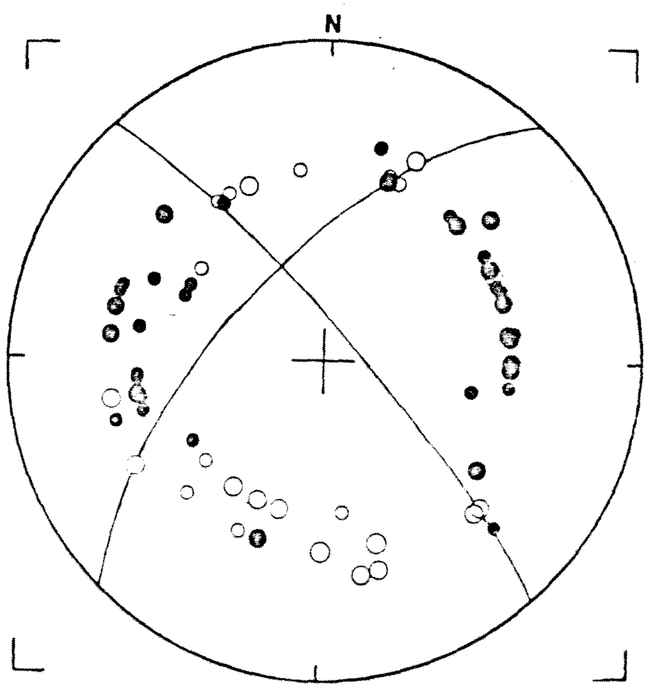


b. May 28, 1981 Goat Rocks Foreshock
M = 4.0

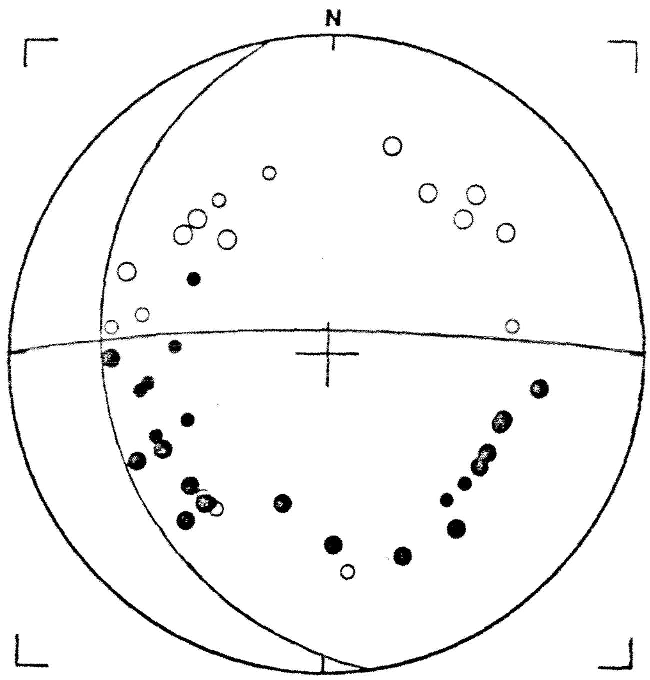
II-3 Focal mechanisms for selected larger earthquakes in the Cascades. Solid circles are compressions, open are dilations. Symbol size is proportional to quality of first motion.



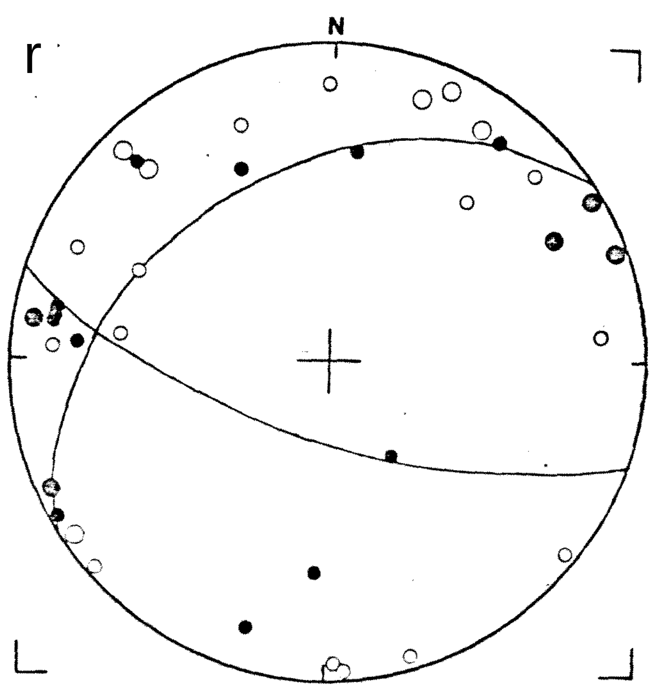
c. May 28, 1981 Goat Rocks Mainshock
M = 5.0



