N70 32970

CR- 108539

SEISMICITY INVESTIGATIONS IN THE CASCADE MOUNTAINS AND VICINITY, OREGON

NASA CR 108539

TECHNICAL REPORT

SEISMICITY INVESTIGATIONS IN THE CASCADE MOUNTAINS AND VICINITY, OREGON

Prepared for

Lunar and Earth Sciences Division
National Aeronautics and Space Administration
Manned Spacecraft Center
Houston, Texas

by

H. Richard Blank, Jr. and Morris M. Brown
Center for Volcanology, Department of Geology
University of Oregon, Eugene, Oregon

NASA/MSC CONTRACT NAS 9-9690

3 July 1970

CONTENTS

ILLUSTRATIONS

TABLES

APPENDICES

Appendix A.	*	Pine Mountain Seismic Station ("PMT") daily data tabulation, short-period (1-Hz) vertical seismometer visual recorder records, 22 September 1969 - 27 April 1970
Appendix B	**	Ultra-portable seismic system, technical data and specifications.
Appendix C	**	Micro-earthquake reconnaissance survey data tabulations, 1-Hz ultra-portable seismic system smoked paper records, July 1969 - April 1970

* omitted from all copies of report. Original tabulations sent to J. K. Westhusing, Lockheed Electronics Company, C-24, 16811 El Camino Real, Houston, Texas 77058. Duplicate tabulations on file at Center for Volcanology, University of Oregon, Eugene, Oregon 97403.

** included in report copies 1 and 13 only.

SEISMICITY INVESTIGATIONS IN THE CASCADE MOUNTAINS AND VICINITY, OREGON

H. Richard Blank, Jr. and Morris M. Brown

INTRODUCTION

This report concerns work performed by personnel of the Center for Volcanology, University of Oregon, under the terms of NASA/MSC Contract NAS 9-9690 during the period 1 May 1969 - 30 April 1970. The work was directed towards a study of seismicity in the Cascade Mountains and vicinity, Oregon, a Cenozoic volcanic region of diverse structural and lithologic aspects which offers an array of terrestrial analogs to lunar and planetary volcanic terrains. Concurrently with the work reported here, a complementary program of seismic field studies in Oregon was undertaken by personnel of Lockheed Electronics Company under the terms of a separate NASA/MSC Contract; a report of that work has been prepared by Westhusing (1970), and is germane to the discussion which follow.

Specific objectives of the University of Oregon program included 1) installation and operation of a seismic station at the suitable site on Pine Mountain in central Oregon (in conjunction with Lockheed); 2) design and fabrication of an "ultra-portable" (back-pack capability) seismic system for the detection of micro-earthquakes; 3) determination of absolute and relative seismicities of major Cascades volcanoes by means of reconnaissance micro-earthquake surveys; and 4) comparison of seismicity levels in the High Cascades with seismicity levels in adjacent volcanic provinces. The first two of these objectives have been achieved in full. The latter two have been partially achieved, as will be seen, but owing to delays in equipment procurement, which resulted in a shorter than anticipated 1969 field season, and the generally very low seismicity levels encountered, which require long-term monitoring for statistically valid samples, it will be necessary to extend and reinforce the seismicity data obtained to date. This work will be greatly enhanced by the application of remote data transmission using the RF data link which is an integral part of the ultra-portable system.

Progress has been made in the review and tabulation of data from the station at Pine Mountain, although to date only the visual recorder records of a short-period (1-Hz) vertical seismometer have been canvassed. Detailed study of all components for specific events was not possible during the contract period due to delay in delivery of a magnetic tape playback system and reader-printer for the microfilm records.

Studies beyond those specified in the original contract have been carried out at Crater Lake with the operation of a tripartite seismic array and a tilt meter system during fall and winter 1969-70.

Seismicity studies in volcanic terrains. With the development of high-gain portable seismographs many investigators have turned to the study of micro-earthquakes in relation to specific geologic structures and tectonic environments. Pioneering work in the application of micro-earthquake studies to volcanic problems was done at Asama in Japan by Asada (1957) and Minakami (1960), who used time-and space distributions of micro-earthquakes in the prediction of volcanic eruptions. Hamada (1966) used similar techniques in a study of the Matsushiro earthquake swarms. In Alaska the work of Matumoto and Ward (1967) in the Katmai region demonstrated for the first time that micro-earthquakes could be used for the detection of subsurface magma reservoirs in andesitic terrains, although Eaton (1962) and others have long used earthquake distribution to trace the subterrarean movement of highly fluid basaltic magma in Hawaii. Some investigations of aftershock sequences, such as those of Page (1968) in Alaska and Eaton (1967) in California, shed additional light on micro-earthquake source mechanisms, while the report of Oliver and others (1966) on micro-earthquakes in Nevada affords comparison with seismicity over wide areas in a single geologic province. By now many studies have been made on local seismicities of the mid-oceanic ridge system (e.g. Isacks, Oliver and Sykes 1968). Of direct importance to terrestrial volcanic problems is the work of Ward and others (1969) on the mid-Atlantic ridge in Iceland, where the high local seismicity is at least partly attributable to geothermal activity.

The first study of micro-earthquakes associated with volcanoes in the Pacific Northwest was that of Unger (1969) and Unger and Decker (1969) on Mt. Rainier. An average of 11 local events per day was detected, and it was shown, through use of an array sufficient for accurate determination of hypocenters, that the bulk of these events is probably related to an isostatic adjustment of the volcanic massif under its own weight, while a relatively minor residuum of about 8% of the events may be related to magma movement at a depth of 0.2 to 20 km. directly beneath the summit of the volcano. The Rainier study is continuing, and in addition, Decker and Harlow (1970) have completed a brief reconnaissance survey of seismicities of major volcanoes throughout the Cascades in Washington, Oregon, and California. Array studies of seismicity at Mt. St. Helens and Mt. Lassen are also in progress (Unger, 1970, oral communication).

Previous seismicity studies in Oregon. Except for the recent work by Decker and Harlow (op. cit.), which included surveys of 6 Oregon volcanoes, previous seismic investigations in Oregon have been concerned with analysis of specific events and aftershock sequences. Dehlinger and others (1965) showed that analysis of all teleseismic data then available indicated a gross decrease of mantle velocity passing from east to west across the Oregon Cascades, but his data was insufficient to provide details of appropriate velocity models. Smith's (1919) catalogue of Oregon earthquakes was made current by Berg and Baker (1963). The Portland Earthquake of May 13, 1968 (magnitude 3.7 on the Richter scale), was studied by Couch and others (1968), and the Warner Valley (southeastern Oregon) 1968 earthquake and aftershock sequence, by Couch and Johnson (1968). A third region of relatively high seismicity -- in addition to the southeastern Oregon and Portland areas -- is present off the Oregon coast and has been reported on by Couch and Pietrafesa (1968). The study of the specific relation of seismicity in Oregon to volcanoes and volcanic terrains, however, began with the program of investigation reported here.

Acknowledgments. We have benefitted considerably from technical and scientific discussions with J. O. Annexstad and J. K. Westhusing of NASA/MSC and Lockheed Electronics Company, respectively; J. P. Eaton, R. M. Hamilton and J. D. Unger of the U. S. Geological Survey; R. W. Decker and D. Harlow of Dartmouth University; T. Matumoto and P. L. Ward of Lamont-Doherty Geological Observatory; and S. D. Schwarz of Geo-Recon, Inc. Special acknowledgment is also made to M. McCoy, Millican, Oregon, for his faithful attention to the problems of the seismic station during the long winter at Pine Mountain, and to H. F. McCormick, District Ranger of the Fort Rock Ranger District, Deschutes National Forest, Bend, for advice in site selection and implementation of the program with respect to the use of National Forest lands. The assistance and cooperation of the National Park Service during Crater Lake operations is greatly appreciated.

