FINAL TECHNICAL REPORT

Oct. 1, 1981 - Sept. 30 1982

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Principal Investigator: R. S. Crosson
Geophysics Program AK-50
University of Washington
Seattle, WA 98195

Government Technical Officer: J. H. Pfluke
External Research Program
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

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SUMMARY

This report contains a summary of research under USGS contract 14-08-0001-19274 during the contract year beginning October 1, 1981 and ending September 30, 1982. The funding provided under this contract is mainly for network operation in western Washington but includes preparation of bulletins and some analysis of network data related to earthquake hazards. In this report, we include data and discussion on the earthquake activity during 1982 (annual), the network operation during the contract period, and description of the research work that was sponsored and related to the network operation. Where more extensive reports have been prepared, these are included as appendices to this report, however brief descriptions of these appendices are also included in the report text.

Network operations continued with few serious problems. Skagit Valley stations LYW and RPW were lost due to loss of funding for their phone line. An on-line P-picker was installed in late September of 1982 by Rex Allen and Jim Ellis of the USGS, and evaluation of a new amp/vco unit designed by S.T. Morrissey of St. Louis University was begun. In general, no unusual earthquake activity occurred in western Washington in 1982. Of course, Mt. St. Helens continued its pattern of episodic swarm activity associated with volcanism. The largest event was of M_C 4.4 located near Elk Lake, north of Mt. St. Helens. The total number of events in our catalog, including Mt. St. Helens activity was 469. A somewhat unusual group of 4 events occurred in the eastern Puget Sound basin, near Redmond.

Two graduate student theses were completed during this period, both of which are included as appendices. One was a study of the application of linear predictive processing to the automated discrimination of earthquakes and

explosions in a local or regional network (Hesser, 1982). Using digitally recorded data from known explosions and earthquakes within our network, some promising discrimination techniques were found. This work has obvious application to the ever present problem of event identification using network data and to the problems of developing automated network processing algorithms. The second thesis was a two-part study of focal mechanisms in the shallow earthquake distribution in the Puget Sound region and two unusual swarms of earthquakes that occurred near Seattle from 1971 through 1974 (Yelin,1982). In addition, a manuscript was published on a magnitude 4.6 earthquake that occurred in the south Puget Sound basin in 1978 (Yelin and Crosson, 1982), and another manuscript was prepared based on network data; a study of the Elk Lake sequence of earthquakes, north of Mt. St. Helens in 1981 (Grant et al., 1984).

Network Operations

A map view showing location of University of Washington telemetered seismographic stations is shown in Fig. 1. This contract supported Puget Sound stations west of longitude 121W. Appendix 3 includes a listing of stations used to locate events.

An on-line P-picker was installed in late September of 1982 by Rex Allen and Jim Ellis of the USGS. An evaluation of the system performance indicates that it cannot replace human analysts because it has a tendency to pick arrivals late, and is considerably less sensitive to low-amplitude arrivals. For Puget Sound data alone it seems to work somewhat better than average, probably because Puget Sound events tend to have fairly sharp P-wave first arrivals. The system is helpful in rapid location of shocks large enough to have been felt, and performs well on some of these events.

