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on

Earthquake Monitoring of the Hanford Region, Eastern Washington

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Geophysics Program

University of Washington

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I. INTRODUCTION AND OPERATIONS

There has been a significant change in the operations of the eastern Washington seismic network during the past year. The field operations and the station distribution has changed little; the recording and data reduction has changed a great deal and is still in a state of flux. The seismic stations of the current network are listed in table II-1. The on-line computer recording system is now fully operational and the off-line processing routines are developed to the point where they are usable but are not polished to their final form. There is considerable work left to do before routine processing can be accomplished with reasonable dispatch.

The arrival of an active volcano in our backyard has presented numerous problems which we have had to deal with as best we can. Its timing was both good and bad; good that the on-line system was up and running and recorded thousands of earthquakes, bad that the off-line analysis routines were being developed at the time and thus were not available to help process these data. The Mount St. Helens data that has been processed was done mostly by hand; at least until very recently. As of July 1 we are processing data within a few days to a week of its being recorded.

The rate of earthquake activity at Mount St. Helens is no longer extreme; it compares with the activity throughout the entire rest of the state now. During the height of the pre-eruption earthquake swarm we were recording as many as 600 events per day, only 10% of which were not earthquakes from the volcano. Presently there are an average of about 70 triggers of the on-line system per day, 50 to 60 of which are not seismic events of interest. These non-earthquakes include wind or vehicle noise as well as telemetry noise due to radio interference or telephone problems. While the on-line system had to work about 5 times harder during the March 20 - May 18 period, the amount of data to process by the off-line system was over a hundred times greater than that of the previous two months. During the period January 1 to March 20, seven magnetic tapes were filled with earthquake data needing analysis. During the following two months over 250 tapes were filled. The amount of data which must eventually be processed is astounding. Because of the importance of timely analysis of at least some of the Mount St. Helens data, the analysis of much of the data from other parts of the state is being postponed until it can be done efficiently and acurately with the off-line processing system.

The plan is to start keeping up with all of the current data and then work backwards to catch up on the past half year. We intend to process all of the non-St. Helens data before trying to systematically look at the some 20,000 earthquakes in the St Helens sequence. This is almost four times as many events as have been located in the entire state over the past 10 years. The eastern Washington earthquake data will be processed as soon as the off-line system is stable and we can then begin to work our way back through it. This report does not contain information about earthquakes which occurred since Jan 1, 1980.

Even though St Helens earthquakes do not directly impact the DOE operations and structures in eastern Washington, the volcano surely has had some impact. As part of this report we include in the appendix the monthly seismic reports which we have put together as part of our response to the activity there.

Other aspects of our research on eastern Washington seismicity and structure has continued and is covered in separate sections in this report.

Section II contains the analysis of the seismic data from the first half of this fiscal year. This includes a brief description of one of the swarms which took place last fall in the Cold Creek valley, and some of our work on stong motion seismology as well has a summary of a P-delay study of the Cascades. Section III is the interim report on our fracture studies. This includes the description of well log analysis for the purpose of classification of basalt rock units from well log data alone. Crack logs of core taken from hole DC-8 have been analyzed for rock quality and permeability. Section IV is a comparison of the geology and seismology of several different basalt plateau regions. The Columbia River Basalt Plateau is compared with the Deccan Traps, the Karroo basalts, and the Serra Geral basalts. The shear wave velocity structure study is included in section V. Both group and phase velocity curves for western Washington and the Cascades have been calculated and the data have been obtained for the eastern Washington structure. Section VI is a detailed description of the computer recording and analysis system nearing completion. It includes manual pages for the principle analysis programs as well as a discussion of the details of the real-time programs in the on-line system.

We are anticipating a significant change in our field operations. The high quality recording of the on-line computer system has made it obvious that the weak points in our instrumentation are station reliability and calibration. In order to upgrade the quality of the remote stations we feel that sevice personnel must both be physically near the remote stations and have no other obligations to distract them from maintainance duties. After numerous discussions with other people involved with the operation of large seismic networks we have concluded that the best way to accomplish this is to subcontract remote station maintainance to a firm that specializes in this activity. There are several such firms which have expressed interest in doing this type of work in eastern Washington. Tentative cost estimates indicate that it will cost roughly the same as our present field operations. Our contract proposal to DOE for next year's funding reflects this change by reducing our technical staff and supplies.