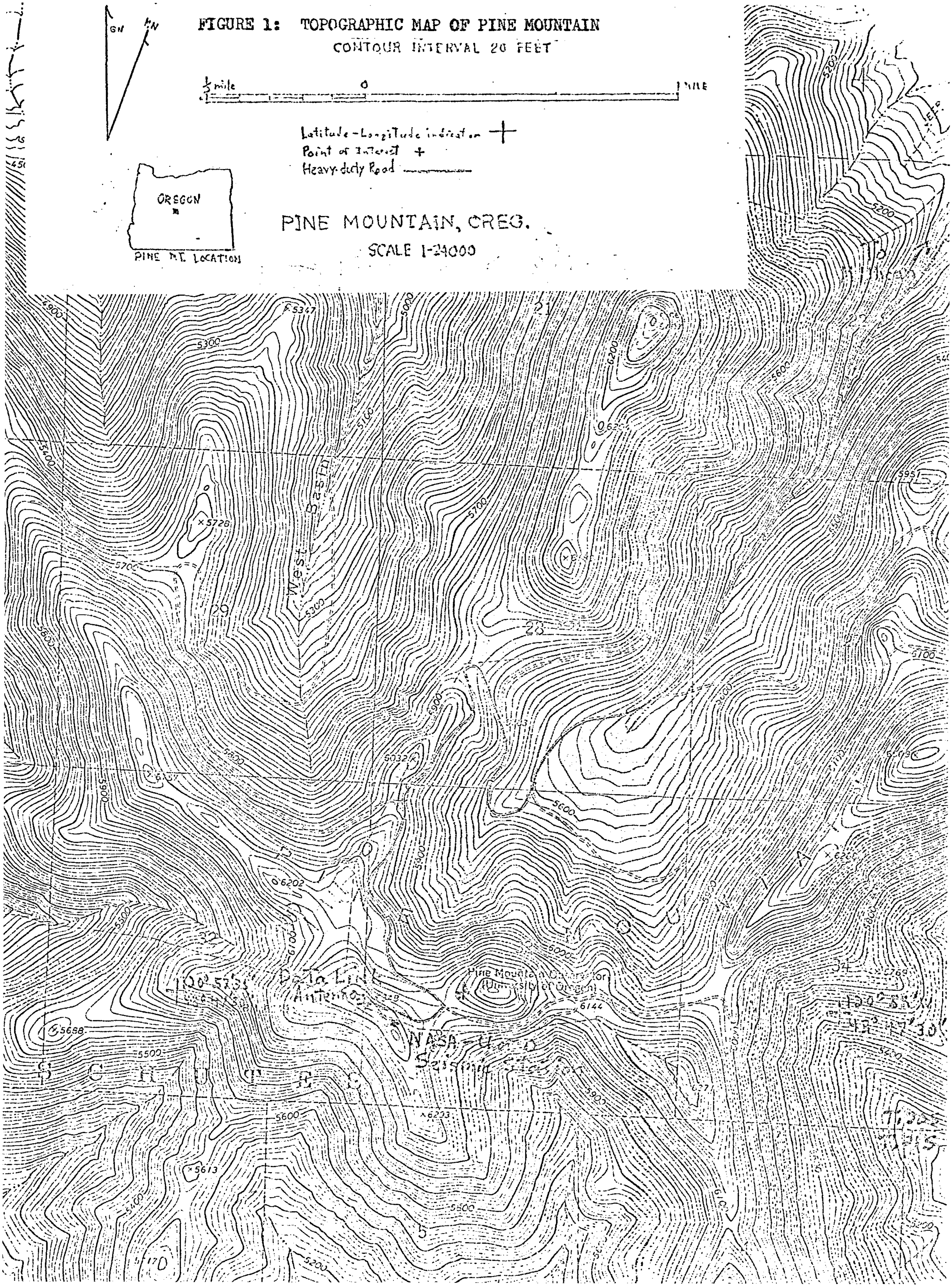
PINE MOUNTAIN SEISMIC STATION

The Pine Mountain seismic station was installed and operated during summer 1969 by personnel of Lockheed Electronics Company with the assistance of personnel from the Center for Volcanology, under the general direction of J. K. Westhusing. The station currently consists of a 3-component long-period (15 sec.) LT-304 seismometer and 4 short-period (1 sec.) Geotech 18300 seismometers--2 vertical and 2 horizontal--housed in insulated tank vaults and connected to the NASA/MSC 11-ton Field Geophysical Van which contains facilities for calibration, timing, filtering, etcetera, and data storage (35 mm film, visual recorder, and magnetic tape). The site is located on Deschutes National Forest Lands (Fort Rock Ranger District) about one-fourth mile west of the Astronomical Observatory of the University of Oregon near the summit of Pine Mountain, about 9 miles south of Millican, a hamlet some 26 miles southeast of Bend on U. S. Highway 20. It is immediately adjacent to a recently constructed Pacific Northwest Bell Telephone Company microwave relay station linking Bend to Glass Butte, and can normally be reached in about 20-30' by gravel-surfaced road from Millican. Power is provided at the site by the Central Electric Cooperative of Redmond; water must be hauled from the nearby Observatory. The coordinates of the station are 43° 48' north latitude and 120° 56' west longitude, and the approximate elevation is 6320±10' (see figures 1,2).

Technical particulars of the station, as well as an account of its installation and summer operation and maintenance, are contained in the report by Westhusing (op. cit.).

FIGURE 1: TOPOGRAPHIC MAP OF PINE MOUNTAIN

CONTOUR INTERVAL 20 FEET



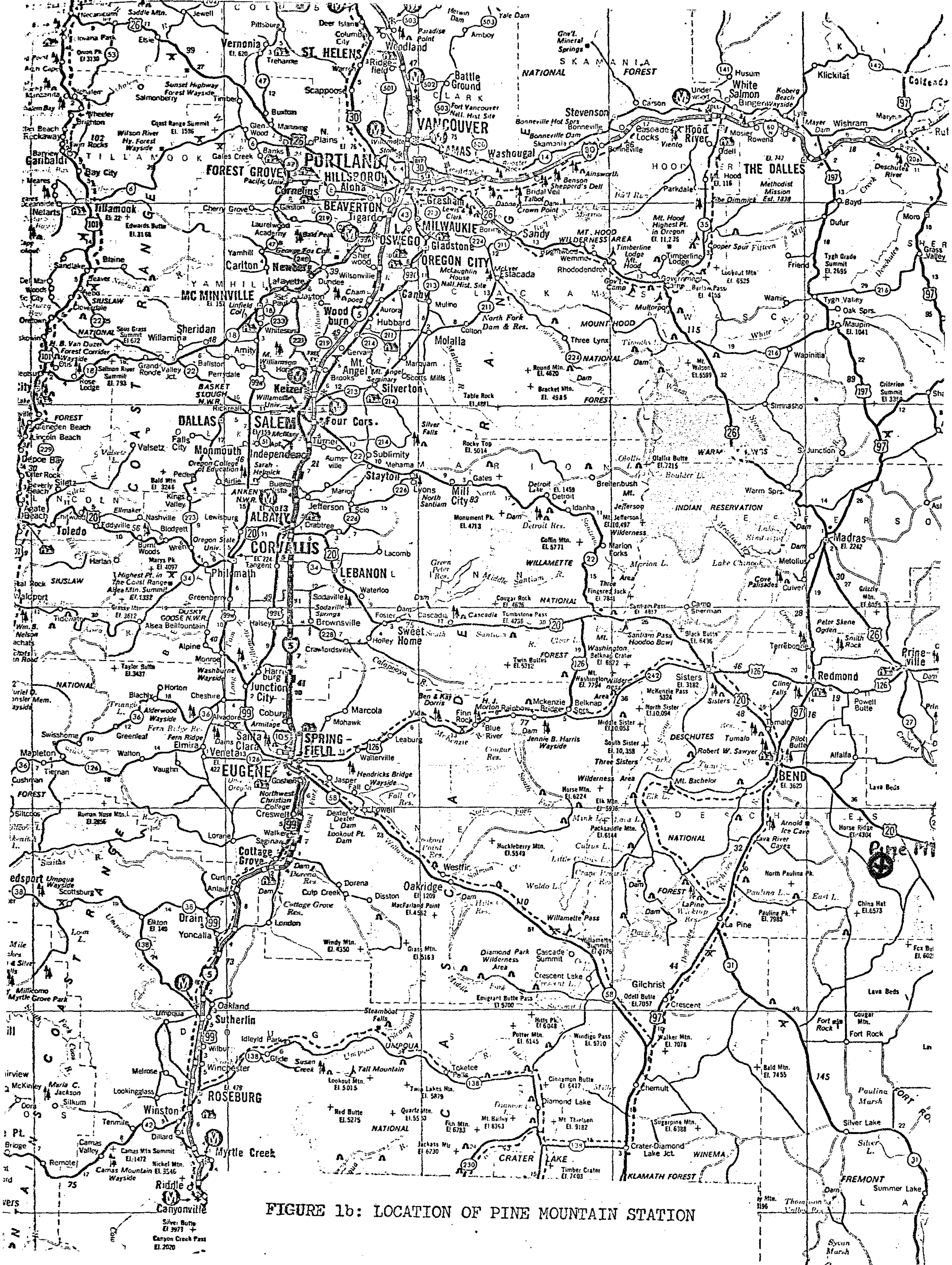


FIGURE 1b: LOCATION OF PINE MOUNTAIN STATION

Section 33 Twp. 20S Range 15E Scale 1" = 100'