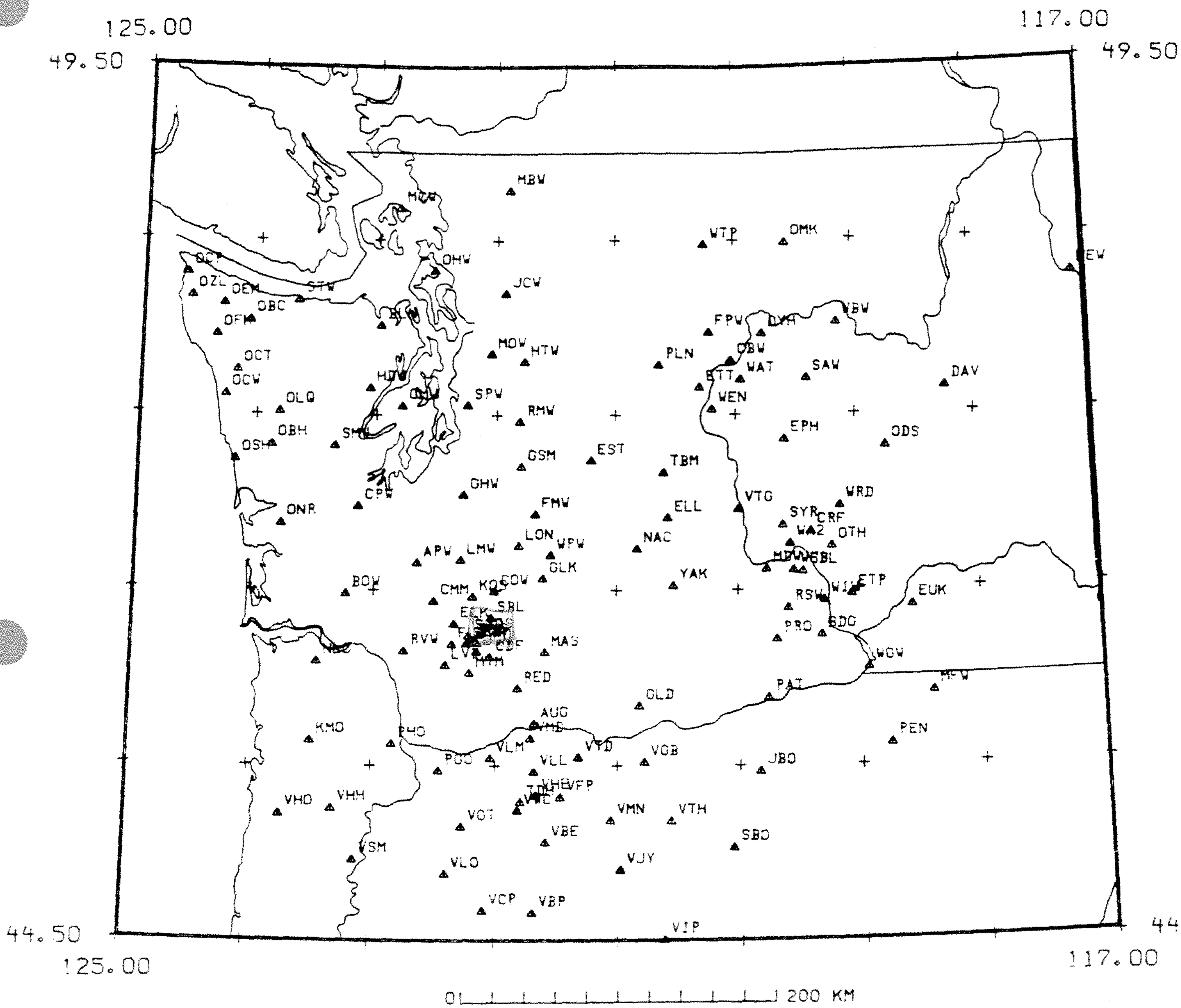

Figure 1. Locations of University of Washington telemetered seismograph stations. Large triangles are stations planned for installation or currently being installed. This contract involves station operation in western Washington, mainly west of 121 degrees exclusive of the Mt. St. Helens local network and the Olympic Penninsula Network..

Operations of individual sites were fairly stable. Skagit Valley stations LYW and RPW were discontinued due to loss of funding for the phone line, which had been paid for from a grant from the Washington Public Power Supply System. These stations will be reestablished using radio telemetry. A major data outage occurred at the Olympic Penninsula station BLN, lasting from mid-May to mid-December 1982. Logging operations damaged the installation, and continued logging activities made replacement impractical for several months.

Some changes were made in equipment at selected stations. A new amp/vco unit designed by S.T. Morrissey of St. Louis University was installed at MBW and FMW. The new amp/vco generates daily 3 Hz and 10 Hz sine-wave calibrations as well as DC pulses, giving us a daily record of the stations' response curve through the entire telemetry system. The FMW change was combined with installation of a calibrated S13 seismometer to replace the HS10 installed in 1972.

1982 Seismicity

This section summarizes the major observations of seismicity for western Washington during 1982. Although this does not correspond to the contract term, it is a more useful and standard interval. In this section we include an epicenter map as Fig. 2. Seismicity located between 46 and 49 degrees of north latitude and between 121 and 125 degrees west longitude with coda-length magnitudes greater than 1.5 is shown in Fig. 2, and cataloged in Appendix 3.

