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TECHNICAL REPORT NO. 70-4

FINAL REPORT, Project VT/8703
January through December, 1969

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TELEDYNE GEOTECH

TECHNICAL REPORT NO. 70-4

FINAL REPORT, PROJECT VT/8703
JANUARY THROUGH DECEMBER, 1969

by

LRSM Staff

Sponsored by

Advanced Research Projects Agency
ARPA Order No. 624

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TELEDYNE GEOTECH
3401 Shiloh Road
Garland, Texas

11 March 1970

IDENTIFICATION

AFTAC Project No:	VELA T/8703
Project Title:	Long-Range Seismic Measurements
ARPA Order No:	624
ARPA Code No:	8F10
Contractor:	Teledyne Geotech
Contract No:	F33657-69-C-0757
Contract Date:	1 January 1969
Amount of Contract:	$1,185,191
Amendment 002:	$236,064
Contract Expiration Date:	31 December 1969
Project Manager:	R. G. Reakes (214) 271-2561 Garland, Texas

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ILLUSTRATIONS, Continued

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GLOSSARY OF TERMS

AFTAC	Air Force Technical Applications Center
Anemometer	An instrument for measuring or indicating the speed or force of the wind
ARPA	Advanced Research Projects Agency
BCD	Binary Coded Decimal
dB	Decibels
EDP	Electronic Data Processing
LASA	Large Aperture Seismic Array
LP	Long Period
LPH	Long Period Horizontal
LRL	Lawrence Radiation Laboratory
LRSM	Long-Range Seismic Measurements
Microbarograph	An instrument designed to detect and record very small variations in atmospheric pressure
NTS	Nevada Test Site
PTA	Phototube Amplifier
SDL	Seismic Data Laboratory
SP	Short Period
TFSO	Tonto Forest Seismological Observatory
Triax	Applies to a description of instrumentation that interests itself in three axes that intersect at a common point. Two horizontals oriented 90° from one another and a vertical seismometer is a triaxial device. Three symmetrical triaxial seismometer modules all oriented to detect motions in an axis 55° from vertical and 120° from one another is also a triaxial device.
USC&GS	United States Coast and Geodetic Survey
VELA-Uniform	The research and development program for the improvement of detection of underground nuclear explosions.

ABSTRACT

The progress of the Long-Range Seismic Measurements (LRSM) Program during the period 1 January through 31 December 1969 is described.

At the beginning of this report period, there were nine mobile observatories and eleven portable seismograph systems in the LRSM program. These seismograph systems participated in related programs and experiments such as MIRACLE PLAY, RULISON, JORUM, and MILROW. The portable seismograph systems continue to demonstrate their versatility and effectiveness during all field assignments. Six portable strain systems were designed, prefabricated, and deployed to the Nevada Test Site. The site selection was completed in late September and site preparation and installation was started during November 1969.

A review of the studies and evaluations made is included in this report. Studies conducted were directed toward: 1) the analysis of data from portable and mobile systems and 2) the investigation of long-period and short-period data.

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FINAL REPORT, PROJECT VT/8703
January 1969 through December 1969

1. INTRODUCTION

The Long-Range Seismic Measurements Program (LRSM), a VELA-Uniform project, was first contracted on 1 June 1960. The VELA-Uniform research project is directed towards creating major advances in all areas of seismic detection, identification, and location techniques, to the end that a better understanding of the detection and identification of underground nuclear explosions will be achieved.

The LRSM program has provided a majority of the detection and recording systems in support of the VELA-Uniform objectives. A vast amount of data is presently available on a nonclassified basis for use in arriving at a technical assessment of the effectiveness of a test-ban control system. In addition, these data are available to others in the scientific community for use in many varied studies.