TABLE II-1 EASTERN WASHINGTON SEISMIC STATIONS

STA	LAT	LONG	ELV(km)	S. DELAY	N.DELAY	TIME	NAME
MDW	46 36.80	119 45.65	.330		.53	7/75-	Midway
SYR	46 51.78	119 37.07	.260		.47	7/75-	Smyrna
OTH	46 44.34	119 12.99	.26		.39	7/75-	Othelo
WAH	46 45.12	119 34.68	.230		.55	7/75-5/78	Wahluke
WA2	46 45.40	119 33.76	.23		.55	5/78-	Wahluke2
CRF	46 49.51	119 23.09	.260		.47	7/75-	Corfu
GBL	46 35.86	119 27.59	.360		.57	7/75-	Gable
ETP	46 27.89	119 03.54	.250		.30	7/75	Eltopia
BDG	46 14.08	119 19.05	.410		.48	7/75-	Badger
EUK	46 23.75	118 33.72	.400	-.10	.26	7/75-	Eureka
PRO	46 12.76	119 41.15	.600		.54	7/75-	Prosser
RSW	46 23.47	119 35.32	1.130		.62	7/75	Rattlesnake
PEN	45 36.72	118 45.78	.460	-.15	.18	7/75-	Pendleton
WGW	46 2.88	118 55.96	.160		.35	7/75-	Wallula Gap
WIW	46 25.93	119 17.29	.130		.55	7/75-	Wooded Is.
HER	45 50.14	119 22.85	.190		.47	7/75-11/77	Hermiston
IRG	45 53.15	119 29.92	.200		.47	11/77-6/79	Irrigon
MFW	45 54.18	118 24.35	.430	-.15	.18	7/75-	Milton-Free
OMK	48 28.82	119 33.65	.450	-.12	.23	7/75-	Omak
DYH	47 57.63	119 46.16	.900	-.20	.07	7/75-	Dyer Hill
WBW	48 1.07	119 08.23	.910	-.22	.11	7/75	Wilson B
SAW	47 42.10	119 24.06	.800	-.25	.06	7/75-	St. Andrews
CBW	47 48.42	120 01.96	1.290	-.30		7/75-	Chelan B
WTP	48 28.27	120 14.87	.855			7/77-	Winthrop
FPW	47 58.00	120 12.77	.360	-.30		7/75-	Fields Pt.
PLN	47 47.08	120 37.97	.670	-.30		6/77-	Plain
ETT	47 39.30	120 17.60	.930	-.30	.09	6/77-	Entiat
WEN	47 31.77	120 11.65	1.140	-.30		7/75-	Wenachee
EPH	47 21.13	119 35.77	.500	-.14	.20	7/75-	Ephrata
ODS	47 18.40	118 44.70	.610	-.20	.11	7/75-	Odessa
DAV	47 38.30	118 13.56	.780	-.20	.11	7/75-	Davenport
WRD	46 58.19	119 08.60	.410	-.05	.35	7/75-	Warden
WAT	47 41.92	119 57.25	.900	-.25	.04	11/76-	Waterville
ENT	47 40.73	120 13.80	.860	-.24	.07	11/76-6/77	Entiat
VTG	46 57.48	119 59.24	.210		.28	7/75	Vantage
NEW	48 15.83	117 07.22	.830			5/77-	(USGS)
FMC	45 37.47	120 01.70	.300	-.20		1/77-	(PGE-local)
RPK	45 45.70	120 13.83	.330	-.20		1/77	(PGE-local)
ALD	45 49.17	120 04.00	.290	-.20		1/77-	(PGE-local)
GLD	45 50.33	120 48.85	.610			11/77-	Goldendale
NAC	46 43.98	120 49.47	.738			6/79-	Naches
ELL	46 54.58	120 34.10	.805			7/79-	Ellensburg
YAK	46 31.73	120 31.22	.619			6/79-	Yakama
EST	47 14.28	121 12.53	.756			7/79-	Easton
TBM	47 10.17	120 31.00	1.064			9/79-	Table Mt.
RPW	48 26.90	121 30.82	.850	-.20		6/77-	Rockport
WPW	46 41.92	121 32.42	1.200			4/80-	White Pass

II SEISMICITY

by Al Rohay, Steve Malone

There have been no highly unusual earthquake sequences in eastern Washington during the past year. The normal activity in the south Lake Chelan area has continued at roughly the same level as in previous years. There have been several swarm sequences, most in areas which have had previous swarms. There was a felt earthquake north of Yakima on December 10, 1979 (magnitude 3.4).

A swarm which occurred from October through December, 1979 was one of the most intense swarms in the past five years. Almost 60 earthquakes have been located in this swarm with an average epicenter of 46° 55.34' North 119° 34.49' West ±1.2 km. This is just north of Royal City on the Royal Slope. The average focal depth for these events was 2.3 ±1.4 km as determined by the regional array whose nearest station is 7 km away. The largest event in this swarm was a magnitude 3.4 earthquake on November 24, approximately the middle of the swarm. In just about every respect this swarm had similar characteristics to most of the other swarms that have occurred in the Columbia Basalt Province.

In early January another smaller swarm began in the Corfu area. This swarm did not last as long nor have as many earthquakes as the Royal City swarm. The data for this swarm are not fully processed since it was recorded by the on-line system.

Cold Creek Earthquake Swarm

A small swarm of earthquakes occurred in the Cold Creek syncline area on September 8, 1979. This is an area which has had very little previous earthquake activity. Seven events occurred in a three hour period with one large event (magnitude 2.4) followed by six smaller events. There had been three earlier events in this sequence one and two months earlier. A magnitude 2.1 event occurred the following day (9/9/79) with another earthquake a month later.

The average depth for these events was 3.0±0.8 km which is deeper than for other swarms. This may be an artifact of the data reduction since the nearst station is 8 km away which means that the depth control for shallow events is not particularly good. Spatially the entire swarm was bounded by a rectangle 2 x 3.5 km, elongated in the east west direction much like other swarms. The events on 9/8/79 were concentrated in the center of this area.

Similar to other swarms studied, focal mechanism plots indicate that different events within this swarm produced differing polarities at some stations. This indicates some variability in the slip planes. A composite plot of the first motion data for this swarm is shown in figure II-1. The plotting of these data are particularly sensitive to the depth of the events and to the velocity model. Errors in one or both of these parameters may cause some of the inconsistencies in the first motion data. Our best estimate of the appropriate nodal planes is similar to those of other swarms studied. A NNW-SSE nearly horizontal compression axis and near vertical tension axis is indicated. Possible slip surfaces inferred from the composite plot are either nearly horizontal (dipping 20° to 30° to the north or north-west), or near vertical (dipping 60° to 70° to the south or south-east). The strike of the possible slip planes are east to north east in either case. All mechanisms are primarily thrust with only a minor strike-slip component. Since the spacial distribution of the events is tight with no obvious trend, it does not help determine the ambiguity between the fault plane and the auxilliary plane.