A coda-length magnitude (M_C) 4.4 earthquake in the vicinity of Elk Lake on 03/01/82 was felt from Portland to Seattle. This event is part of an aftershock sequence of over 1500 events following a M_L (Richter magnitude) 5.5 event in February, 1981. Another aftershock in the same sequence with coda-length magnitude 3.0 was felt on May 31, 1982. Both events occurred at essentially the

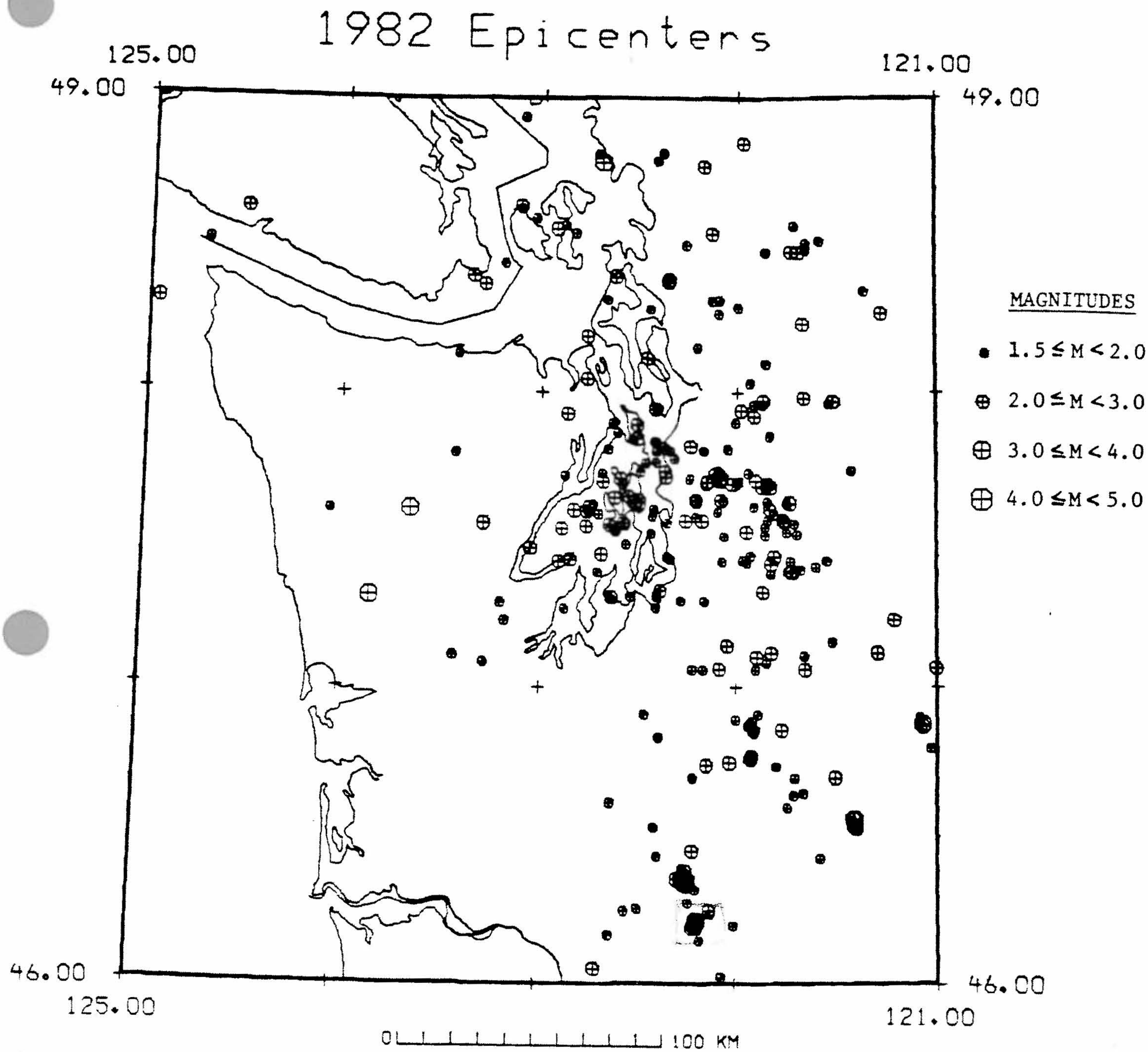

Figure 2. 1982 Earthquake epicenters in western Washington between 121° and 125° W longitude; 46° and 49° N latitude. Events shown have coda length magnitudes greater than or equal to 1.5. Explosions and probable explosions have been excluded.

same epicenter as the main shock, but about 5 km deeper. Focal mechanisms indicate nearly horizontal right lateral strike-slip faulting on a north-south striking plane (Grant, Weaver, and Zollweg,1984).