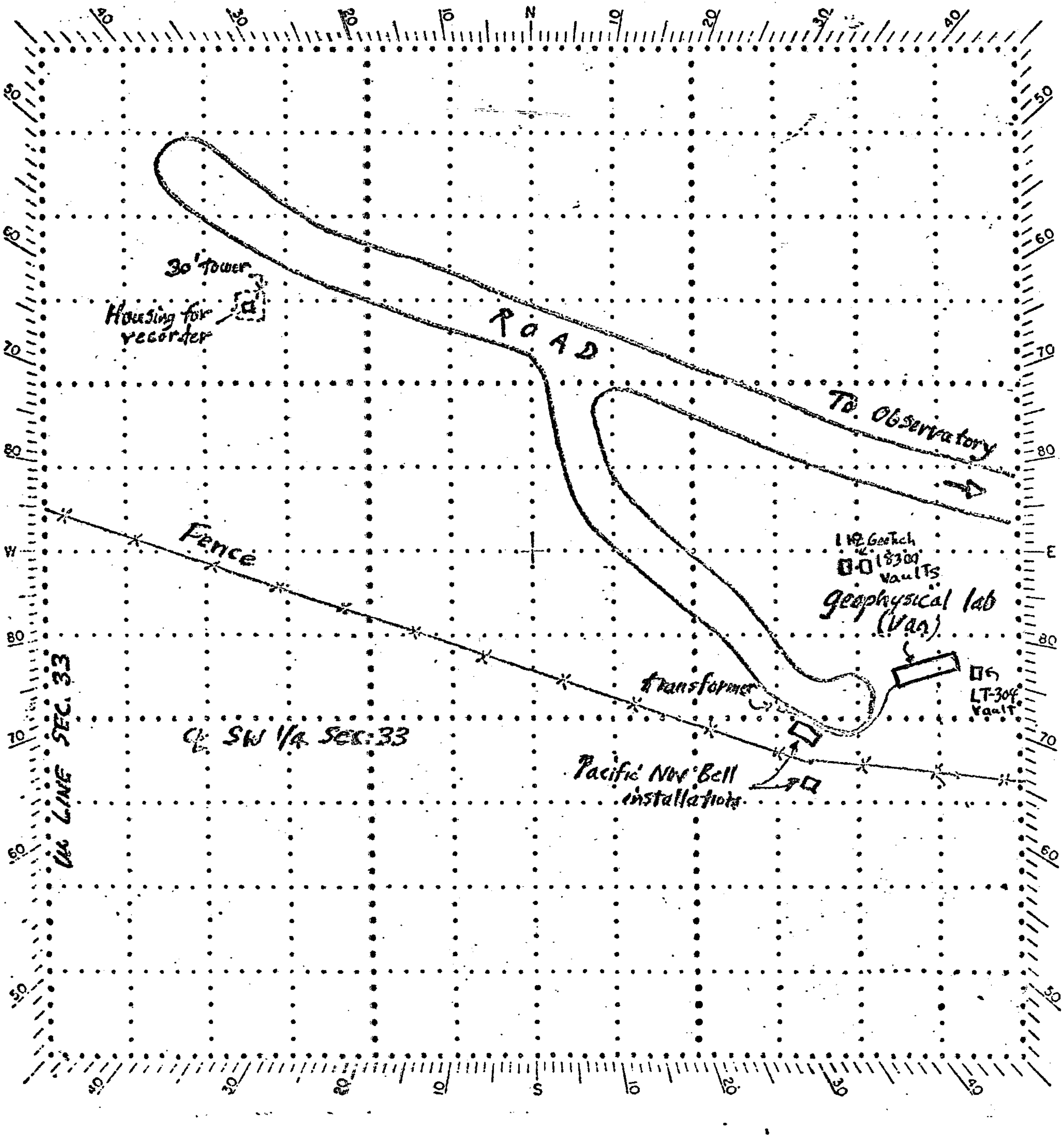


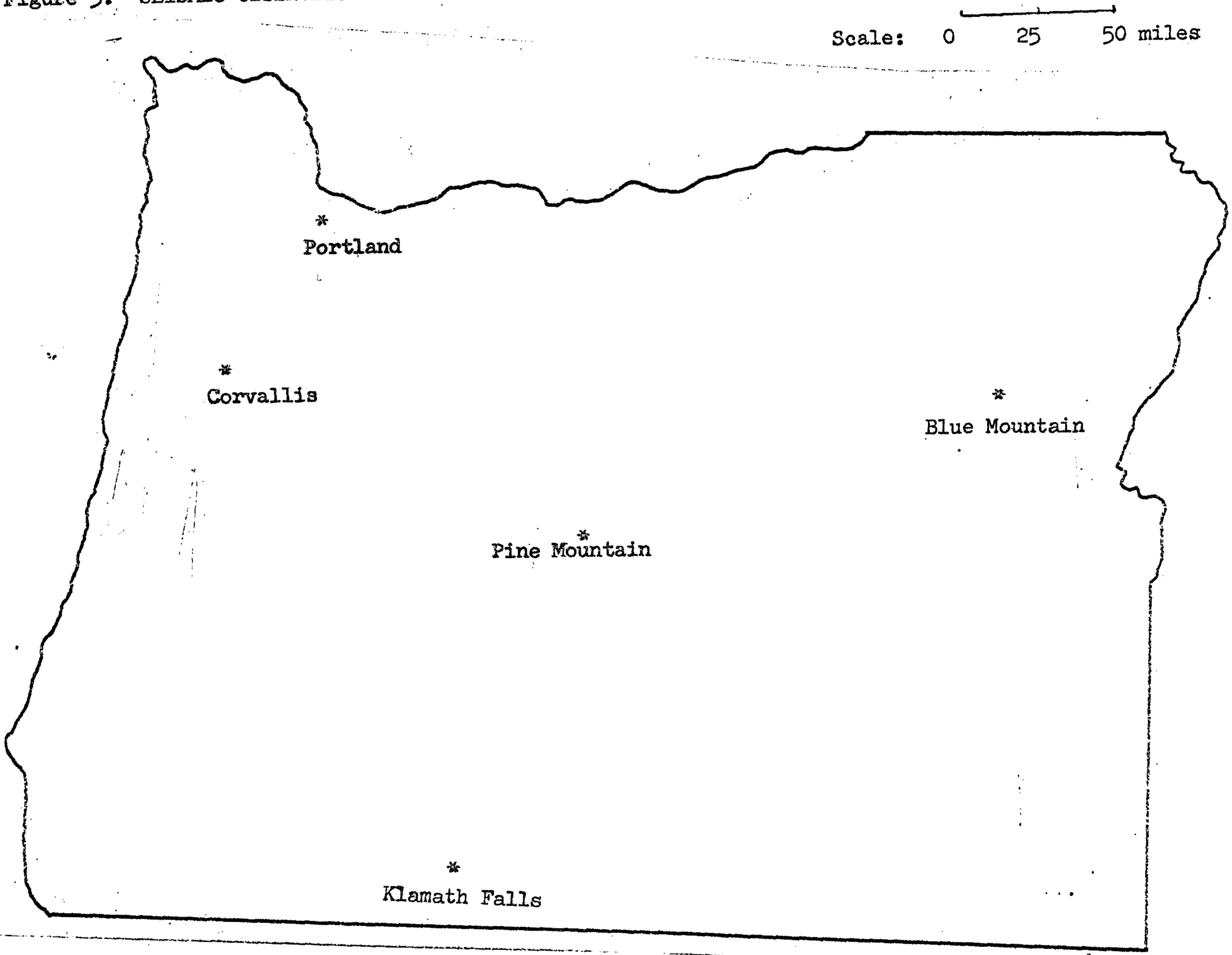
Figure 2: SKETCH MAP SHOWING LOCATION OF PINE MOUNTAIN SEISMIC STATION

Winter operation and maintenance. Operation and maintenance of the station became the responsibility of the Center for Volcanology after about mid-September 1969, when winterization was completed and the resident custodian/technician for the Pine Mountain Observatory, Martin McCoy, had completed a supervised training period. Various problems of maintenance are recounted by Westhusing (op. cit.). These were generally surmounted, with minimal down time, by McCoy in telephone consultation with Westhusing and the Center for Volcanology, and did not require direct assistance.

During the winter months the Millican road is frequently inaccessible by auto owing to heavy snowfall and subsequent drift accumulation; this inconvenience has the positive effect of eliminating traffic noise. However, winter storms may also temporarily limit effective magnification of the seismic systems by increasing background noise from wind.

Assessment of environment. The Pine Mountain site is strategically located almost exactly in the geographical center of the state of Oregon (figure 3), and provides, in conjunction with other seismic observatories in Oregon, an excellent means of studying Cascades crustal structure through analysis of regional earthquakes. It is offset somewhat to the east of the Cascade Range, which offers further advantages as a collection point for seismic data telemetered from the upper slopes of High Cascades volcanoes; all of the major Cascades volcanoes in Oregon except Diamond Peak are visible from Pine Mountain, and a telemetry data link already exists between Pine Mountain and Eugene. Moreover,

Figure 3: SEISMIC OBSERVATORIES IN OREGON



in terms of achievable magnifications the station as presently configured is probably superior to any in Oregon save the ESSA array at Blue Mountain. The specific site was selected on the basis of convenience to logistical support, including electrical power and the availability of a year-round custodian/technician, and it is conceivable that this situation could be duplicated elsewhere in the vicinity, but the great geographical advantage of the present site should not be lightly abandoned.

According to the reconnaissance mapping of Walker and others (1967), Pine Mountain consists of a silicic plug-dome of probably Pliocene Age; immediately to the west of the seismic station the silicic rock is apparently cut by a thick (50'+?) dike of vesicular basalt that forms the crest of the ridge for at least half a mile in a northwesterly direction. The plug-dome is one of several such masses situated in the Brothers fault zone, a broad and nebulously-defined west-northwest trending shear zone extending between Bend and the Harney Basin, and probably well beyond these limits--perhaps one of the fundamental tectonic features of Oregon (Walker, 1968, oral communication). The exact relation between basalt and silicic rock has not been detailed. A thick sequence of basaltic lavas comprises the bedrock of lowlands surrounding the mountain. To the north of the Brothers zone is the High Lava Plateaus province, while the region to the south belongs to the Basin-Range province. As evidenced by the nearly total lack of micro-earthquake activity at Pine Mountain and its immediate environs (see subsequent sections), this part of Oregon appears to be tectonically inactive at the present time.

Data tabulation and analysis. A summary of monthly frequency of events recorded on the short-period (1-sec.) vertical geophone monitored by the visual recorder at Pine Mountain is presented in table 1, as a function of amplitude. "Down-time" given here refers only to loss of Helicorder record and not necessarily to the entire system. Of all events tabulated, probably fewer than 1% represent "local" earthquakes--that is, epicentral distances less than, say, 20 km. from the station, and the remainder represent both regional and telescopic events in sub-equal proportions.

Phase identifications, arrival times, amplitudes, first motions, and other details annotated from the daily records may be obtained by reference to Appendix A. No analysis of these data has as yet been made, for the reasons previously indicated.

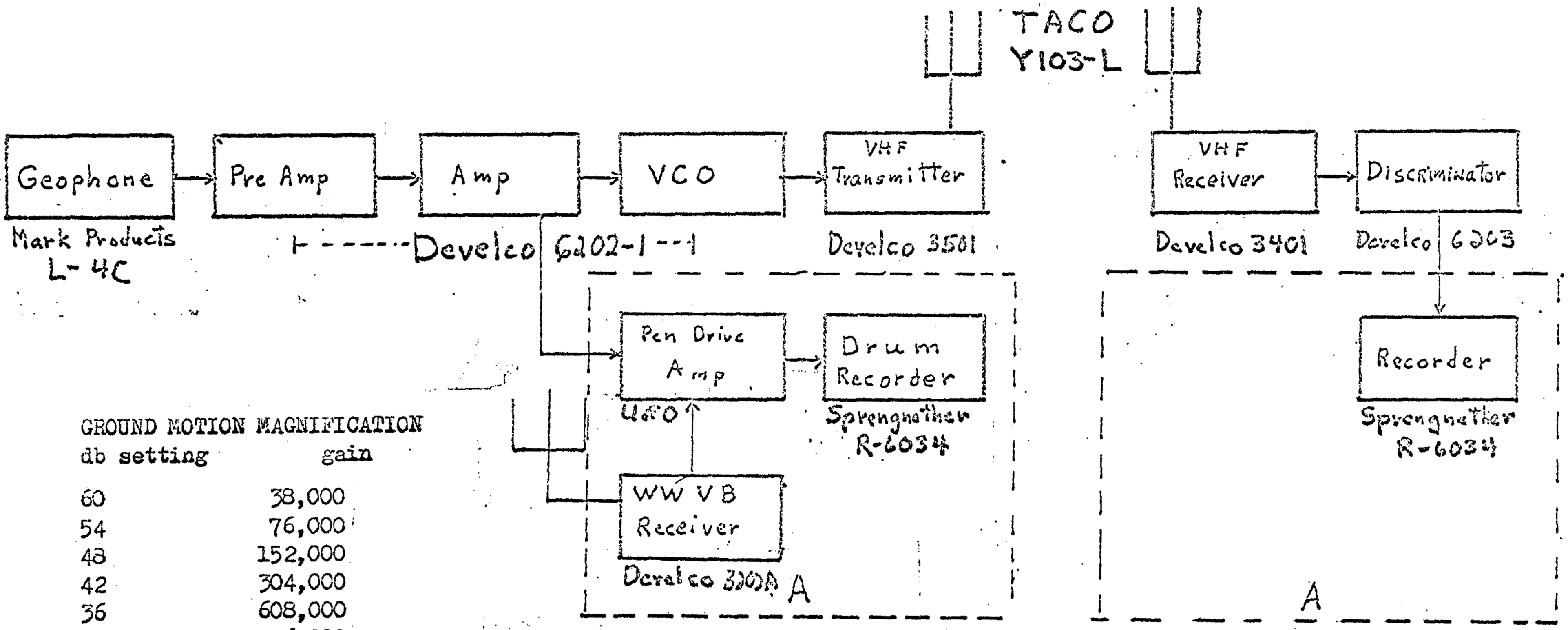
Table 1: SUMMARY OF EVENTS RECORDED ON PINE MOUNTAIN VISUAL RECORDER BY AMPLITUDE

Category Amplitude mm	Month								
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	Total
above 50	0	1	0	0	0	1	1	1	4
above 40	1	0	0	0	0	0	0	0	1
above 30	1	2	1	0	2	0	1	0	7
above 20	2	2	0	0	0	1	3	4	12
above 10	11	9	2	2	2	4	3	2	35
Below 10	25	12	22	46	30	69	53	79	336
Total (month)	40	26	25	48	34	75	61	86	395
Down (Days)	0	10	4	0	0	0	7	3	24

ULTRA-PORTABLE SEISMIC SYSTEM

Design and fabrication of an ultra-portable seismic system proceeded along lines suggested through consultations with seismologists at the Natural Center for Earthquake Research (U. S. Geological Survey), Dartmouth University, and Lamont-Doherty Geological Observatory, as well as with various component manufacturers. The primary objective was to achieve a high degree of portability, say, back-pack capability, in a simple and reliable system with high gains (10^6 and more) and tuned to frequencies associated with micro-earthquakes (above about 0.5 Hz), so that it could be used for reconnaissance local seismicity surveys in a variety of volcanic terrains. In addition, it was desired to incorporate in the system a telemetry capability, for long-term use at a single unattended site.