Six technical reports have been written covering the work performed in the LRSM program previous to the time period covered by this report:

a. TR 61-3, Final Report on Phases I, II, and III, Long-Range Seismic Measurements Program, covers work performed from 1 June 1960 through 31 December 1960.

b. TR 62-22, Interim Report on Operating Procedures, Project VT/074, records the LRSM activities from 1 September 1961 through 31 December 1962.

c. TR 66-78, Interim Report No. 2, Project VT/4051, for the period 1 January 1963 through 30 June 1964.

d. TR 66-92, Interim Report No. 3, Project VT/4051, for the period 1 July 1964 through 31 March 1966;

e. TR 68-19, Final Report, Project VT/6703, for the period April 1966 through March 1968;

f. TR 69-7, Final Report, Project VT/8703, for the period January 1968 through December 1968.

This report describes the progress of the LRSM program during the period 1 January through 31 December 1969. The research was supported by the Advanced Research Projects Agency, Nuclear Test Detection Office, under Project VELA-Uniform and accomplished under the technical direction of the Air Force Technical Applications Center under Contract F33657-69-C-0757.

2. SUMMARY

A detailed review of all work performed by the LRSM program from January through December 1969 is contained in this report. The following paragraphs summarize briefly the information presented in the report.

At the beginning of the report period, there were nine mobile observatories in the LRSM program. In addition, three mobile vans were maintained on a standby status at our Garland, Texas, facility. Two of these vans were equipped with the necessary equipment to operate at the Nevada Test Site (NTS) in support of the accelerometer study. The other van was transferred to the long-period (LP) strain, Project VT/8706. Houlton, Maine (HN-ME), supported the borehole strain seismometer, Project VT/8703, in addition to their regular LRSM duties. Support of the LP triax, Project VT/6706, near Fairbanks, Alaska (FB-AK), was terminated when operation was discontinued in October 1969. Mina, Nevada (MN-NV), operations were discontinued in January 1969, and the van was returned to Garland, Texas. Las Cruces, New Mexico (LC-NM), and Kanab, Utah (KN-UT), operations were discontinued in October 1969, and the equipment was transferred to the Civil Engineering Branch of the Air Force Weapons Laboratory, Sandia Base, Albuquerque, New Mexico. Whitehorse, Yukon (WH2YK), terminated operation in October 1969, and the van and equipment were returned to Garland, Texas. This equipment was later transferred to the Air Force Office of Scientific Research (Office of Aerospace Research) Contract F33C20-69-C-0117 and delivered to the University of Washington in Seattle, Washington. Six portable strain systems were designed, prefabricated, and deployed to Nevada where sites were selected and prepared.

3. FIELD OPERATIONS

3.1 GENERAL

The LRSM mobile observatories and portable systems continued to record seismic signals from earthquakes and underground explosions in support of the VELA-Uniform program. Figure 1 is a map showing the locations of sites occupied in 1969. These field teams also continued to be active participants in related programs and experiments such as MIRACLE PLAY (see paragraph 3.3.1), RULISON, JORUM, and MILROW (see paragraph 3.3.2). Figure 2 shows the sites occupied for the RULISON, JORUM, and MILROW events. Table 1 is a list of LRSM teams, their site locations, designators, and operational dates.

3.2 OPERATION OF THE MOBILE OBSERVATORIES

Nine mobile observatories were operational at the beginning of this report period. In addition, three vans were maintained on a standby status at our Garland, Texas, facility. Figure 3 is a photograph of the LRSM mobile observatory. Figure 4 is a sketch of a typical LRSM mobile observatory installation.