Four events were felt in the Redmond-Woodinville area during 1982. Two events took place on June 4, one on June 5, and one on September 15. All were at about 7 km depth. The June events were located about 3 miles northeast of Redmond, the September event about three miles southeast. Focal plane solutions for the first event on June 4 and the September 15 event are inconclusive, but consistent with maximum compression in a north-south direction. Seismicity shows an apparent increase beginning in November, 1981 in a quadrangle from 121.5° to 123° North longitude and from 46.75° to 48.25° West latitude which includes North Bend and Redmond (personal communication, Craig Weaver, 1984). The increase continues as of this writing (7/84).

Three other earthquakes were felt in the central Puget Sound basin southwest of Seattle in 1982. March 10 a magnitude 2.9 event occurred at 25 km depth on the Kitsap Penninusla near Cromwell. On April 14 a M_C 3.4 event at about 25 km depth on Bainbridge Island near Winslow was reported felt in Seattle, Burien, Port Orchard, and Bremerton. An October 15 event in the vicinity of Port Orchard on the Kitsap Penninsula was felt in Bremerton. This event, also at 25 km depth, had M_C of 3.4.

Other notable activity in 1982 included a shallow event (4 km) of M_C 3.4 on Sept. 26 located 40 miles north-west of Yakima in the Cascade range near Cliffdell, WA and felt in Naches, WA. Two events, M_C 2.2 and 2.0 were felt in Van Horn, WA on January 21st. These events are unusually small to be felt, but occurred at very shallow depths. On January 30th an event of M_C 3.1 was felt in Ferndale, WA and Saanich, B. C..

Eruptive activity at Mt. St. Helens continued in 1982, with primarily dome-building eruptions occurring in March-April, May, and August. The March 20 (U.T.C.) eruption began explosively, and was preceded by a long sequence of small earthquakes occurring at depths of 4-12 km. Earthquakes at similar depths followed the explosive eruptions of 1980, but were not previously associated with dome-building eruptions. The sequence has been interpreted as being due to upward migration of magmatic gas from a deep reservoir beneath the mountain (Weaver, et al., 1983). A major mudflow, the largest since May 18 1980, was generated by snowmelt in the crater after the explosion. A second explosion-mudflow sequence occurred on April 4, 1982, but was smaller than that of March 20. Both the March and April explosions were followed by episodes of dome-building. The May and August dome-building eruptions were not explosive, but occurred after vigorous swarms of shallow volcanic earthquakes. Cumulative energy release in shallow earthquakes for the March and August pre-eruption swarms was greater than for any other eruption since the catastrophic explosion of May 18, 1980.

A swarm of shallow events occurred under Mt. Rainier in late December and continued in January, 1983. Only a few events were locatable. An event of note took place outside the area shown in Fig. 2. This event is not included in Appendix 3, but was felt near Woodland, WA on the Washington- Oregon border November 21, 1982. This earthquake is of interest due to its proximity to the Trojan Nuclear Power Plant. Location, magnitude, and other information are given here in standard format as used in our catalogs (complete description in Appendix 3).

DAY	TIME	SEC	LAT	LON	DEPTH	MAG	NS/NP	RMS	Q	MODEL	TYPE
21	4:57	32.84	45 54.31	122 53.45	24.38	2.7	21/21	0.15	AD	P1	F

Linear predictive processing, pattern recognition, and event discrimination.