These considerations led to development of the bimodal system illustrated by the block diagram of figure 4A. The output from a single-axis (vertical) seismic input transducer or geophone (Mark Products L-4C, 5500 Ω Coil tuned to 1-Hz) with a nearly flat bandpass up to 100 Hz. is fed into a high gain, low power drain pre-amplifier-amplifier which can be coupled to a voltage-controlled oscillator (pre-amp/amp/VCO are unitized as Develco 6202-1). When operating in the on-site mode, the amplifier output is applied directly through an in-house fabricated current pen drive amplifier to an 8" diameter, variable-speed smoked-paper drum recorder (Sprengnether R-6034 Special). Real time is obtained by applying the output of a WWVB receiver (Develco 3202 A) to the current amplifier, so that the time code is continuously



GROUND MOTION MAGNIFICATION

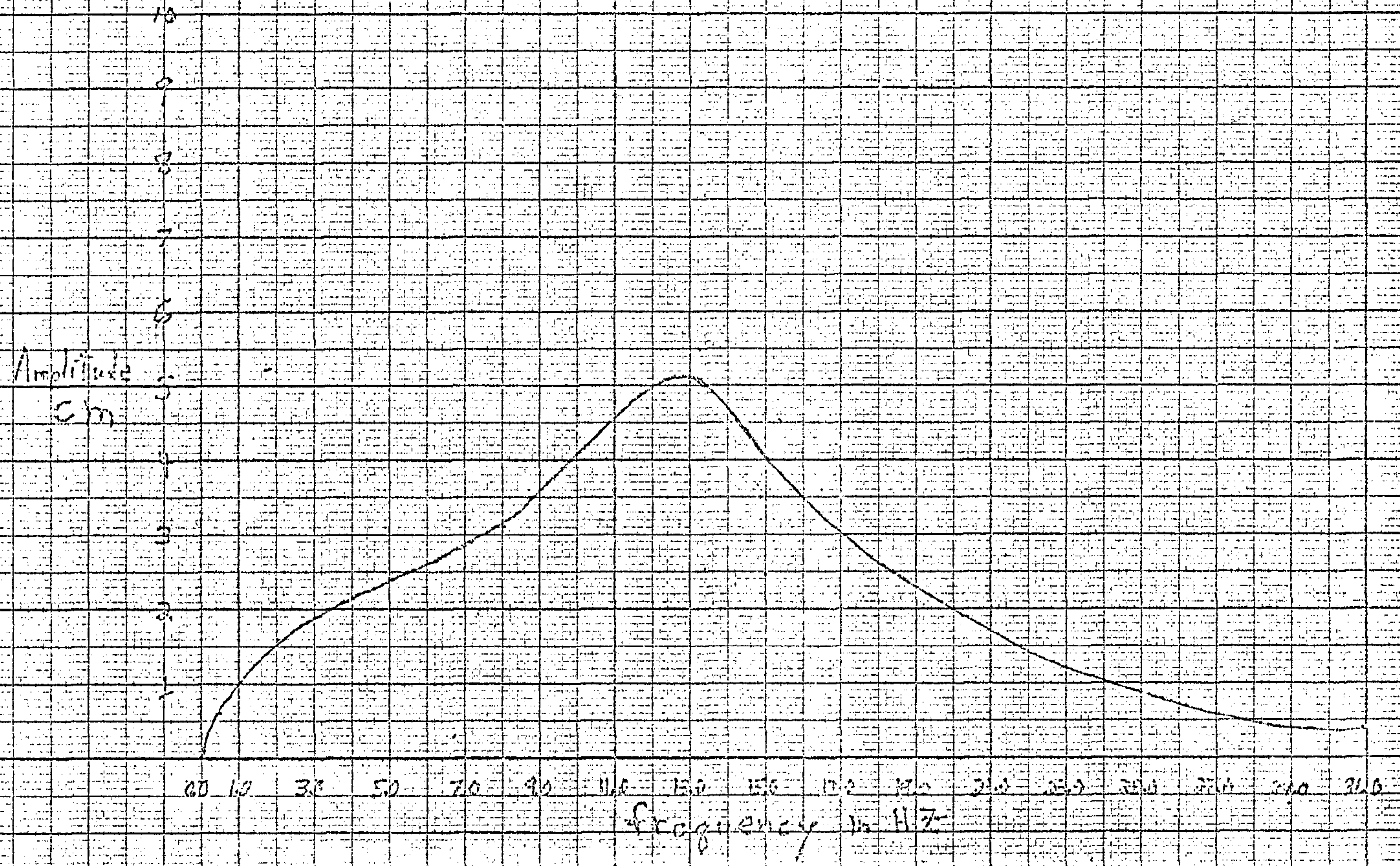
db setting	gain
60	38,000
54	76,000
48	152,000
42	304,000
36	608,000
30	1,216,000

Figure 4A: BLOCK DIAGRAM OF ULTRA-PORTABLE SEISMIC SYSTEM

Note: Unit "A" is interchangable for on-site recording or for remote transmitter operation.

superimposed on the seismic trace at low amplitude. In this mode, the system can be operated over periods up to 60 hours using a single sheet of smoked paper and two 12-V batteries, one wet and one dry, in a ±12 V.D.C. power system (115 V.A.C. for the drum motor is supplied from a unijunction-controlled inverter driven by the wet storage battery). The possible ground motion magnification from transducer to paper recorder is 1.0×10^7, although in practice, the useful gain of the system is invariably limited by background noise. Relative frequency response of the system is shown in figure 4B: the maximum response occurs at about 13 Hz.

In the telemetry mode, the pre-amp/amplifier voltage is coupled with the VCO output to provide an audio signal frequency modulated by the seismic signal. This output is then used to frequency-modulate an RF signal which is transmitted line-of-sight to the collection point. The transmitter (Develco 3501) operates at an output level up to 0.5 watt and at a VHF frequency (recently licensed by the Federal Communications Commission) of 173.30 megahertz. A VHF receiver (Develco 3401) and discriminator (Develco 6203) process the signal for insertion into the recording unit described previously. Field tests of these units by NCER personnel (Menlo Park, Calif.) indicate reliable transmission at 0.1-watt output levels for distances of more than 50 miles; it is anticipated that periods of unattended operation of up to six months will be feasible at most High Cascades sites using this system and a collection point at Pine Mountain. A 30' yagi-type VHF antenna (TACO Y 103-L) has been installed near the seismic station on Pine Mountain for this purpose (see figure 2).



FREQUENCY RESPONSE CURVE
1969 System

Figure 4B

Operating instructions, manufacturer's specifications and circuitry, and other technical data for the ultra-portable system are contained in Appendix B.

Field Operations. By late summer 1969, when fabrication and assembly of the ultra-portable system was completed, field tests and shake-downs of the system could be carried out and the program of reconnaissance seismicity studies begun. The monitoring of High Cascades sites generally required preliminary access investigations in consultation with various land-controlling agencies and individuals, followed by specific site selection--all in advance of actual installation of gear. Optimum sites are those with minimal background noise and reasonable accessibility and proximity to the central target (within a few kilometers of the volcano, preferably on the massif itself).

Site noise conditions are a function of tree cover, ground materials, proximity to roads and trails, proximity to streams and lakes, and general exposure to wind. Best results in wind-protected areas were usually obtained by placing the seismometer directly upon bedrock, if available, without burial.

The drum speeds at road-accessible locations were usually set for a daily change, since slower speeds reduce the resolution of the records. Each smoked-paper record was dipped in alcohol and shellac for preservation after removal from the drum. A simple diesel smudge pot was used to prepare a new sheet for installation.

The ultra-portable system was also used to explore for possible alternative (contingency) sites for the Pine Mountain Station, and to monitor several of the EDZOE shots fired at Revelstoke, British Columbia, along a track in north-central Oregon. Both of these operations provided additional data on seismicity of volcanic terrains adjacent to the Cascade Range.

All sites occupied with the system during summer and autumn 1969 are indicated on the index map of Figure 5. Sample comments on individual localities follow.

Prineville Area--shakedown and background test. Best site on basalt flows from roads and ridgecrests, SE of Prineville. Able to use 42 db attenuation on days with little wind (better by 12 db than even the better Cascades peak sites).

Antelope--background higher than at Prineville. Site located on Roy Forman Ranch far from any roads. High background noise attributed to effect of light breeze in exposed and rugged terrain.

Arlington--background noise similar to that near Antelope.

Boyd Cave--SE of Bend, 20' deep in lava tube cave. Best recording levels obtained in entire survey. Attenuation 30 db better than most Cascade Peak sites. However, logging road ½ mile to south of site receives much logging and recreational use which can result in complete obliteration of record.

Diamond Peak--gear carried in to site on SE side by trail-bike and then back-packing (in wilderness area). Average Cascades background levels. Many sharp events caused by rock-falls on glaciated slopes above timberline.

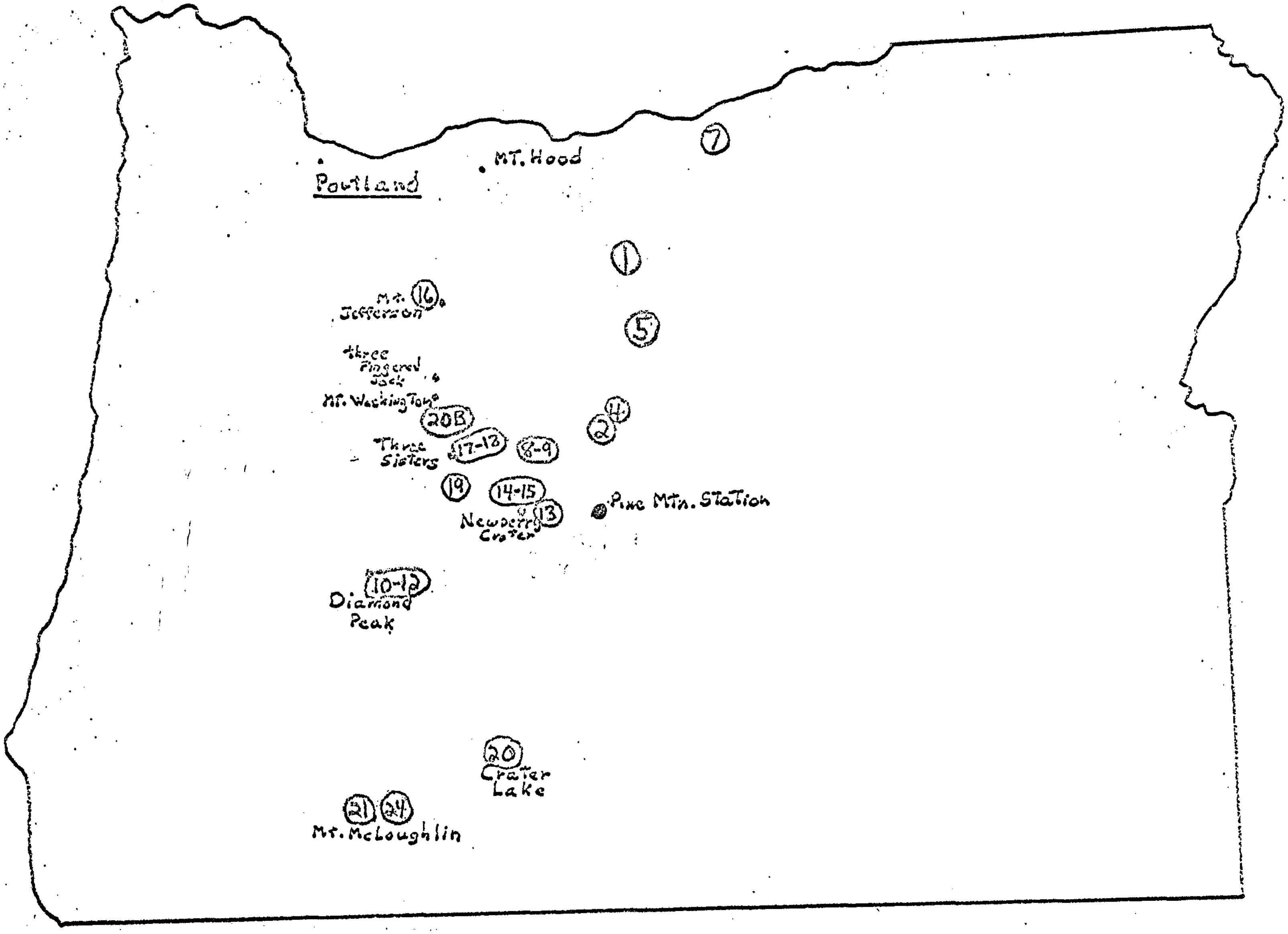


Figure 5.