Strong Motion Seismology

The end result of studies of seismicity, faulting, and tectonics is an estimate of seismic risk or seismic hazard. The hazards to facilities are vibratory ground motion during an earthquake, fault slip during or subsequent to an earthquake, and continuing fracture and deformation associated with tectonic stresses in the crust. Several programs are underway to begin to look at the vibratory ground motion of earthquakes which might occur in the eastern Washington region. These are basic research programs and thus will provide additional insight into ground motion studies, but should not be expected to provide specific engineering estimates for present or proposed structures in the area. Our previous work on seismic attenuation is a good example of a basic research effort which subsequently had some specific value to engineering problems in Washington state through its impact on the location of the 1872 earthquake.

Current areas of study include a review of data from the destructive earthquake near Gazli in the U.S.S.R., analysis of strong motion data from some of the larger earthquakes in the Mt. St. Helens eruptive sequence, and analysis of data from an array recording of the El Centro earthquake of 1979. Each of these examples has some important bearing on ground motion estimations for large facilities in eastern Washington. The Gazli record is of unusual significance since it is the closest instrumental recording of a large (Mag 7 +) earthquake, and presents some new and valuable information on earthquake source dynamics. Translation of basic papers relevant to this earthquake have been completed, and the digital data for ground motion has been obtained. Some correspondance has been established with Soviet investigators who are also interested in special studies of this important earthquake.

The Mt. St. Helens data, and the El Centro data are of special importance because they are the first examples of significant earthquake ground motion recorded on arrays of strong motion (50-300 meter spacing) and thus can be used to look at coherence of ground motion across distances comparable to the dimensions of refineries and waste repositories. Until very recently all earthquake engineering has been under the assumption that an entire structure is simultaneously subjected to the maximum loading of vibratory ground motion. This is probably a signifcant overestimation of actual structural loads because the wave front arriving from a nearby earthquake is not perfectly flat and arriving from directly beneath the structure. It arrives at some vertical angle and thus there is a delay between when the motion arrives at the extreme edges of a structure. Furthermore, the wavefront is not flat or coherent which results in an averaging effect taking place over the foundatin. Both of these effects together have become known in the past several years as Base Averaging Reduction Factors, and it appears that they can be responsible for significant reductions in the earthquake loads that need be considered for very large and massive structures. We have available both sets of digital array data for St. Helens and El Centro and are beginning analysis of the wavelength and frequency spectrum, as well as a coherence calculation.

Teleseismic P-Delay Study

As part of our work on regional crustal structure, a P-delay study of the Cascades and adjacent areas has been under taken by Al Rohay. This study is nearing completion; a paper is currently in preparation. A preprint of this paper will be submitted to DOE as an appendix to this report as soon as Al has completed it. The following is a summary of this paper.

Teleseismic P-wave residuals recorded by a three-hundred kilometer long east-west network of seismic stations in northern Washington indicate a major high velocity anomaly beneath the Cascade Mountains. Relative arrival time differences of up to two seconds are observed for events from easterly azimuths (345 to 165 degrees). There are much smaller travel time differences from the westerly azimuths. This pattern of residuals is compelling evidence for an eastward dipping high velocity slab beneath the north Cascades. The position of this slab indicates that the geometry of the subduction zone did not bend to conform with the bend in the edge of the North American plate, but continued to strike approximately NNW-SSE parallel to the British Columbia coastline.

An analysis of a north-south network of stations in the Washington Cascades indicates that a change in the geometry of the slab occurs at 47.5 degrees north latitude. While the relatively early arrival times in the north Cascades are still of the same magnitude relative to this network as for the east-west network, the southern cascades show no evidence for a high velocity slab. The change in geometry may indicate an offset in the subducted slab to the west in the south Cascades, or that the slab may have been reheated more rapidly there.

The position of the break corresponds to a change in the volume and type of Cascade volcanism, and to an offset of the Quaternary volcanism to the west of the Garibaldi-Baker-Glacier Peak line of volcanic centers. The position of the break also corresponds to the change in geology in eastern Washington, the southeastern region dominated by the Columbia Plateau basalt flows.

There is evidence for a local, near surface low velocity anomaly at Mt. Rainier based on the relative travel times at stations north and south of the volcano in the south Cascades.

ON-LINE RECORDING

The on-line recording system is very closely modeled after the CEDAR system conceived and implemented at Cal Tech by Carl Johnson.[1] The code which we are running was written by Carl Johnson and Alex Bittenbinder and is virtually identical in basic design to that which Carl wrote for the Cal Tech Data General Nova Computer. Obviously the details are different since it is running on a different type of computer with a vastly different operating system.

The basic concept is one of saving all incoming seismic data in digital form on a disk file for only a short period of time. During this time the data are examined to see if a seismic 'event' is underway. If an earthquake, explosion, or other such seismic event is taking place, the data from the disk are transfered to magnetic tape for later analysis. If no such event is taking place then the disk file is simply over-written by new data. In this way the disk file acts as a delay line giving the computer time to look at enough data to make an intelligent decision about whether an event of possible interest is occurring or not. The begining of the event is not lost since data is transferred from the disk to tape from some period before the decision had to be made.

The decision-making process involves two separate steps, one for individual channels of incoming data and the other for combinations of channels that form subnetworks of the 83 total channels. Four statisical parameters are formed for each data channel; these are both a long and short term average of both the rectified and straight signal. By comparing the short term with the long term averages, a fluctuation in the signal from any individual channel can be quantified. When the fluctuation is large enough, a trigger on that channel is declared. Since there are many causes for such fluctuations other than seismic

[1] *CEDAR -- An Approach to the Computer Automation of Short-Period Local Seismic Networks*. Carl Johnson, California Institute of Technology Ph.D Disertation, 1979.

events of interest, it is not desirable to record and save the data when any single channel has an active trigger. The next step of the detection routine is to lump a number of channels together into subnets for which more than one or even two channels must have a trigger active at the same time. To be of much seismological interest an event must be recorded on more than a few stations within a short period of time. When enough channels within a given subnet have active triggers, an 'event' is declared and transfer to magnetic tape is started. First a header is written to tape which includes all information necessary to identify subsequent time series data such as station names, digitizing rate, and absolute time at the begining of the event. Other interesting information about the trigger is also saved in the header. Transfer of data to tape continues until some time after all subnet triggers have turned off.