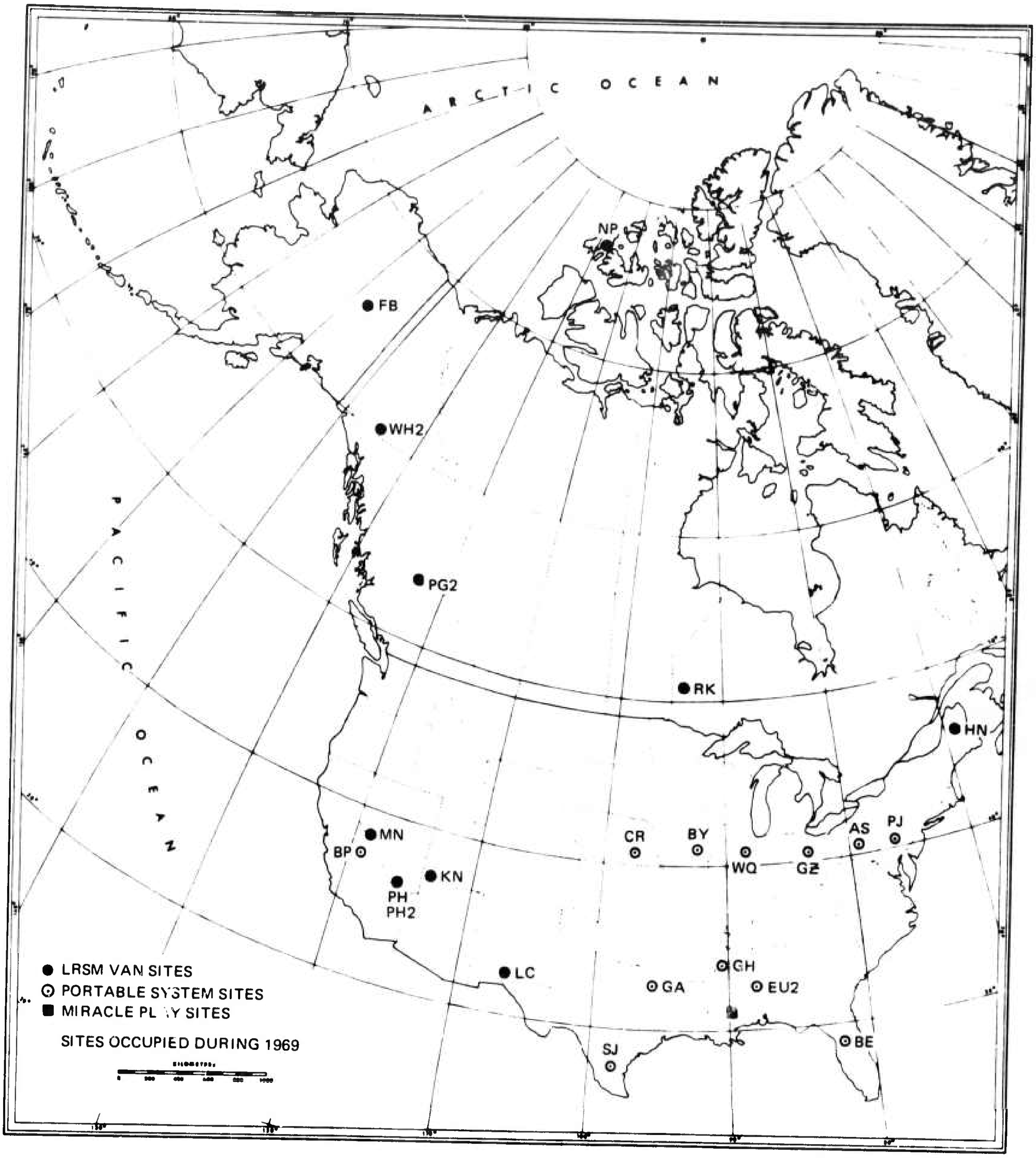


Figure 1. Sites occupied during 1969

G 5776

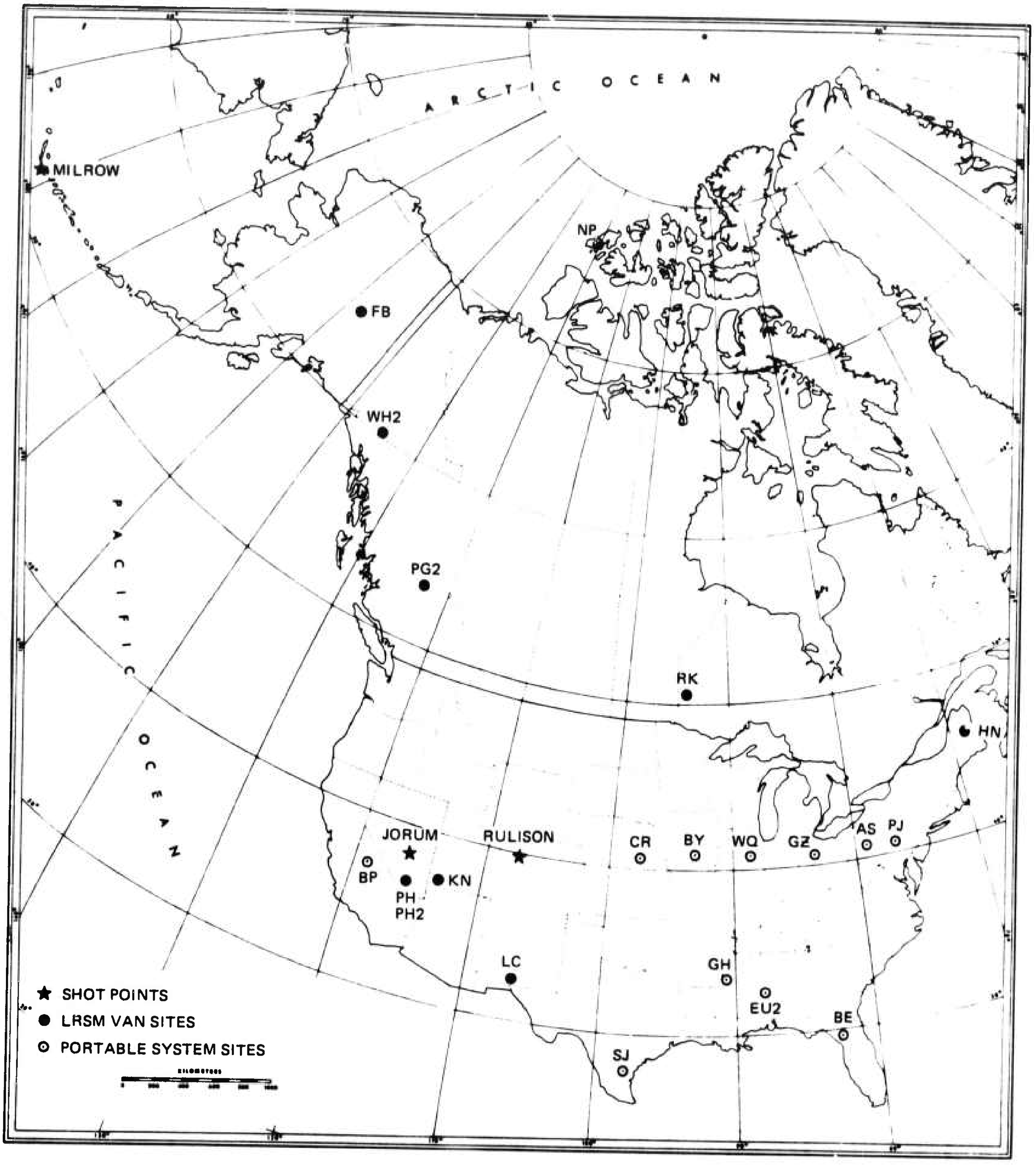


Figure 2. Sites occupied for the RULISON, JORUM, and MILROW detonations

G 5777

Table 1. List of sites occupied during this report period

Mobile Observatories

Team	Site Location	Designator	Date Operational	Date Closed
3	Red Lake, Ontario	RK-ON	17 July 63	-
8	Garland, Texas (standby)	GL-TX	-	-
8	Pahute Mesa, Nevada	PH2NV	15 Sept 69	10 Oct 69
11	Kanab, Utah	KN-UT	9 Dec 61	31 Oct 69
13	Mould Bay, Canada	NP-NT	23 Aug 63	-
15	Las Cruces, N. M.	LC-NM	2 Aug 67	16 July 69
15	Las Cruces, N. M.	LC-NM	1 Sept 69	16 Sept 69
15	Las Cruces, N. M.	LC-NM	26 Sept 69	10 Oct 69
27	Whitehorse, Yukon	WH2YK	24 Nov 66	10 Oct 69
28	Prince George, B. C.	PG2BC	5 Oct 68	-
30	Houlton, Maine	HN-ME	25 Oct 66	-
35	Mina, Nevada	MN-NV	10 Oct 61	15 Jan 69
35	Garland, Texas (standby)	GL-TX	-	-
35	Pahute Mesa, Nevada	PH-NV	15 Sept 69	10 Oct 69
36	Fairbanks, Alaska	FB-AK	3 Sept 68	10 Oct 69