INDEX MAP OF OREGON SHOWING SITES OCCUPIED WITH ULTRAPORTABLE SYSTEM

Scale: 0 25 50 miles

Record Number for the Location shown: ③

Newberry Crater--first site was on flank of volcanic feature called the Dome, SE of East Lake; this site proved nearly useless because seismometer placed on pumice and scoria with poor sonic characteristics. Later site on silicic flow material at small cone between Paulina and East Lakes (on private pumice-mining claims) proved very quiet--gain of 12 db better than average was obtained.

Mt. Jefferson--back-packed to a location on SW side of mountain, 3.5 km. from summit. Mountain is difficult to approach as most of the massif is remote from roads. Site on alluvium near hiking trails and subjected to considerable cultural noise.

Three Sisters--back-pack site located below Sunshine Shelter on W side of complex some 5.2 km. from North Sister. Fairly quiet site but subjected to some pack-train noise.

Crater Lake--site chosen near water-supply tank on S rim, about 4.5 km. S of center of Caldera. Site not subjected to tourist activity and 12 db above average background levels was obtained despite some wind.

Bachelor Butte--site on lava flow in ravine 4 km. W of summit. Average background (60 db). Instrument problems decreased length of usable record.

McKenzie Pass area--site on old stage road 2 km. SE of Belknap Crater and 12 km. NW of N. Sister. Background 6 db higher than average.

Mt. McLaughlin--site on lava flow 4 km. S. of summit. Average background noise (60 db); instrument problems again encountered.

Additional reconnaissance seismicity surveys were conducted during fall 1969 by Dr. T. Matumoto using a portable ("suitcase") seismic apparatus on loan from Lamont-Doherty Geological Observatory.

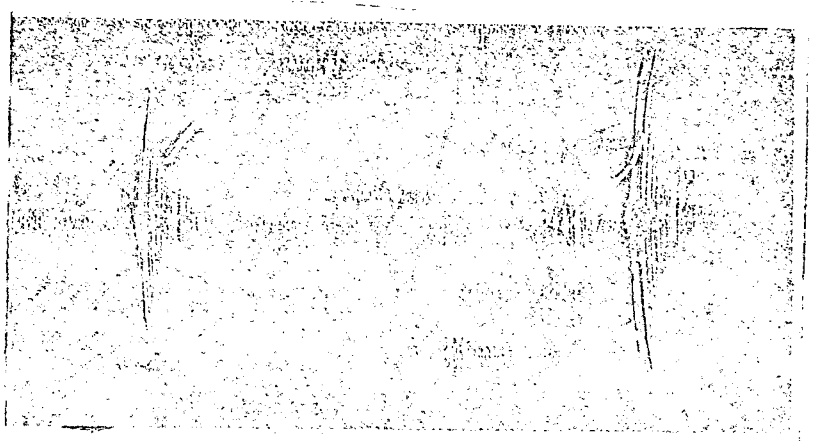
A seismicity profile was made across the Cascades on a line more or less parallel to Highway 58 (Willamette Pass). The results suggest that away from the High Cascades volcanoes, seismicity levels are much like those in the High Lava Plateaus of Central Oregon.

Data Tabulation and Analysis. Each smoked-paper record from reconnaissance operation of the ultra-portable system has been analyzed at the Center for Volcanology for number and amplitude of recognized micro-earthquake events, general classification of events according to envelope characteristics, and phase delays where more than one phase can be distinguished. The complete data tabulations are presented in Appendix C.

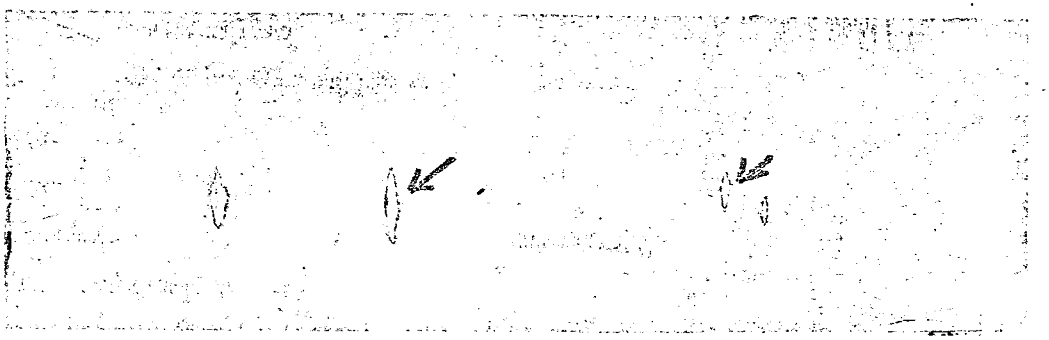
Envelope (coda) characteristics of micro-earthquakes are strongly dependent on nature of the physical medium in the vicinity of the recording site, distance to the hypocenter, and above all on source mechanism. A variety of natural sources ranging from rock falls on spallations to tectonic displacements, as well as cultural disturbances such as sonic booms or certain vehiclar traffic phenomena, are all capable of producing "micro-earthquakes," and there does not appear to be any rigidly objective way, at the moment, for their identification and classification. In general, however, the experienced operator can distinguish the cultural events, usually through absence of impulsive onsets, and he can in a general way separate micro-earthquakes of tectonic or volcanic origin ("normal" events) from surface-produced phenomena ("spike" events) on the basis of frequency content and shape of coda, although it must be recognized that some ambiguity doubtless remains. An illustration of this two-fold and rather arbitrary classification of natural micro-earthquakes is afforded by the examples of figure 6.

Frequency of occurrence of "normal" events at the major Cascades volcanoes monitored to date, i.e., their "seismicities," is shown by Table 2. The recording interval at each site has been normalized to 24 hours. In order to determine seismicity levels, the magnitude of each tabulated event was first calculated by the method of Muramatu (1964), using the ground motion velocity calculated from the trace amplitudes and gain setting, and plotting this value versus epicentral distance calculated from S - P values. The intercept of these two values gives the magnitude of the event. In practice these values are lower than with those obtained using methods developed by Gutenberg and Richter (1954). The relation between magnitude and frequency n, $\text{Log } n = a - 6\ m$. was then employed using a slope, or b value, of 0.88, following Page (op. cit.), to find a best fit for each plot of log n versus M. This entire procedure is somewhat unsatisfactory because it fails to consider frequency, amplifier characteristics and site effects for calculating of magnitude, as has been pointed out by Eaton (in press). For comparison, however, despite these uncertainties, in the next-to-last column of Table 2 the predicted intervals between events of +1 magnitude are calculated for each volcanic target. It can be seen that the seismicities range over two orders of magnitude, with Newberry Crater and Mt. McLaughlin conspicuously less active than any of the other

FIGURE 6: MICRO-EARTHQUAKES RECORDED AT CASCADE VOLCANOES WITH ULTRAPORTABLE SYSTEM: EXAMPLES FROM NEWBERRY CRATER RECORDED IN SEPTEMBER 1969



"NORMAL EVENT", S-P APPROXIMATELY 5 SECONDS



'SPIKE EVENTS"

Table 2: SUMMARY OF EVENTS RECORDED WITH ULTRA-PORTABLE SEISMIC SYSTEM IN CASCADE RANGE AND VICINITY, OREGON

LOCATION	DISTANCE TO PEAK KM.	DATES	EVENTS PER DAY	ATTENUATION DB	DAYS FOR A +1 EVENT	HOURS USEFUL RECORDING
DIAMOND Pk.	1.5	9/4-5/69	4.3	60	20	51
NEWBERRY Cr	0.0	9/12-17/69	1.2	42	249	103
JEFFERSON	3.5	9/21-23/69	9.0	60	9.5	32
N. SISTER	5.2	9/24-25/69	4.2	54	11.5	68
CRATER LAKE	4.5	10/4-6/69	4.9	48	11.0	35
BACHELOR Bt.	4.0	11/2-3/69	1.5	60	28	63
MC LAUGHLIN	4.0	11/9-10/69	2.5	60	600	60

volcanoes. There is no apparent correlation with the records of historical activity of Cascade volcanoes.

Relative seismicities shown here differ considerably from the results of Decker and Harlow (1970), probably as a result of both inadequate recording periods and of differences in the interpretative methods employed. Whether or not the seismicities are actually time-dependent remains to be investigated.

There seems to be no doubt that seismicity of the High Cascades volcanoes exceeds that of the region to the east in Central Oregon. Few micro-earthquakes were detected at any site east of the Cascades, and analysis of Pine Mountain data indicates that the occurrence of micro-earthquakes there may be as seldom as once per month for any detectable magnitude.