Any given seismic network configuration must be tuned to maximize the recovery of useful data and minimize the recording of useless data. A number of parameters are adjustable for determining how sensitive the detection scheme will be. The subnets must be configured keeping sound seismological considerations in mind. How the seismic stations are grouped in subnets and how many active stations within each subnet are required for event triggering must be examined with some care. The length of time any station trigger, as well as the master event trigger stays active, are all adjustable. Experience with operating the system when other methods of continuous recording are available is quite helpful in maximizing its efficiency.

The individual units of the real time system run under the RSX-11M DEC multi-tasking operating system. We currently have 80,000 words of memory and capacity for 128 channels of data although we are only running 96 channels presently. While the system is running there is enough space and time left over to run the file maintaince utilities as well as a small editor. This allows us to do minimum software development, configuration adjustment, and other housekeeping tasks while the on-line system is running. The following routines are separate parts of the on-line system that operate as separate tasks but communicate through a common area of memory.

CORE This is the main task which does all the IO and runs the LPA digitizer. It sets up and initializes the digitizer, controls the disk transfers, and controls the mag-tape writing. All crash diagnostics are issued by *core*, and it checks the timing to make sure everything is getting done.

TRIGR This is the trigger routine that computes all the statistics for each channel, checks the subnets, and can declare an event trigger such that *core* will start saving the event on tape.

LOGGER This is a small task to simply issue one line of information to the console when ever an event has occurred.

Other routines which help maintain the system and communication between the different parts of it include the following:

COMMON This is a separate partition in memory which all tasks have access to and can modifiy if need be. Part of COMMON is where the incomming data goes before being written to disk. It also contains all the channels statistical information as well is the network configuration. Intertask communication such as declaring an event to be starting or ending is handled through flags in COMMON.

WRTCOM This is an independent routine which is used to save the configuration part of *COMMON* on a disk file. It can be run while the on-line system is active to take a snapshot of the current state.

RDCOM This does the reverse of *WRTCOM* by reading a file called COMMON.DAT and loading the COMMON partition of memory. A combination of these two routines, with a text editor modifying the intermediate COMMON.DAT file is used when a change in the system configuration is needed. This can usually be done without bringing the system down.

There are currently two versions of this on-line system available. The first version which was operational early in 1980 will run only one A-D multiplexer and therefore is limited to only 64 channels. It also does not have some of the frills that the second version, which was completed in May 1980 has. These extras include the *logger* task as well as capability for an external high accuracy clock and a crash alarm system. This version will also handle two A-D systems and therefore can accomodate up to 128 channels.

Since the on-line systems have been running, we have had very good success in recording seismic events in Washington. There have been over 20,000 triggers since we began. Over half of these are seismic events of some potential interest, although 90% of these are from the Mount St. Helens earthquake sequence. During the relatively normal times when Mount St. Helens is not producing great quantities of earthquakes about three-quarters of the on-line system triggers are not seismic events of interest but are caused by various noise sources such as wind, vehicles, or telemetry noise. We consider this an acceptable rate of false triggers since we have the system tuned to a fairly senstitive level.

OFF-LINE PROCESSING

Once a tape has been written by the on-line system it is moved to the PDP-11/70 for analysis. While the on-line system has been running for some time now the off-line analysis is far behind. There is considerably more computer code involved with the many different aspect of processing the data. Like the on-line system our off-line system is closely based on the work of Carl Johnson. Some of his computer code has been adopted to our particular needs and other code has been written from scratch. The general concept of data flow is much like that of the CEDAR system at Cal Tech although our large disks and the tree structure of the UNIX file system facilitates the data organization and book keeping. The following sections outline the different steps taken in analysing the seismic data. Manual entries for the individual programs used are included as part of this document.

Preliminary Trace Plots (PTPLOT)

The program **ptplot** [2] is used to produce a two page preliminary trace plot of each trigger on the original 11/34 data tape. Only the first thirty seconds of the triggered stations are plotted on the Versatec electrostatic plotter so that each trigger can be visually examined to determine if it represents a seismic event of interest or noise. **Ptplot** also produces an index with the time of each triggered event and its length listed. **Ptplot** normally plots only the triggered stations but has many options for plotting any set of channels at various gains and decimation factors.

Demultiplexer (DMUX)

The routine **dmux** is a one pass demultiplexer that puts the trace data from the 11/34 data tape directly on to disk files. The data from each triggered event is stored on a single disk file with the channels run end to end. Before **dmux** can start it must know how long the data for each channel will be. This information can be obtained from the index produced by **ptplot.** [3] The data for each event is

[2] Each routine which handles the 11/34 data directly has two versions; one for the older version of the on-line system, and a second for handling the newer version which has much longer header records. The new version has an **l** prepended to the name such as *lptplot*.

[3] Currently this information must be entered by hand as an argument to **dmux**. A new version is being written which will automatically use the index information as well as do book keeping in a *history* file.

stored in two files; one which contains the header information and one which is just the trace data.