In an MS thesis completed in 1982, Hesser (1982) explored the application of linear predictive filtering and pattern recognition to the discrimination of seismic events such as explosions and earthquakes. This work was motivated by the success that linear predictive analysis (LPA) has enjoyed in speech recognition and synthesis. The basic idea is that complex waveforms (such as speech) can often be reduced to a relatively small number of parameters by linear predictive estimation of the autoregressive coefficients when the autoregressive model is a reasonable approximation to reality. In the case of speech, the source is a quasi-stationary repetitive process and the voicing is characterized by the autoregressive coefficients. A corresponding analog for a seismic event would reverse the roles in that the source would have the autoregressive description, and the transmission medium would have the quasi-stationary description. In neither of these cases does the model hold strictly, but in practice the method works well in speech synthesis (the Speak and Spell toy is a common example). Application to seismic signals is made in an attempt to reduce the source characteristics to a relatively small number of manageable parameters. The alternative is to treat the entire waveform which in practice is impossible computationally because of the large number of coefficients required, and furthermore a great deal of redundancy exists in this case. The small number (of the order of 10) of coefficients can then be utilized in formal pattern recognition schemes to separate categories of events (e.g., explosions vs. earthquakes) on the basis of their feature vectors. In Hesser's study, this analysis was done empirically.

Hesser found that there were distinctive differences in the extracted parameter vectors between earthquakes and explosions. These are illustrated dramatically by the diagrams on pages 97 to 100 of his thesis. These diagrams can be thought of as a type of deconvolved seismograms which reflect the source complexity. The dramatic differences in complexity between the earthquakes and explosions indicate that the explosions have a far simpler source time dependence than earthquakes as one might imagine. Hesser was able, with good examples, to obtain essentially 100 percent success in classification using the extracted vectors. This success would clearly not be achievable in routine practice, but nevertheless the method has promise. Although this research provides a promising basis, implementation of this method on a routine basis for network operation is still a major undertaking with which we are not proceeding due to manpower, computing, funding, and priority limitations. Such a task should be undertaken but would require a new subproject organization and additional computing resources. Hesser's thesis is included in this report as Appendix 1.

Study of Seattle Swarms and Focal Mechanisms

In an MS thesis completed during this contract period, Yelin examined two swarms occurring near Seattle between 1971 and 1974, as well as completing an analysis of focal mechanisms of shallow earthquakes in the Puget Sound basin. The two swarms had an apparent temporal connection (the first swarm ceased abruptly when the second began) but were widely enough separated to appear spatially independent. The structures on which these two swarms occurred are unknown, or at least not understood in terms of the shallow regional structure. Swarm 1 was located on the east side of Lake Washington at a depth of about 20 km. Although this swarm was elongated in a NE direction, an error ellipse analysis indicated that this is in part due to the station distribution. However, the limited polarity data from this swarm do not contradict a NE trending fault surface as the origin. A repeat of this swarm with the current station distribution would no doubt resolve this issue. The second swarm occurred on the west side of Lake Washington, at a much shallower depth (less than 10 km), near the central part of Seattle. This swarm provided little evidence upon which to judge the causative structure.

In the second part of his thesis, Yelin analyzed 27 well recorded earthquakes occurring between 1976 and 1981 for focal mechanisms. An objective of this study was to relate P axes for the overlying plate (continental plate) to the regional tectonics. Yelin found that there was somewhat more variation for earthquakes with focal depths less than 10 km, but that deeper events yielded P axis directions that were quite consistent with NS compression. This is a result that tends to confirm, with a higher quality data set, the P axis directions found from other studies of shallow earthquakes both in eastern and in western Washington. There is still substantial uncertainty as to why these observations are not consistent with stress trajectories predicted from underthrusting. Yelin suggests some sort of partial decoupling as a possible explanation. Yelin's thesis is included as Appendix 2 of this report.

Elk Lake earthquake and aftershocks

The magnitude 5.5 Elk Lake earthquake which occurred on February 14, 1981 a distance of slightly less than 20 km north of Mt. St. Helens, was the largest earthquake to occur in Washington State since the introduction of telemetered seismograph networks in about 1970. The mainshock occurred at a depth of about 6 km and a large number of aftershocks were generated ranging in depth from near the surface to almost 15 km. This event is reported in detail by Grant and others (in press). Grant et al. postulate that the earthquake resulted from right-lateral strike-slip rupture on a fault plane oriented slightly west of north, and that the rupture propagated bilaterally and downwards. Focal mechanisms of many of the aftershocks are consistent with a single rupture surface, and Grant et al. postulate that the time sequence of events in this region correlate well with an asperity model.

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Appendix 1

LINEAR PREDICTIVE PROCESSING AND PATTERN RECOGNITION FOR

AUTOMATED CLASSIFICATION OF SEISMIC EVENTS