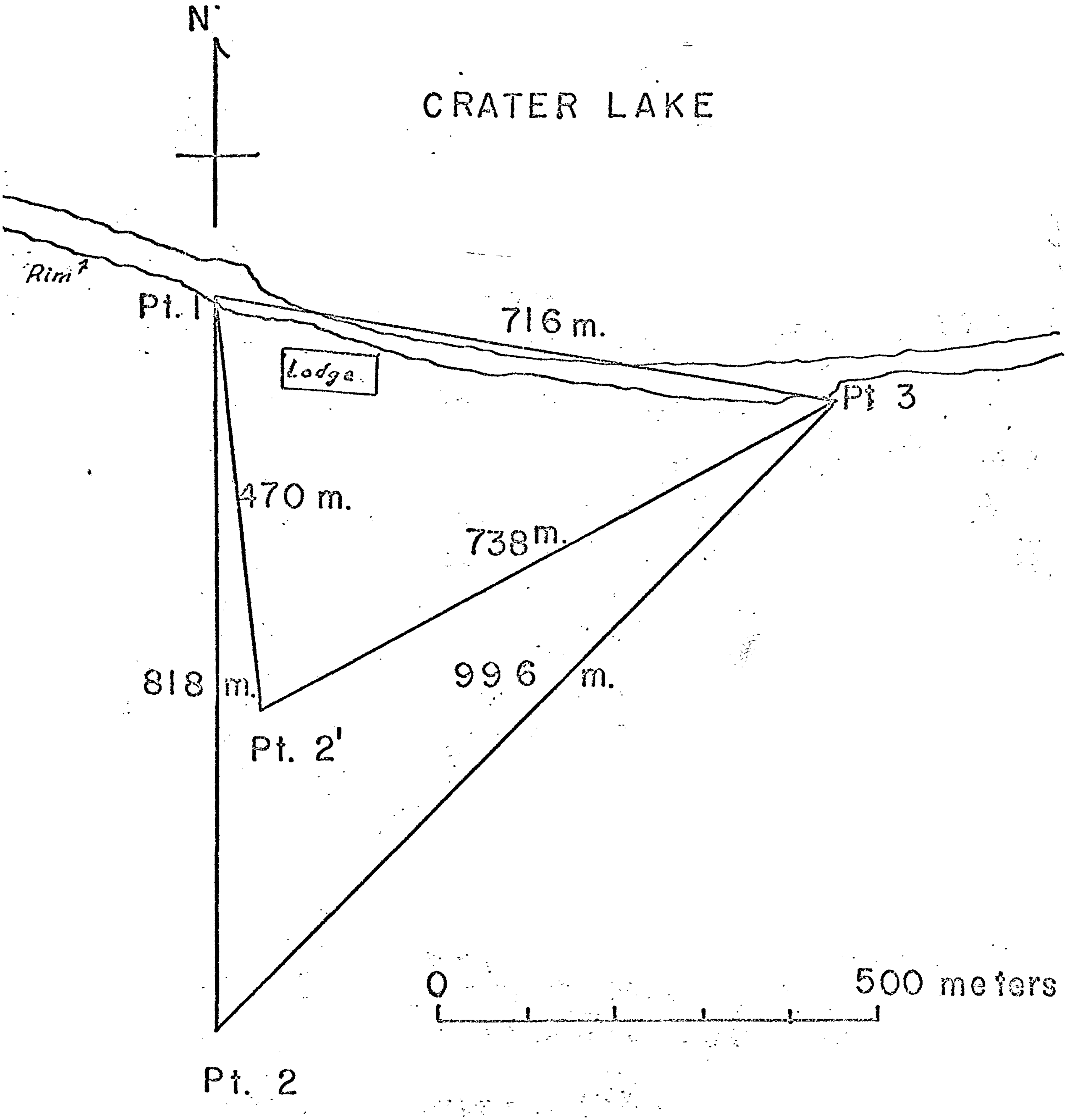
CRATER LAKE PROGRAM

During fall and winter 1969-70 a tripartite, 1-Hz, vertical component seismic system equipped with a magnetic tape recorder was loaned by Lamont-Doherty Geological Observatory to the Center for Volcanology for use by Dr. T. Matumoto, who was for that period a visiting Senior Research Associate at the University of Oregon. The array was installed on the south rim of Crater Lake Caldera in early October, with the central electronics housed in the basement of Crater Lake Lodge (figure 7).

Data collection was seriously hindered by three factors: 1) Until a heavy snow-cover was in place, extensive and continual cable damage was caused by rodents. Protective measures discussed by J. R. Tigner (1968) will be employed in the future. 2) With the heavy snow came a new problem of cable parting due to snow movement on steep slopes (necessitating relocation of part of the array in January; see figure 7). 3) Temporary power failure occurred not infrequently during the winter months. Nevertheless a considerable body of micro-earthquake data was recorded.

"Normal" micro-earthquakes --relatively near-focus events with characteristic codas and S - Minus P travel times of about 0.5 to 5 seconds --occurred on the average six times daily, a rate comparable to that recorded by the ultra-portable system during a two day monitoring period on the south rim. However, not all of these events were sufficiently well-recorded on each of the three geophone traces to be usable for epicenter determinations. A preliminary plot of representative

Figure 7. CRATER LAKE TRIPARTITE ARRAY



PT. 2 OCT.- DEC. 1969
PT. 2' JAN.- MAR. 1970

epicenters for the better recorded events is shown on figure 8. The majority of events close to Crater Lake are of shallow origin and have short wave trains. North and south of Crater Lake the focal depths range from 0.5 to about 20 km. Some suggestion may be seen in the epicenter distribution, of ring fracture and regional tectonic control of the activity. It is interesting to note the similarity of seismic trends and the aeromagnetic trends published by Blank (1968) for the same region (figure 9), although the seismicity pattern must be refined with many more determinations before statistically valid comparisions can be made.

"Spike" events are commonly seen on individual traces of the Crater Lake records, particularly for the early part of the recording period. They generally consist of from only 2 to 10 cycles in a burst and occur in "swarms," or a group of similar events in rapid successions. The characteristic wave forms of these events may be seen and contrasted with normal micro-earthquakes with various S - P times on the seismographs illustrated in figure 10 (note the expanded time scale for spike events of increasing duration). Possible source mechanisms are limited to very near surface or surface phenomena such as rock falls, shifting snow, thermal fracture of glassy lavas, or even autos striking road surface irregularities. The most plausible explanation for at least some of the spikes, however, may well be thermal rock fracture. Figure 11 shows the correlation of spike events with precipitation and daily temperature ranges at Crater Lake

Figure 8: PRELIMINARY EPICENTERS DETERMINED FOR CRATER LAKE MICROEARTHQUAKES

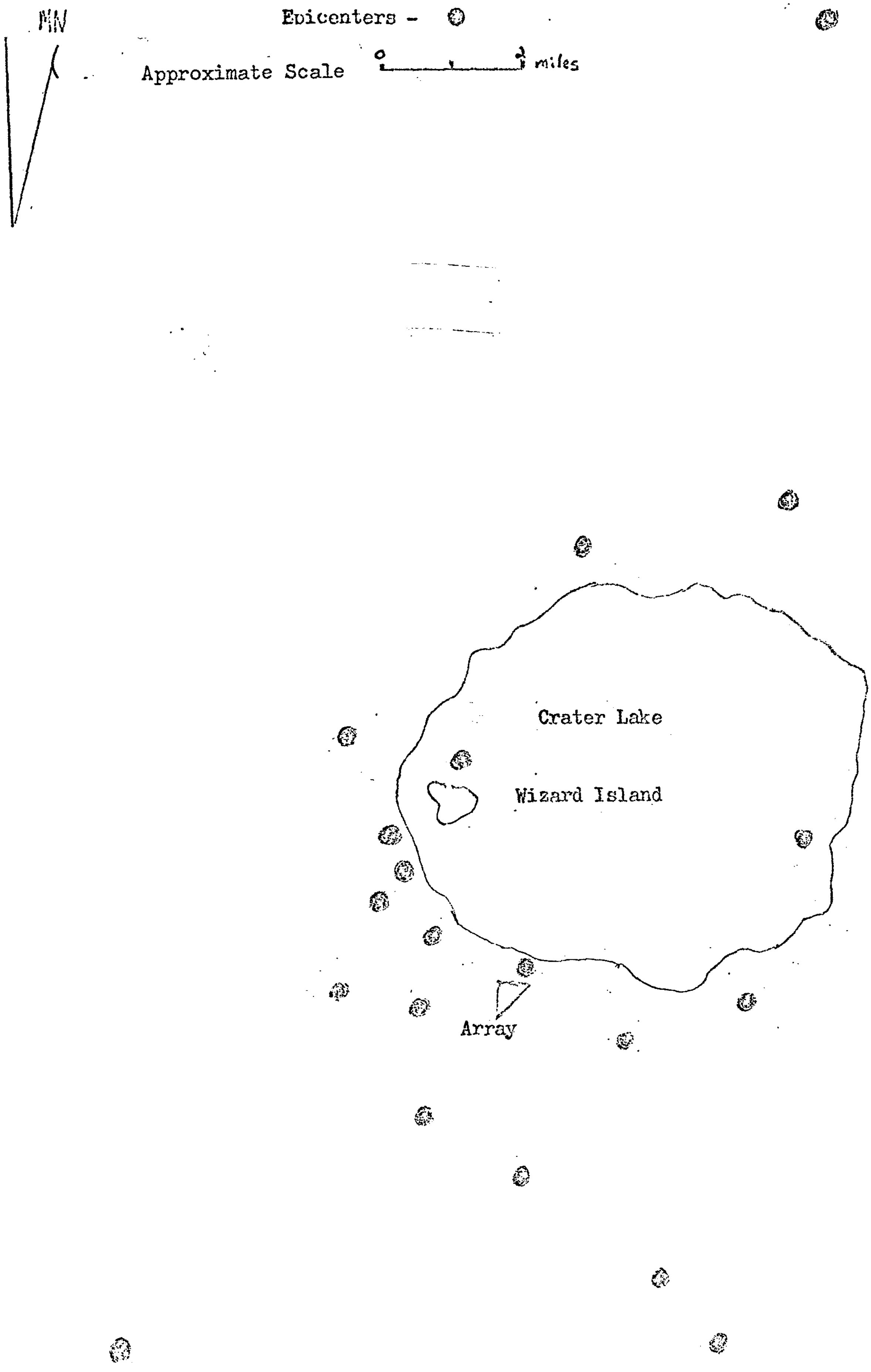
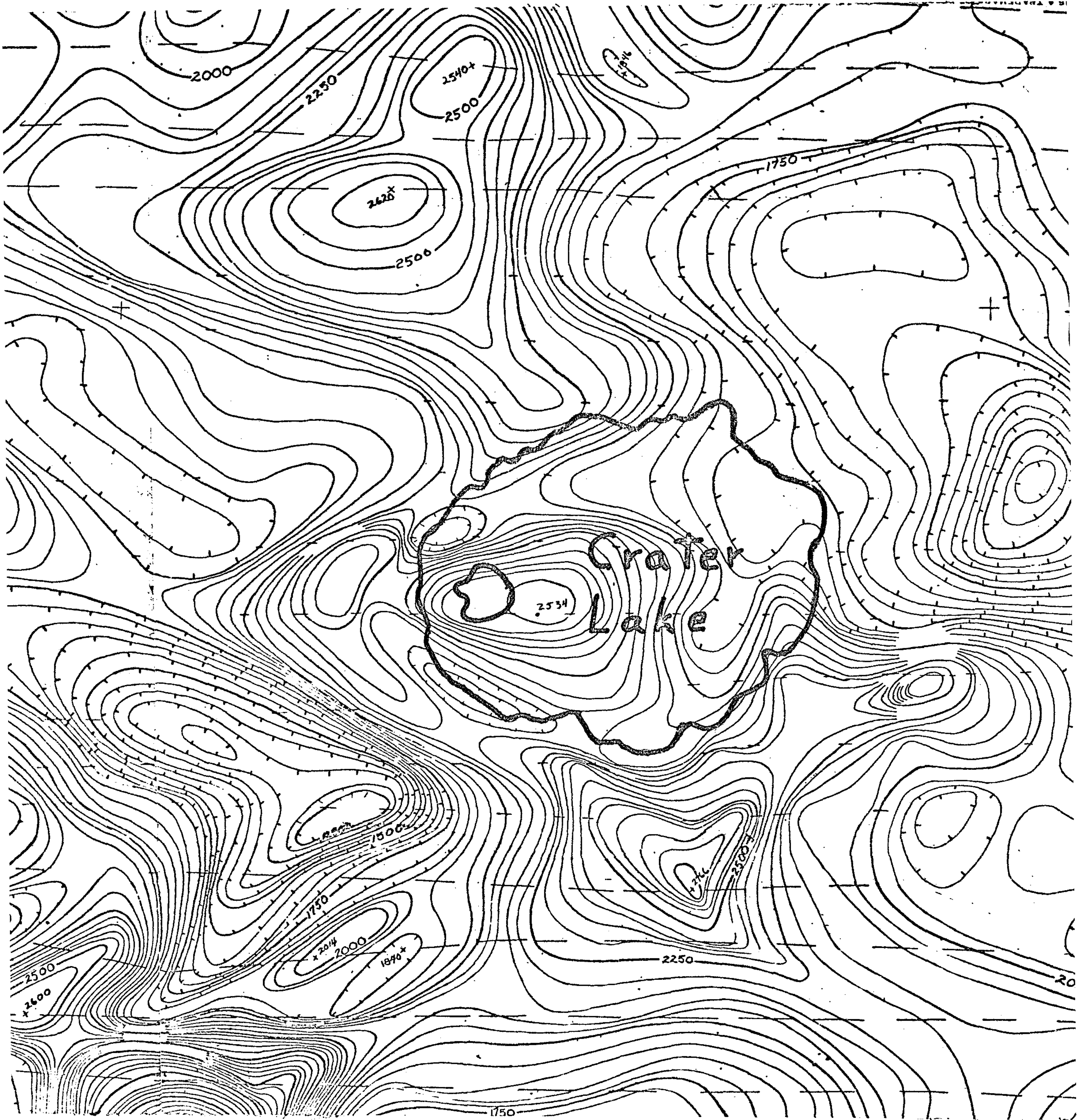