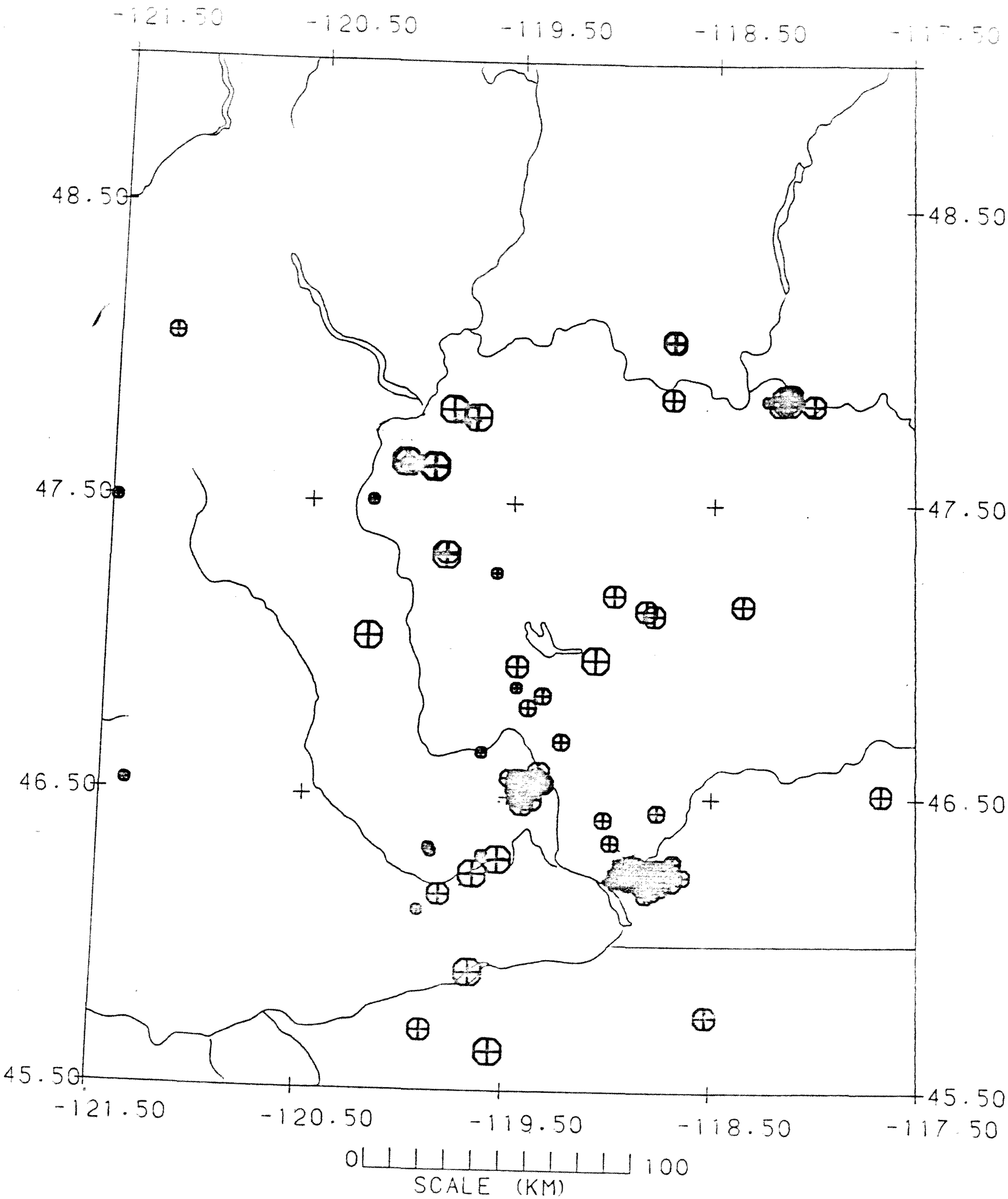
d. Feb. 2, 1981 Toppenish Ridge Earthquake
M = 4.0