Interactive Trace Picking (PING)

To obtain arrival time information and other parameters from the trace data an interactive picking routine has been written which uses a Tectronix 4014 graphix display terminal. This routine, called **ping** heavily uses the high speed interface to the 4014 for rapidly displaying the trace data for an operator, using the cursor controls to 'pick' information for later analysis. **Ping** can take a list of stations either from a separate file or from the key board and display any number of channels simultaneously in a decimated form. The operator then choses which channels are to be examined more closely by using the cursor. These channels are then displayed one at a time. Each may be scaled in either time or amplitude and band passed filtered to bring out special features. Both P and S can be 'picked' with weights and polarity being input by hand. If absolute time is not known from the header information, a time code trace will be displayed for 'picking' a known time to establish absolute timing. The output of **ping** is a *pickfile* which looks very much like old fashion phase cards. This file is in a free format and has a lot of flexibility for including other types of data. Comment lines can be freely used in **ping** which will be kept in the *pickfile* and passed on by all subsequent analysis. **Ping** can reread events already processed and use the *pickfile* to show where picks have previously been made. If the event has been located the time residuals for each channel are displayed along with the previous pick.

Location Routine (PONG)

We are currently using a modified version of HYPO79P which comes from the U.S.G.S. This routine has been modified to process one event at a time and use our *pickfile* format for both the input and output. Our version of this location routine is called **pong** which rewrites the *pickfile* with a new first line containing the location of the event and time residuals for each station. (Note that one can go back and forth from picking an event to locating and back to picking in a ping-pong fashion.) **Pong** is actually a small 'shell' script that may exist in different directories in different forms and contains such information as the velocity model, and weighting coefficents. It calls the actual location program from a separate directory.

Final Hardcopy Plot (PUNT)

After an event has been picked and located a final plot can be made using **punt** which will include all phase and location information along with plots of each picked station with a cross-hair marking each pick. This plot is used as the permenent visual record of the event and is easier to access once the trace data for the event has been archived on tape and removed from the disk file system.

Data Compression and Archiving (SQUASH)

The trace data for an 80 station network is quite voluminous and would be cumbersome to try to keep it around in its entirety. For most earthquakes, *i.e.* the smaller events, only a part of the seismic network will be sensitive enough to detect it. The data for stations which do not detect an event need not be kept. The program **squash** rewrites the data files using the *pick* file to determine what data to keep. Stations for which phases have been picked as well as any other stations listed will be saved by **squash**. Typically a compression factor of from 4 to 6 is possible. This means that the number of events available for rapid retrieval from an RP06 disk increases from about 150 to over 600. Ultimately the trace data is stored on standard archived tapes in the compressed form.

Future Improvements

The processing system as outlined above has been in operation since the begining of July and seems to be able to keep up with the level of earthquake activity which we are currently having. There are several major additions which will be shortly forthcoming. The concept of a *history* file will soon be implemented. This will be a file which has a one line entry each time some action is taken on an event. For example when an event is first demultiplexed an entry will be made indicating that this has happened. Each time it is picked or located an entry will be made. In this way a search of the *history* file keyed to the event's time will describe everything which has been done to it.

An automatic picker is available in an algorith developed by Rex Alen. We plan to implement this routine to do the preliminary picks for events which will later be checked by an analyst. There are numerous minor other modifications which will be added as they are developed and as time allows.

University of Washington and U.S. Geological Survey

Mount St. Helens Seismic Report

May 1 to May 31, 1980

On May 18, 1980 at 0832 local time (PDT) a major geological event occurred with the cataclysmic eruption of Mt. St. Helens. The eruption followed two months of intense seismic activity, that began with a single magnitude 4.0 earthquake on March 20, 1980. Prior to March 20, only a single seismic station was operating within 50 km of Mt. St. Helens. By May 1, a total of 15 seismographic stations were operating within a radius of 32 km of the summit, including one station on the Dogshead. The station distribution included both telemetered stations being recorded in real time at the University of Washington and 5-day recorders that operate remotely in the field. The eruption of May 18 destroyed three telemetered sites and two of the 5-day recorders.

Virtually all of the earthquakes prior to May 18 occurred in a small area of 5 km radius centered approximately 2 km directly north of the summit (Figure A-1). Depths range from 0 to about 5 km with a few events possibly as deep as 10 km beneath the average topographic surface. Because of a lack of control on the velocity structure, the depths of the earthquakes are still preliminary, but it seems probable that many moderate earthquakes (magnitudes 3 to 4) occurred at shallow depths near the base of the volcanic edifice.

The blast of May 18 was preceded by no anomalous seismic activity on a time scale of hours to days. As noted in the April report, count and energy statistics have been kept since the beginning of the earthquake sequence for earthquakes exceeding magnitude 3.2. After reaching a peak of 8 to 10 earthquakes per hour at this threshold level during the evening of March 25, the rate of activity declined irregularly until the explosive event of May 18. The rate of seismic energy release followed the count curve, although the decrease is not as great. This reflects the fact that large earthquakes continued at a slightly increasing rate through April and May, while the smaller events decreased in frequency. Earthquakes larger than magnitude 4 occurred at an average rate of 5 per day in early April and at the rate of 8 per day during the week preceeding May 18; the number of events larger than magnitude 3 went from 77 to 28 during the same period. The largest magnitude earthquakes recorded in the entire sequence were in May prior to the eigthteen and were approximately magnitude 5.

At 0832 on May 18, an earthquake occurred at a depth of 3 km beneath the bulging north side of the volcano. This event appears to have triggered a landslide on the north side of the mountain which led imediately to the explosion. A standard Wood-Anderson seismograph in Seattle recorded a magnitude 5.1 event at this time though the signals are more complicated than expected for a single earthquake. After the initial seismic event was over (it lasted for over 8 minutes) the earthquake activity dropped back to a level of only one or two discrete events per minute. This period of relative quiesence lasted for over three hours when both the earthquake activity and volcanic tremor increased. There was a steady increase in the level of seismic activity from 1140 PDT until 1530 PDT when all seismic stations within 100 km were completely saturated by strong tremor; at times tremor was recorded 250 km away during the May 18 eruption. Around 1730 PDT the tremor and earthquake activity abruptly diminished, although low-level tremor continued to be recorded on the mountain for much of the remainder of the month of May. One change in the seismicity associated with the eruption was a significant deepening of the earthquakes. Prior to the eruption, seismicity was confined to the upper 10 km of the crust; after the eruption the earthquakes are much deeper, most located between 10 and 20 km. Similiar observations have been made for the May 25 eruption.