Figure 9: AEROMAGNETIC ISOINTENSITY CONTOURS FOR CRATER LAKE AND VICITY
(after Blank,1968)

MN

Approximate Scale 0 2 miles



Contour interval 50 gammas (total field intensity, referred to arbitrary datum)

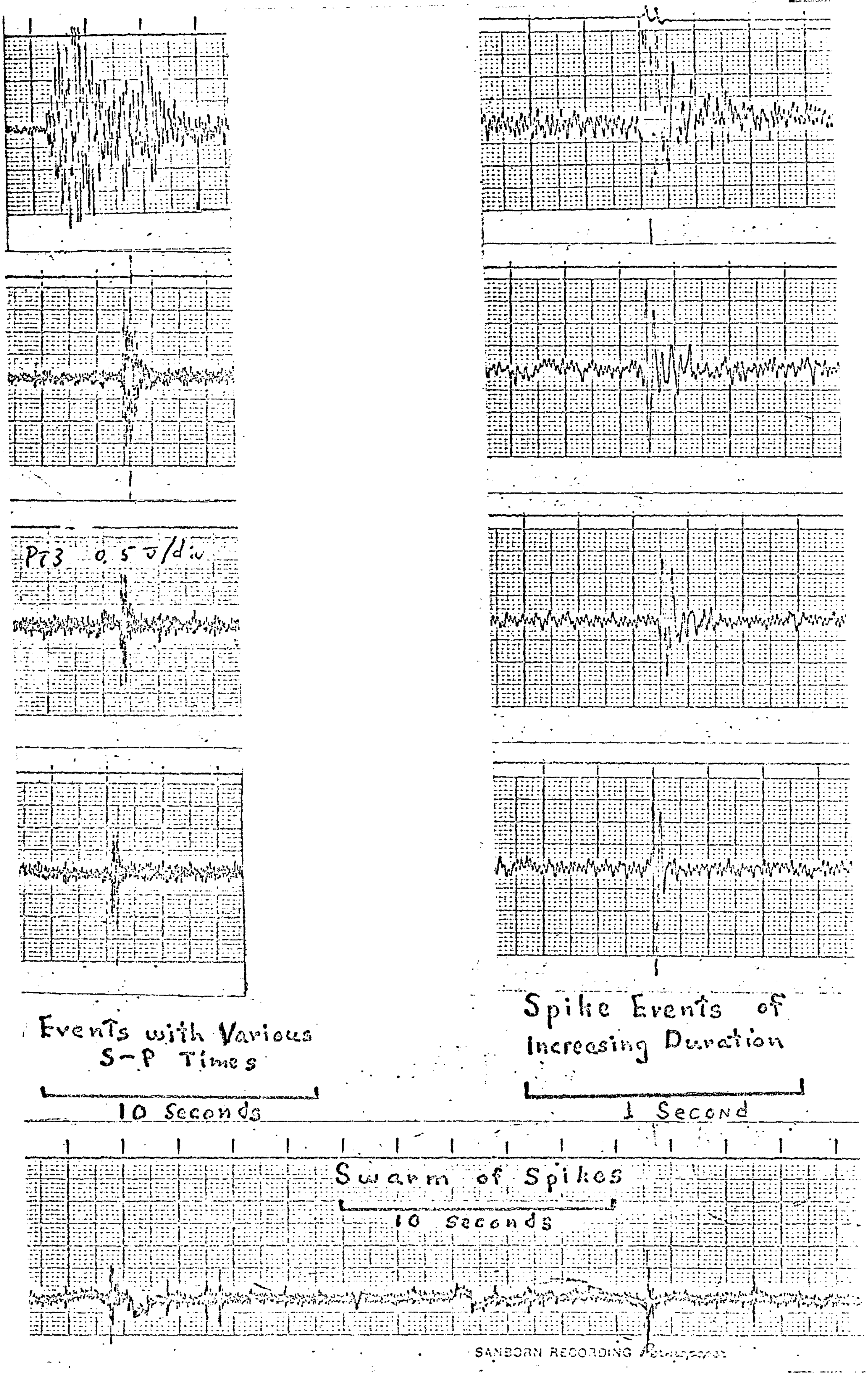


FIGURE 10: MICROEARTHQUAKES RECORDED AT CRATER LAKE WITH TRIPARTITE ARRAY

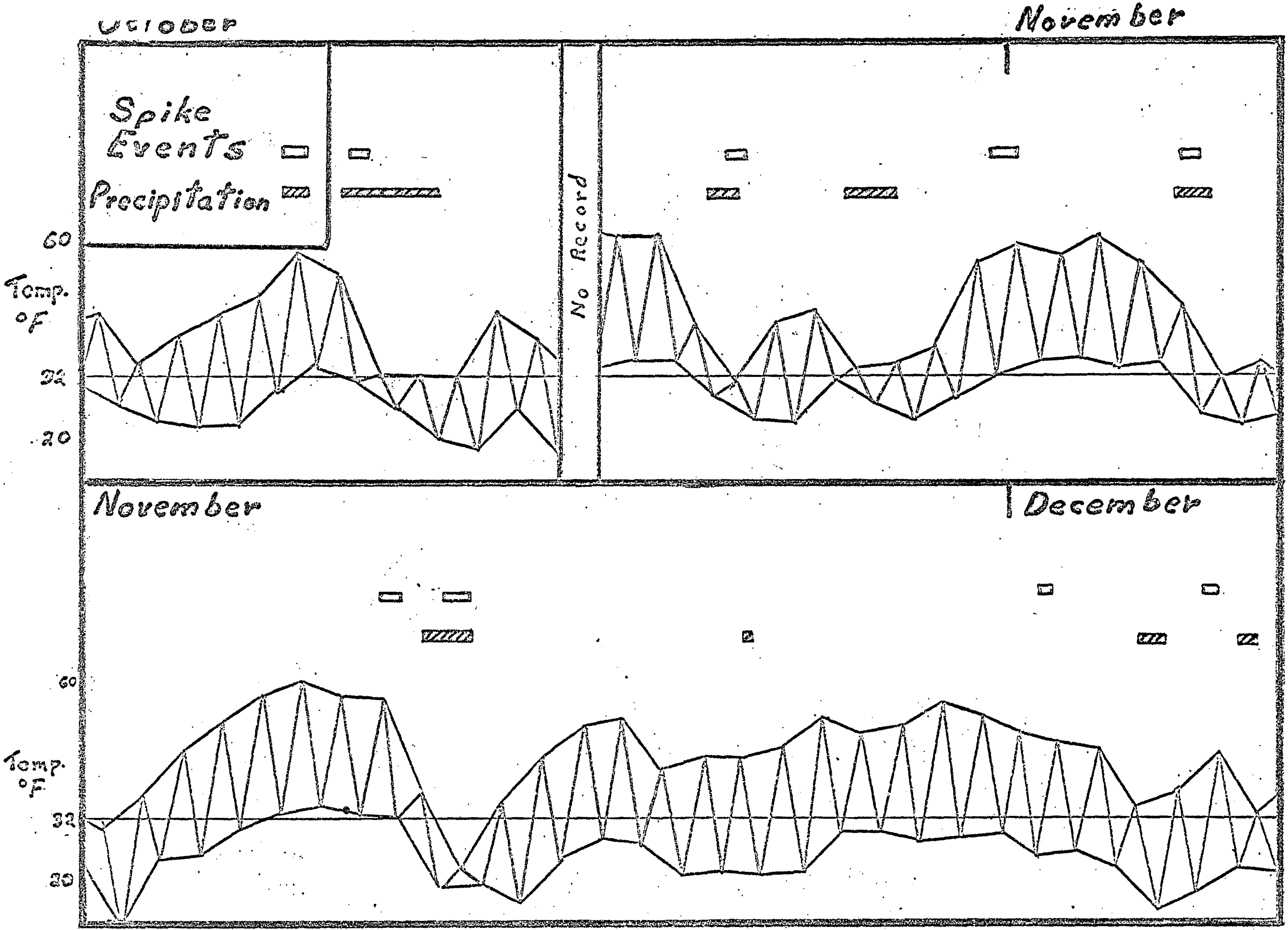


FIGURE 11: CORRELATION OF "SPIKE" SWARMS WITH METEOROLOGICAL PHENOMENON RECORDED AT CRATER LAKE

National Park Headquarters for the recording period October - December 1969. The maximum figure of occurrence appears to coincide with a drop in temperature through the freezing point following a period of precipitation.

A Lamont-Doherty experimental recording tiltmeter of the twin-pendulum type was operated on a concrete slab in the Lodge basement concurrently with operation of the seismic array. Temperature stability was non-ideal but some tilt trends may be visible after removal of temperature effects. Evaluation of the tiltmeter data has not yet been completed.