Portable System Teams

Team	Site Location	Designator	Date Operational	Date Closed
50	Laurel, Mississippi	LL-MS	17 Jan 69	2 Feb 69
	Greenville, Mississippi	GH-MS	22 Aug 69	10 Oct 69
51	Lucedale, Mississippi	LD3MS	18 Jan 69	2 Feb 69
	Altoona, Pennsylvania	AS-PA	26 Aug 69	10 Oct 69
52	Lumberton, Mississippi	LU-MS	17 Jan 69	2 Feb 69
	San Jose, Texas	SJ-TX	21 Aug 69	10 Oct 69

Table 1. List of sites occupied during this report period, continued

Portable System Teams

Team	Site Location	Designator	Date Operational	Date Closed
53	Richton, Mississippi	RI-MS	18 Jan 69	2 Feb 69
	Crete, Nebraska	CR-NB	22 Aug 69	10 Oct 69
54	Picayune, Mississippi	PC-MS	15 Jan 69	2 Feb 69
	Belleview, Florida	BE-FL	21 Aug 69	10 Oct 69
55	Lucedale, Mississippi	LD-MS	19 Jan 69	2 Feb 69
	Bishop, California	BP-CL	29 Aug 69	10 Oct 69
56	Grand Saline, Texas	GA-TX	18 Oct 68	23 Apr 69
	Watseka, Illinois	WO-IL	23 Aug 69	10 Oct 69
57	McComb, Mississippi	MB-MS	17 Jan 69	2 Feb 69
	Galion, Ohio	GZ-OH	23 Aug 69	10 Oct 69
58	Lucedale, Mississippi	LD2MS	18 Jan 69	2 Feb 69
	Eutaw, Alabama	EU2AL	27 Aug 69	10 Oct 69
59	Bloomfield, Iowa	BY-IO	23 Aug 69	10 Oct 69
60	Grand Saline, Texas	GA2TX	25 Oct 68	23 Apr 69
	Pottstown, Pennsylvania	PJ-PA	29 Aug 69	10 Oct 69