The tremor during this period was not the monochromatic "harmonic" tremor that had been seen earlier during non eruptive periods. The tremor on May 18 was characterized by many bursts of large amplitude motion with a variety of frequency components. The source of this tremor is likely the movement of magma up to and out of the eruptive vent. The pulsating nature of the tremor may be due to individual explosions within a continuous eruptive process. The relativly quiet period between 0842 and about 1140 PDT suggests that juvenille material was not being erupted (hence no major movement of magma and no strong tremor in the volcanic system) rather the vent was being cleared of old material by large phreatic eruptions. After the removal of a large part of the north side of the mountain by the avalanche and the subsequent phreatic eruptions, the confining lithestatic preasures in the magma were reduced to the point that the magma could easily move to the surface. This movement is the likely source for the strong volcanic tremor. With the exhaustion of the intitial source of gas charged magma the eruption terminated abruptly at about 1730 PDT.

The seismic activity associated with the May 25 eruption was quite different than that associated with the catacysmic eruption of May 18. There had been no shallow earthquakes after the May 18 eruption although harmonic tremor had continued at varying low levels throughout the week. The harmonic tremor amplitudes were relatively larger for most of the day preceeding the May 25 eruption. During the two hours imediately before this eruption the harmonic tremor declined to a very low level. As the eruption began a large seismic signal was recorded which turned into strong harmonic tremor lasting for several hours. There were no shallow earthquakes associated with this eruption, but a swarm of deeper earthquakes began approximately 15 minutes after the onset of the eruption. A detailed plot of the harmonic tremor for the entire period will be included in next month's report.

University of Washington and U.S. Geological Survey
Mount St. Helens Seismic Report
June 1 to June 30, 1980

Seismicity

The earthquake activity in the Mount St. Helens area has been comparatively low during June with the excepton of the period imediately following the eruption on June 12. Since the catacysmic eruption of May 18, the seismicity has consisted mostly of small shocks located at depths of 7 to 11 km both below the mountian and scattered to the north and south of the mountain. Only 36 events have been large enough to obtain preliminary locations on and 21 of these occurred in the 8 hours following the June 12 eruption. There have been no earthquakes located at shallow depths such as the majority of those preceeding May 18. There were no earthquake precursors to the eruptions of either May 25, nor June 12.

The epicentral distribution of the June activity is shown in figure A-2. The cluster of events just to the west of the summit of Mount St. Helens are the after shocks of the June 12 eruption. The events to the north-north east in the Elk Lake area occured in mid and late June, the events to the south-south east near Marble Mountain occurred within three minutes of each other on June 25, and the three events just to the east of the summit occurred in mid June. The earthquakes located off the cone to the north and south do not seem to have any direct relation to the volcanism at the mountain but may be related to regional stress redistribution in the wake of the eruptions.

Harmonic Tremor

Harmonic tremor has been observed as a possible precursor to both the May 25 and June 12 eruptions. In both cases an increase in the amplitude of harmonic tremor prior to the eruptions is evident on the records. The amplitude of harmonic tremor as recorded on the SHW station has been plotted against time in figure A-3. In these figures the ampitude on the SHW helicorder records of changes in harmonic tremor are noted. The scale is in mm on the record at a fixed attenuation of -6db. Periodic bursts of harmonic tremor like signals of less than 10 minutes duration are not recorded. Five days around each eruption is plotted in the bottom two figures while the entire period May 22 through June 30 is shown at the top. While the time scales of the precursors in the two eruptions is quite different the pattern as a whole is similar. Tremor increases in amplitude hours to tens of hours ahead of the eruption; then before it begins there is a hiatus of one to two hours at which time the tremor dies back to almost background level. This pattern was not detected ahead of time in the May 25 eruption but was detected before the June 12 outburst. A change in the harmonic tremor was noticed in the early afternoon of June 12. By 7pm the tremor level had increased significantly. There was a quiet period lasting for about an hour between 8 and 9pm when the major eruption began.

During all eruptions strong harmonic tremor is observed which dies away over a period of several hours as the eruption loses strength. On June 2 a change in harmonic tremor similar to that on May 25 and June 12 occurred. If harmonic tremor can be considered as a predictive tool, the change on June 2 must be considered a false alarm. Its pattern of increase and then hiatus is very much like the times when eruptions did occur. Following the increase and hiatus there was even a period of large harmonic tremor which decayed gradually just as if an eruption were in progress. There have been other minor changes in the tremor level without obvious associated volcanic events. We still consider the harmonic tremor to be a significant possible precursor and remain alert to changes in its level.