CONCLUSIONS AND RECOMMENDATIONS

The bulk of this report has been devoted to an account of seismic investigations accomplished in the field, and to various technical aspects of the program. Apart from tabulation and description of events recorded at Pine Mountain, Crater Lake, and the reconnaissance sites occupied to date, scientific contributions are restricted to preliminary evaluations. Some conclusions at this point are tentative and others are incomplete; a full scientific report will be made following analysis of all data.

Pine Mountain.

1) The Pine Mountain site is optimally located for crustal studies in Oregon, and well located for crustal studies in the Pacific Northwest.
2) The station systems are capable of providing signal magnification and qualities suitable to those tasks.
3) The site, insofar as local earthquakes are concerned, is virtually aseismic. It is subject to occasional storm wind noise in winter and traffic noise in summer.
4) The station is convenient to logistical support and can be satisfactorily operated on a year-round basis.
5) It is recommended that the station be operated essentially in its present configuration for as long as possible in the future. It may be more convenient to use a slower tape speed so that tapes need be changed on a less frequent basis.

6) It is recommended that the telemetry receiving point for seismicity surveys be tested, and that a means be explored for recording telemetered data directly onto equipment in the mobile laboratory.

7) It is recommended that the possibility be explored of telemetering both data from field sites and from the Pine Mountain geophones directly to Eugene, as is now done with data from the Pine Mountain Astronomical Observatory.

Ultra-portable seismicity surveys.

1) The ultra-portable system utilized in the present program is a satisfactory reconnaissance instrument, but could be improved by a) flattening frequency response curve (chiefly through adjustment of RC-circuit parameters in stage coupling); b) miniturizing pen-drive amplifier and including this circuit in a spare slot in the Develco amplifier housing; and c) digitizing WWVB timing output and inserting 10-second, one-minute and one-hour time marks from this output into pen-drive amplifier, along with complete (unaltered) WWVB time code each 4 hours. One-second pulses could also be used to synchronize the pen motor. This method would be superior to recording geophone signal and time code on the same trace, and eliminates dependence on a chronometer (WWVB has proved extremely reliable).

2) Site selection is of great importance in seismicity surveys. Protection from wind and direct contact with solid bedrock are the prime prerequisites.

3) A calibration signal should be applied at the beginning and end of each record to provide a systems check and a quantitative basis for magnitude calculations.

4) The results of reconnaissance surveys completed to date show that: a) the high lava plateaus of North Central Oregon, the Brothers fault zone, and the High Cascades exclusive of Plio-Pleistocene to Recent volcanoes are relatively aseismic; b) Newberry Crater and Mt. McLaughlin are about an order of magnitude more seismic than the afore-mentioned environments but are still relatively "quiet" seismically; c) the remainder of the High Cascade volcanoes monitored are about another order of magnitude more seismic than Newberry and McLaughlin; several micro-earthquakes per day can be detected.

5) Present methods of calculation of magnitudes for micro-earthquakes are satisfactory for relative purposes but apparently are unsatisfactory for absolute values, and are being revised.

6) The overall low seismicity of central Oregon, as indicated on the Barazangi and Dorman (1969) computations of epicenters for earthquakes of magnitude >3, is substantiated by the present micro-earthquake studies. Low frequency of events requires long-term monitoring for statistically valid samples.

7) It is recommended that the remainder of the field program of reconnaissance seismicity studies be executed; in particular that improved sites at previously occupied stations be located and monitored, that certain superior sites be reoccupied for time-variation studies, and that additional volcanic targets be surveyed.

8) It is recommended that the reconnaissance surveys be utilized primarily for the location of areas of high seismicity in volcanic terrain, such as geothermal areas, tectonically active areas, and seismically active volcanoes; and that follow-up surveys with multi-component arrays be utilized for the study of specific locations and source-mechanisms (a twelve-geophone, 3-component diamond array would provide maximum information.) Unger, (1970, oral communication), reports considerable difficulty in evaluating S - P times from arrays using vertical components only).

Crater Lake program.

1) Crater Lake (Mt. Mazama) has a seismicity typical of the more active class of High Cascades volcanoes, with several events per day being detected.

2) From preliminary determinations of epicenters it can be tentatively concluded that the seismic events are tectonically and perhaps ring-fracture controlled; their distribution trends roughly parallel the aeromagnetic trends for the same region.

3) Spike events (near-surface or surface sources) at Crater Lake may be produced by thermal rock fracture, as they show a crude correlation with falls of temperature through the freezing point following periods of precipitation.

4) It is recommended that additional array studies be carried out at Crater Lake with a view towards elucidating source mechanisms and spatial distribution of hypocenters.

5) Future field operations at Crater Lake should ensure protection from rodent damage by application of repellant to all cables.

REFERENCES CITED

Asada, T. (1957), Observations of near-by microearthquakes with ultra-sensitive seismometers, *J. Phy. Earth*, *5*: 83-113.

_________ (1958), Observations of near-by microearthquakes with ultra-sensitive seismometers at Matsushiro, Japan, *J. Phys. Earth*, *6*: 23-33.

Barazangi, M. and Dorman (1969), World seismicity maps compiled from ESSA, Coast and Geodetic Survey, Epicenter Data, 1961-1967, *Bull. of the Seismo. Soc. of America*, *59*, no. 1, 369-380.

Berg, J. W., Jr., *et al*. (1966), Crustral refraction profile, Oregon Coast Range, *Bull. Seism. Soc. Am.* *56*, No. 6, 1357-1362.

Berg, J. W., Jr. and C. D. Baker (1963), Oregon earthquakes, 1841 through 1958, *Bull. Seism. Soc. Am.* *53*, No. 1, 95-108.

Blank, H. R. (1968), Aeromagnetic and gravity surveys of the Crater Lake region, Oregon, *State of Oregon Dept. of Geology and Mineral Industries Bulletin 62*.

Boucher, G., Matumoto, T., and J. Oliver (1968), Localized microearthquakes in the Denali Fault Zone, *J. of Geophysics Res.* *73*, No. 14, 4789-4793.

Couch, R., Johnson, S. and J. Gallagher (1968), The Portland Earthquake of May 13, 1968 and earthquake energy release in the Portland area, *The Ore Bin* *30*, No. 10, 185-190.

Couch, R. and S. Johnson (1968), The Warner Valley earthquake sequence, May and June 1968, *The Ore Bin* *30*, No. 10, 191-204.

Couch, R. W., and L. J. Pietrafresca (1968), Earthquakes off the Oregon Coast: January 1968 to September 1968, *The Ore Bin* *30*, No. 10, 205-212.

Decker, R. W. and D. Harlow (1970), Microearthquakes at Cascade Volcanoes (paper read at AGU meeting, Washington D.C., April 1970).

Dehlinger, P., Chiburis, E. F., and M. M. Culver (1965), Local travel-time curves and their geologic implications for the Pacific Northwest states, *Bull Seism. Soc. Am.* *55*, No. 3, 587-607.

Dehlinger, P., Bowen, R. G., Chiburis, E. F. and W. H. Westphal (1963), Investigation of the earthquake of Nov. 5, 1962 north of Portland, *The Ore Bin* *25*, No. 4, 53-68.

Eaton, J. P. (1962), Crustral structure and volcanism in Hawaii, Crust of the Pacific Basin, *Geophys. Monogr.* *No. 6*, 13-29.

____________ (1967), Instrumental seismic studies, in the Parkfield-Cholame California Earthquakes of June-August, 1966, *U. S. Geol. Survey Prof. Paper 579*.

Gutenberg, B. and C. F. Richter (1954), *Seismicity of the earth and associated phenomena*, 2nd ed., Hofner Pub. Co., New York.

Hamada, K. and T. Hagiwara (1966), High sensitivity tripartite observation of Matsushiro earthquakes, Part 1. *Bull. of the Earthquake Research Institute 44*, 1213-1238.

Isacks, B., Oliver, J., and L. R. Sykes (1968), Seismology and the new global tectonics, *J. of Geophys. Res. 73*, No. 18, 5855-5899.

Matumoto, T., and P. Ward (1967), Microearthquake study of Mt. Katmai and vicinity, Alaska, *J. Geophys. Res. 72*, 2557-2568.

Minakami, T. (1960), Fundamental research for predicting volcanic eruptions, Part 1, *Bull. Earthquake Res. Inst. Tokyo University 38*, 480-544.

___________ (1959), The study of eruptions and earthquakes originating from volcanoes, Part 1-3, *Bull. Volcano Soc. Japan 4*, 104-151.

Moore, J. G. and H. L. Krivoy (1964), the 1962 flank eruptions of Kilauea volcano and the structure of the EAST Rift Zone, *J. Geophys. Res. 69*, 2033-2045.

Muramatu, I. (1964), On the equation to define the earthquake magnitude, *Zisin*, Ser. II, 17, 210-221.

Oliver, J., Ryall, A., Brune, J. N., and D. B. Slemmons (1966), Microearthquake activity recorded by portable seismographs of high sensitivity, *Bull. Seism. Soc. Am. 56*, No. 4, 899-924.

Page, R. (1968), Aftershocks and microaftershocks of the great Alaska earthquake of 1964, *Bull. Seism. Soc. Am. 58*, No. 3, 1131-1168.

Pakiser, L. C. (1964), Gravity, volcanism, and crustal structure in the southern Cascade Range, California, *Bull. Seism. Soc. Am. 75*, 611-620.

Rasmussen, N. H. (1967), Washington State earthquakes, 1840 through 1965: *Bull. Seism. Soc. Am. 57*, 463-476.

Smith, W. D. (1919), Earthquakes in Oregon, *Bull. Seism. Soc. Am. 9*, No. 3, 59-79.

Tigres, J. R. (1968), Chemical protection methods progress, *Electronic Packaging and Production*, April 1968.

Tocher, D. (1956), Earthquakes off the North Pacific Coast of the United States, *Bull. Seism. Soc. Am. 46*, No. 3, 165-173.

Unger, J. D. (1969), The microearthquake activity of Mt. Rainier, Washington, Ph.D. thesis, Dartmouth College, 187 p.

Unger, J. D. and R. W. Decker (1969), The microearthquake activity of Mt. Rainier, Washington (paper read at AGU meeting, Washington D. C.).

Walker, G. W., Peterson, N. V. and R. C. Greene (1967), Reconnaissance geologic map of the east half of the Crescent Quadrangle Lake, Deschutes and Crook Counties, Oregon. U. S. Geol. Survey, Misc. Geologic Investigation Map I-493.

Ward, P. L. and T. Matumoto (1967), A summary of volcanic and seismic activity in Katmai National Monument, Alaska, Bull. Volcanol. 31, 107-129.

Ward, P., Palmason, G. and C. Drake (1969), Microearthquake survey and the Mid-Atlantic Ridge in Iceland, J. of Geophys. Res. 74, No. 2, 665-684.

Westhusing, J. K. (1970), Report on seismic field operations for the summer of 1969, Lockheed Electronics Company for NASA Manned Spacecraft Center, Houston, Texas.