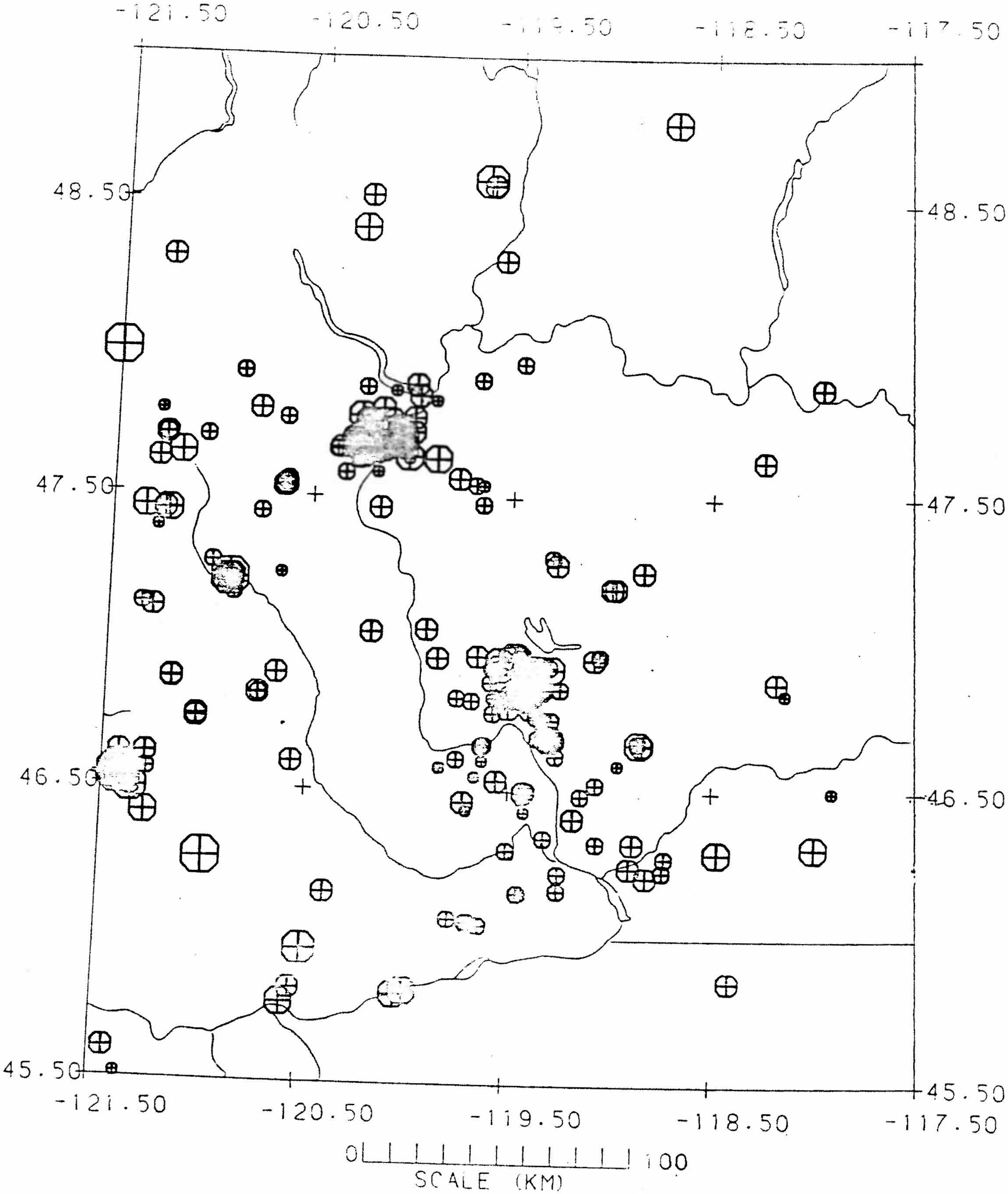
e. Feb. 18, 1981 Cle Elum Earthquake
M = 4.2



f. June 14, 1981 Goldendale Earthquake
M = 3.3



II-4 Eastern Washington known and probable explosions



II-5 Eastern Washington Earthquakes January 1980 - June 1981

III. STRUCTURAL STUDIES

There have been two major efforts during the past year to improve our understanding of the eastern Washington regional structure as well as the local structure within the Columbia River basalts. A good deal of the work thus far is background work developing the tools to investigate the specific problems. This includes the acquisition of a state-of-the-art borehole seismometer and its testing in the lab. The connections for this instrument and its recording equipment are presently being tested. Computer programs are being developed for use in interpreting the data from the borehole instrument as well as for surface records. This includes ray tracing and synthetic seismogram programs. We have also developed the capability of generating record sections from the on-line computer data.