FIGURES

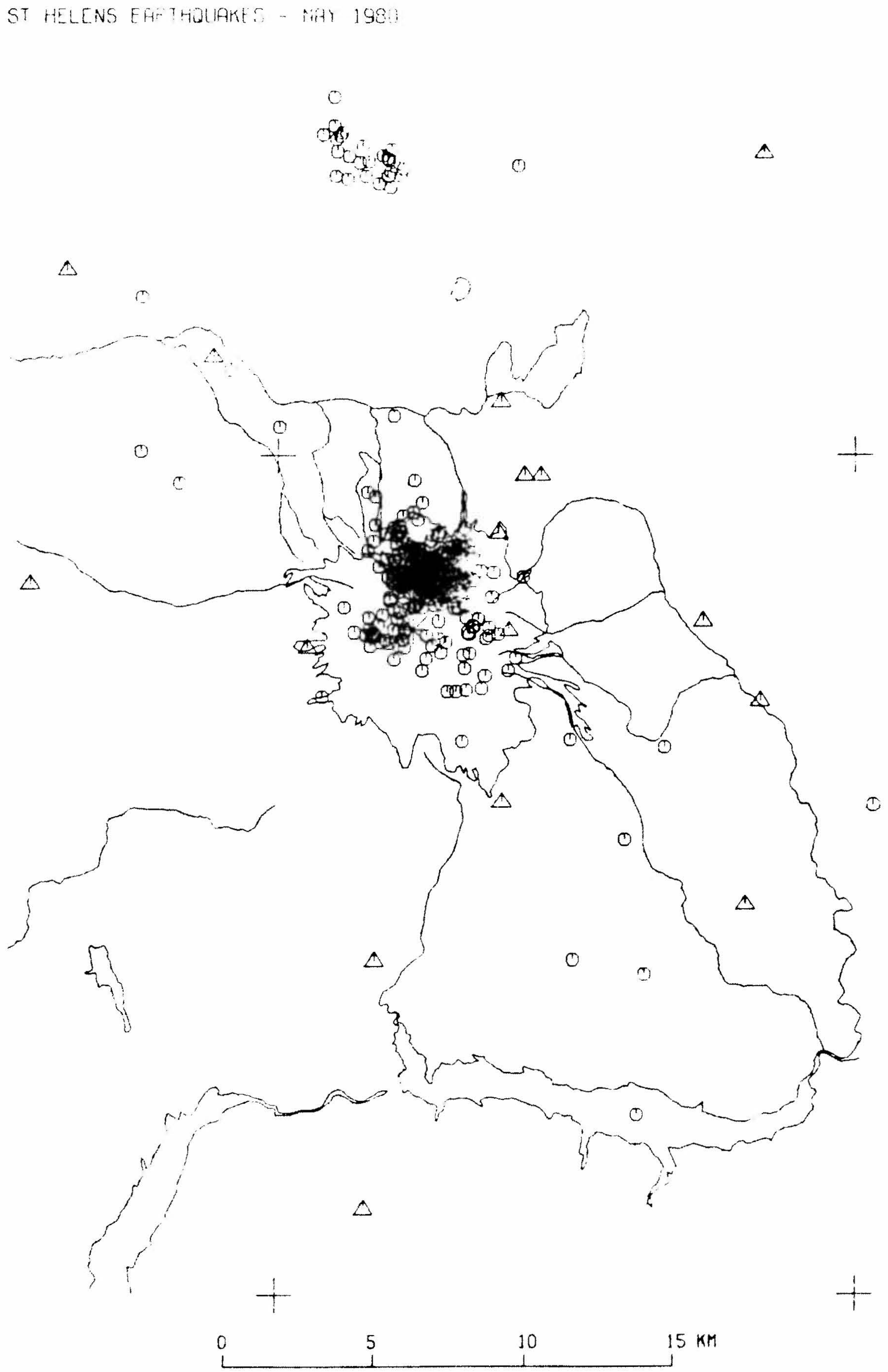

Figure A-1: Plot of earthquake epicenters from May 1, 1980 through May 31, 1980 showing a concentration of activity on the north side of the mountain beneath the explosion crater formed on May 18.