Ray Tracing and Synthetic Seismograms

Primary concentration has been in the development of ray tracing programs for the analysis of the borehole seismic data. This software models the distribution of energy emanating from a buried source, whatever the nature of the source, and can also model borehole seismometer response. A plot of typical output from the ray tracing program, accompanied by plots of the corresponding velocity and attenuation models, is provided in Figure III-1.

Integral to the ray tracing studies of the Columbia Plateau basalts is the development of software to model the attenuation characteristics of the basalts. This is being approached in two ways: first, by the development of computer programs to operate on field data for attenuation analysis; second, by the generation of working models of seismic wave interaction in fractured, multilayered basalts.

A computer program package has been developed to analyze local earthquake data using the spectral ratio technique. This method has been used in several published studies, and although some technical problems exist with the method, it appears to be more consistent than other currently available techniques. The software is being tested in a study of the Elk Lake earthquake sequence of February 14, 1981, and will be used in the coming year in conjunction with the borehole seismology program.

An understanding of the attenuation effects of multilayered fractured rock is necessary in seismic modeling of the Plateau basalts. Zones of high fracture density will attenuate seismic energy passing through the region, and may create focusing effects in the transmitted energy. Interpretation of borehole seismic data must take these variations into account. Thus, as part of the borehole interpretation software, a wave attenuation-wave interaction program is being developed. Expressions now exist from which the propagation constants of elastic waves traveling through material containing a distribution of cracks may be calculated. The cracks are assumed to be randomly distributed and may be randomly oriented. The wavelengths involved are assumed to be large compared with the size of the cracks and their separation distance. Thus the formulae, based on the mean taken over a statistical ensemble, may reasonably be used to predict the properties of a single statistical sample.

Explicit expressions (correct to lowest order in the ratio of the crack size to a wavelength) have been derived for the overall wavespeeds and attenuation of elastic waves in cracked materials, in which the mean crack is circular and the cracks are either aligned or randomly oriented. The cracks may be empty or filled with solid or fluid material (e.g., alteration materials or groundwater). Completion of the software (implementation of the equations) will be completed within six months.

Refraction Record Sections

In our *Annual Technical Report - 1977* we developed the dual velocity models we have been using to locate earthquakes in eastern Washington. This work, as well the previous work of Eaton used a time-term method of determining major refractor velocities as well as depths to refractors. The data for these studies came from reading develocorder film records from known explosions, and thus consisted of arrival times at the network stations for a variety of sources. Using the film data allowed only good first arrivals and on rare occations later arrivals to be used. With the advent of the digital recording techniques now used, we hope to refine the models developed in 1977 by the use of record sections. Examples of three record sections for eastern Washington stations are shown in figures III-2 through III-4.

Figure III-2 shows a record section for stations in the southern part of the eastern Washington network recording the Elk Lake main shock of Feb. 14, 1981. A reduction velocity of 8.0 km/sec was used such that arrivals with a phase velocity of 8 km/sec will line up parallel to the distance axis. Our first arrival picks are indicated by a spike superimposed on the traces. Note that our interpretation of the phase velocities show a 7.7 km/sec refractor changing to a 8.4 km/sec refractor at a distance of about 225 km from the source. Since this profile is an unreversed line it is impossible to separate the actual refractor velocity from the effect of its dip. These data are consistent with a 8.0 km/sec mantle velocity dipping to the west at about 6 degrees. This would take it from a depth of about 26 km under the Pasco Basin to 38 km under the Cascades. The 7.7 km/sec arrivals could likewise be caused by a dipping 7.4 km/sec intermediate layer. Figures III-3 and III-4 show record sections for composites of several blasts near Gable Mountain and Ice Harbor Dam respectively. A composite is produced by taking several blasts located in different places but in the same general region and plotting their data all on one record section. In that way some of the stations appear more than once since they will be at different distances for different blasts. In both cases the major well defined arrivals are from a 5.1 km/sec refractor; that is the in situ velocity of the Columbia River basalts. For the Gable mountain shots there is a very poorly defined 5.5 km/sec set of arrivals and for the Ice Harbor Dam shots a better determined 6.5 km/sec set of arrivals. Neither of these velocities fit well with our existing velocity model for the area though the 6.5 km/sec arrivals could be explained by the thinning of the basalts to the north, causing an apparent high velocity of the 6.1 km/sec layer.