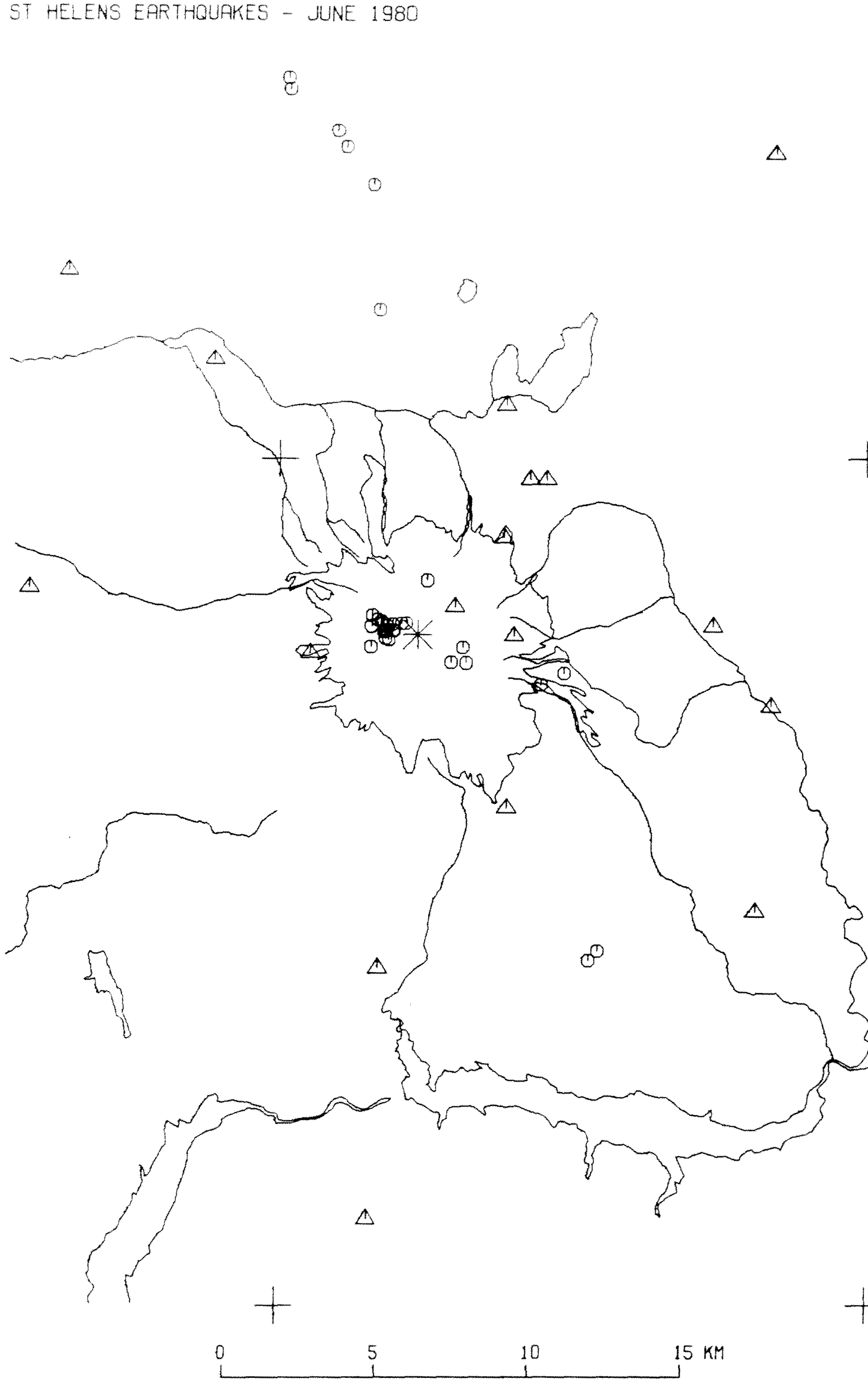

Figure A-2: Plot of earthquake epicenters from June 1, 1980 through June 30, 1980 showing a decrease in number of events under the north flank of the mountain. Almost all of these events are deeper than 6 km.

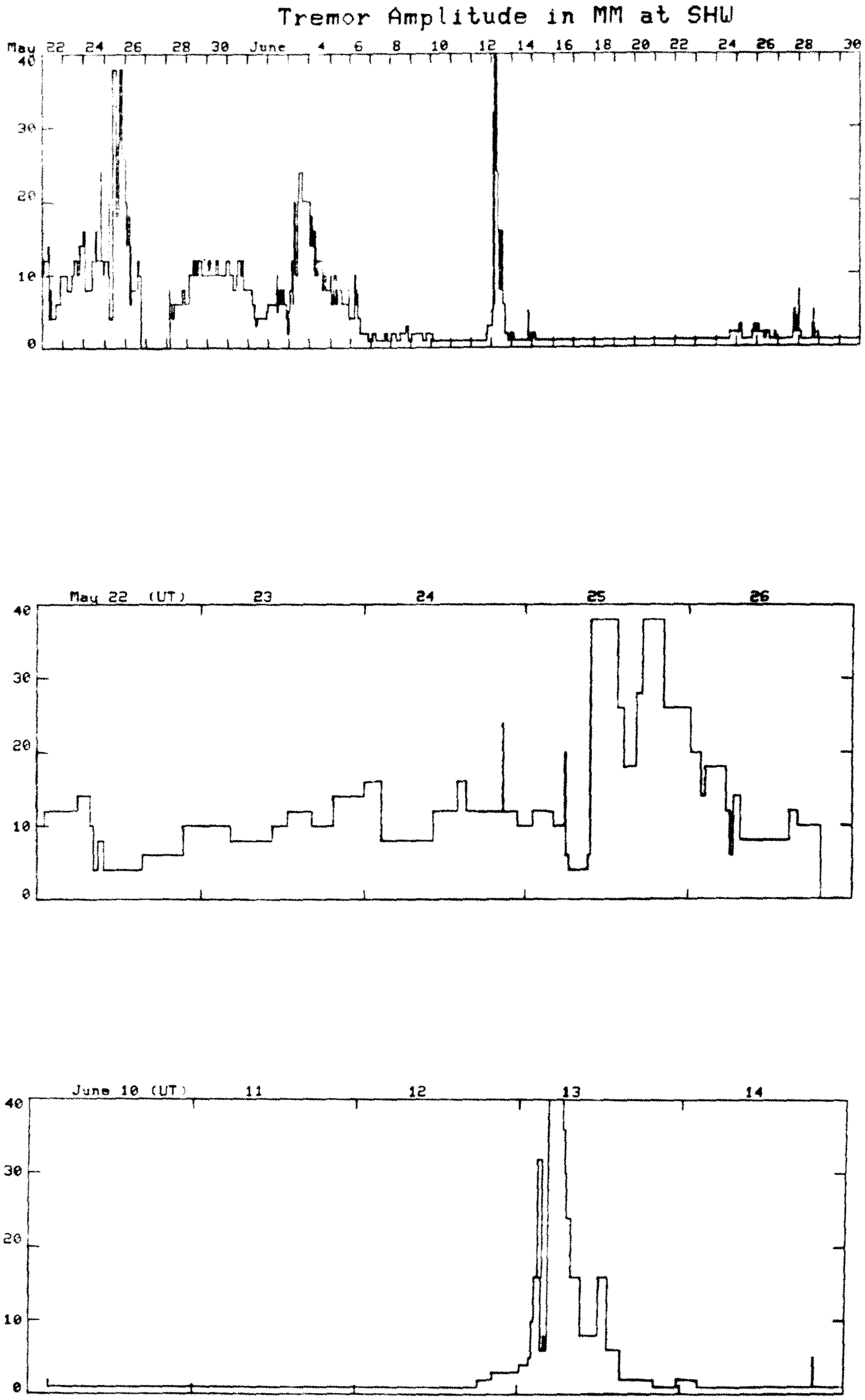

Figure A-3: Plots of harmonic tremor level on SHW station at an attenuation of -6db. Top figure is for the period May 22 through June 30, 1980. The middle figure is centered around the May 25 eruption. The bottom figure is centered around the June 12, 1980 eruption.