These record sections are presented as examples of what can be done with the digital data. There are a number of additional blasts which can be used and future explosions and earthquakes will provide a better sampling of the entire region.

In addition to these crustal structure investigations, we are presently in the middle of a thorough teleseismic P-wave delay study of the entire northwest. P arrivals for 42 teleseisms have been read using the digital data from an average of 80 stations throughout the State. These data are being compared with standard velocity models to look for areas of anomalous travel times. The results thus far are too preliminary to report at this time.

V. REGIONAL SHEAR WAVE VELOCITY STRUCTURES IN WASHINGTON

This is a progress report of surface wave study to define the regional shear wave velocity structures in the state of Washington. The data set has been enlarged not only to include the previously described three stations at Mt. Constitution, Liberty, and Walla Walla, but also the WWSSN stations at Corvallis (COR) Oregon, Longmire (LON) Washington, and the NEIS station at Newport (NEW) Washington. Phase velocities of Rayleigh and Love waves are measuresd along the lines between: 1) COR, LON, 2) LON, MCW, 3) LON, NEW. Earthquakes used are from three different source regions: 1) South Pacific Ocean, 2) Central America, 3) Southern California. These earthquakes are selected such that the difference between azimuthal angles for each pair of stations are within one degree, i.e. the travel paths are along the same great circle. The following sections will describe the data used and some preliminary results.

1. The data

The earthquakes used in the current report are listed in Table V-1, which includes date and time of occurrence, epicentral location, origin time and magnitude (if it is known). Figure V-1 shows the delineation of stations and the directions of approaching from each source region. Except MCW which was using an FM tape recorder as a data medium, all the data of the other three stations are helicorder paper records.

These records are hand digitized at a nonuniform sampling rate. The spiral trend of the recorder and the non-zero mean value are removed at the first step of data preparation. A linear interpolation routine is then applied to provide the necessary uniform increment in the data along the time scale (the sampling rate is 1 point/sec). The data is then passed through a zero-phase low pass filter which removes the high frequency noises introduced by hand movement of digitization.

The final digital data are plotted and compared with the original paper records to check if there is any discrepancies between them. Errors of digitization are within 2 seconds when the lengths of digital data are compared with the real time paper records.

2. Analysis

Since the difficulties of measuring phase velocities are related to the contamination of multiple arrivals, proper filtering and selection of signal sections is crucial to satisfactory results. Although several techniques of doing this measurement by the two-station method have been tried, the most satisfactory results are obtained by using the phase difference method. The time series are first analized by a moving window analysis (Landisman el al., 1969) to generate an energy plot in frequency and travel time domain. This result provides a reliable tool to select and adjust the group velocity windows which define the length of signal for the phase velocity measurement. After the selection of group velocity windows at each frequency, the phase value of the signal within this window is directly calculated by performing a Fourier integral. This is equivalent to narrow bandpass filtering of the signal (Landisman et al, 1969). The final step is the removal of the instrument phase response and calculating phase velocities by the definition:

3. Results

Figure V-2 to Figure V-4 are phase velocity dispersion curves for the station pairs: 1) COR, LON, 2) LON, MCW, 3) LON, NEW. There is little difference in the region of mantle phase, but three distinctly different branches of the higher frequency crustal phases can be recognized. Only with numerical modeling can the structures along these three lines be better defined. Therefore, we will focus our discussion on the errors in these measurements.

The cause and range of errors in phase velocies in this study can be categorized as follow:

1) Errors in origin time, epicenter location, station clock correction and digitization. The maximum range is about 5 seconds for the South Pacific events, and less for events from Central America, and Southern California.

2) Variance caused by different group velocity windows used to calculate the signal phase values, and the subjective decision made by the analyst to choose a particular window length in order to have a smooth dispersion curve. We will take minimum weight for this variance because it is the nature of this kind of measuremuent. This variance is within 0.02 km/sec.

3) Variance due to repetitive measurements. This term is evident when the number of measurements increases. In this study the maximum range is 0.04km/sec. In some cases of phase velocity measurement, people tend to ignore the errors caused by 2) and 3), because of the nature of the techniques applied or lack of repetitive measurement. In this study the range of the combined error is within 0.08 km/sec.

4. Summary

The phase velocities are measured along three lines in the state of Washington and Oregon. These lines represent three different geological regions, namely, Northern Columbia River Plateau, Puget Sound low land, and Willamite Valley. Future work will involve numerical modeling and inversion of the data to define the best models in these regions.