Figure 3. LRSM mobile observatory

G 766

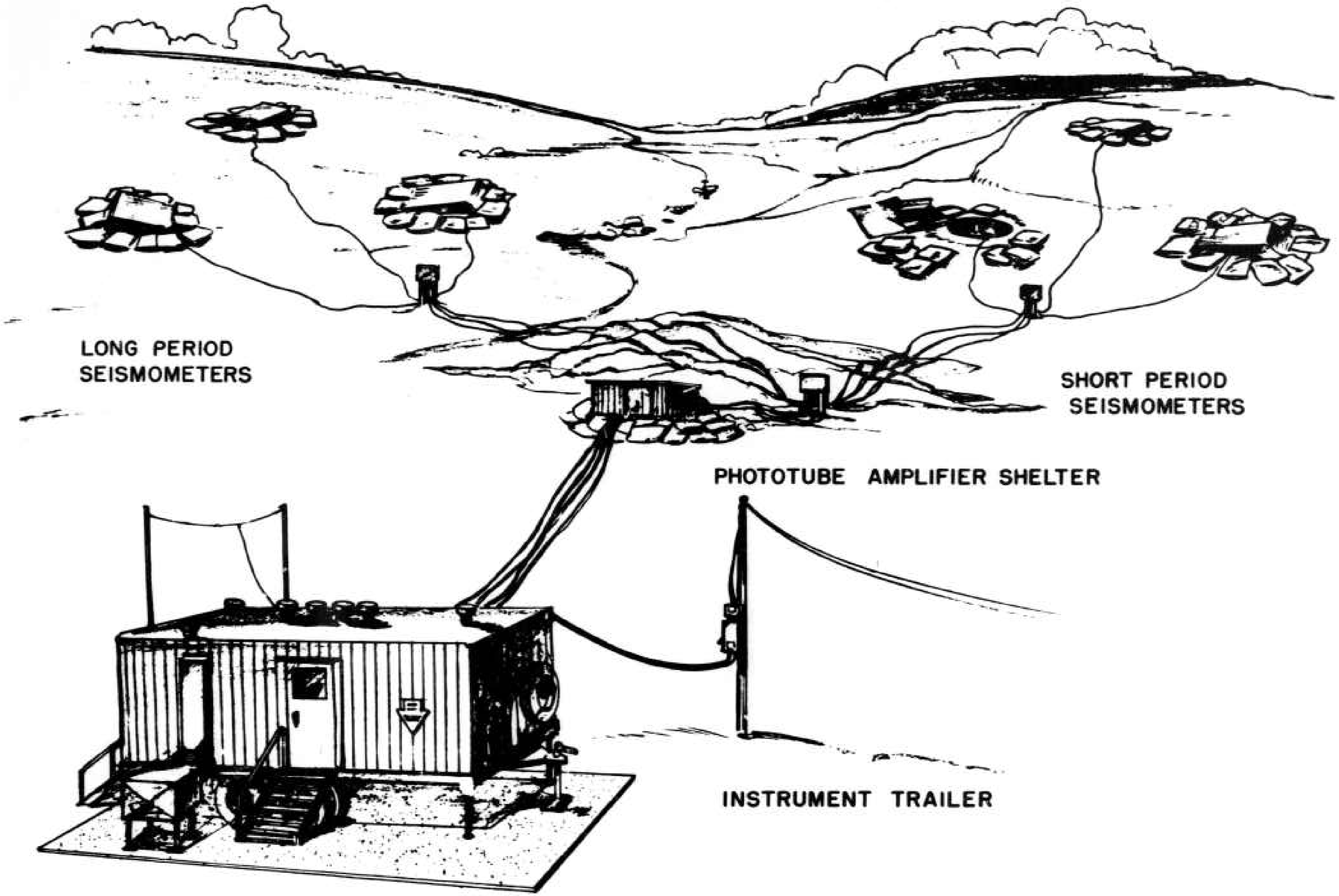


Figure 4. Typical LRSM system field setup

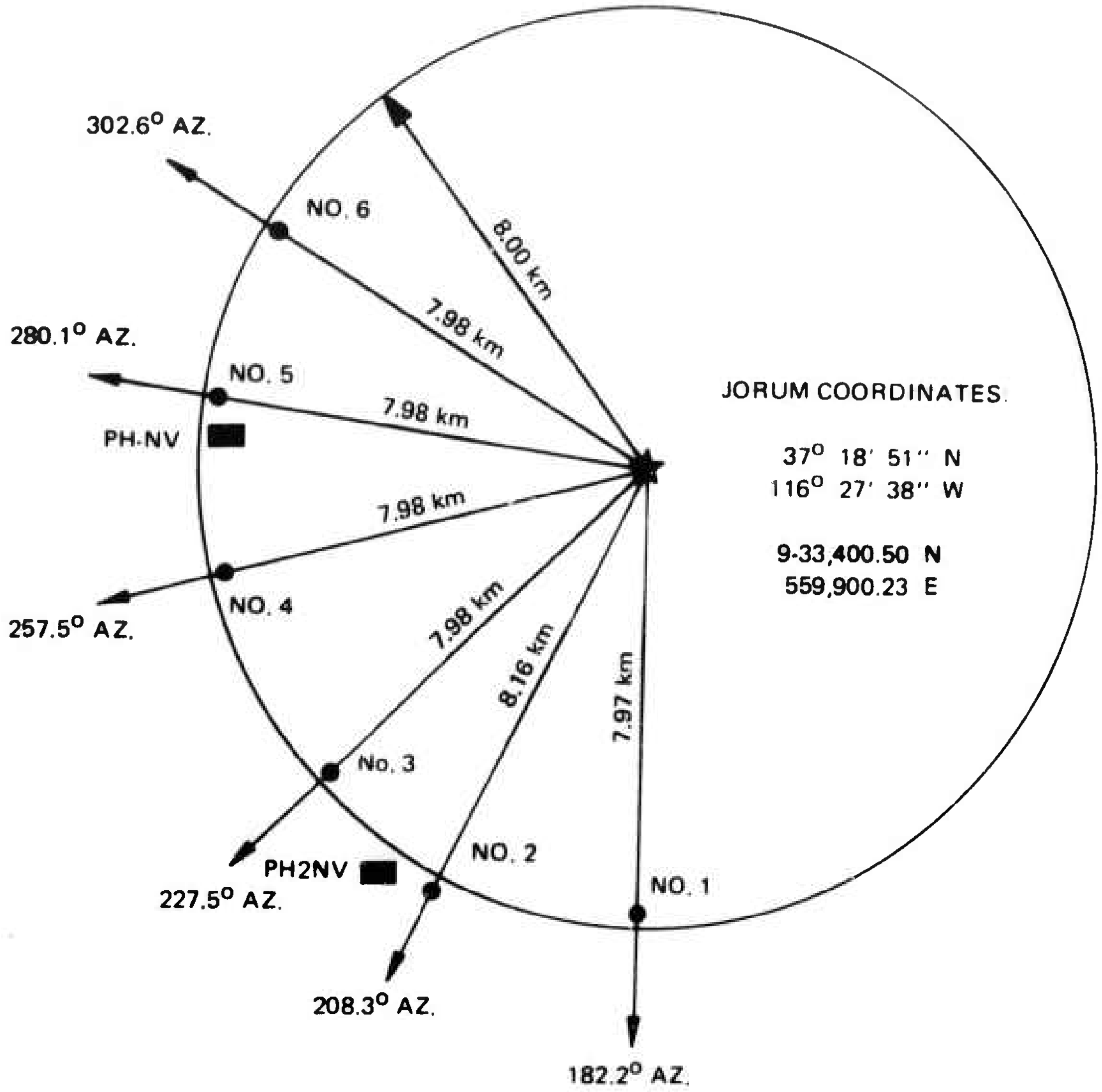
G 4159

3.2.1 Two of the mobile observatory vans located at the Garland, Texas, facility were equipped to operate at NTS in support of an accelerometer study for the collection of accelerometer data for the University of California. The vans departed Garland, Texas, on 6 August 1969 and arrived at NTS on 11 August 1969. The van sites occupied were designated Pahute Mesa, Nevada (PH-NV and PH2NV). Figure 5 shows the location of the six three-component accelerometer stations. Data were recorded on magnetic tape from 15 September 1969 through 10 October 1969; and after operations were discontinued, the vans were moved to a vehicle compound at NTS where they remain in storage on standby status for use in early 1970.

3.2.2 A vertical strain seismograph and comparison inertial seismograph were installed in shallow boreholes at the LRSM site at HN-ME as a logical followup on the successful enhancement of P waves at the Garland test facilities. Figure 6 is a block diagram of the seismograph system at HN-ME. The installation work at HN-ME, which started on 13 January 1969 and was completed on 4 February 1969, was accomplished under Contract F33657-68-C-0021 and supported by Contract F33657-69-C-0757. Equipment for signal control, recording, monitoring, and calibration was furnished by the LRSM program. Routine operation of the strain system by LRSM station personnel was started on 4 February 1969 and maintained throughout the LRSM contract period. Operational data from 4 February to 25 April 1969, recorded on magnetic tape, Develocorder, and Helicorder, were analyzed at the Geotech facility in Garland, Texas, and the results reported in Technical Report No. 69-20 entitled Supplement to Final Report, Project VT/8704, Short-Period Multicomponent Strain System. The results showed that the predominant microseisms, which are retrograde Rayleigh waves occurring in the range of 0.12 to 0.7 Hz, are suppressed by nearly 10 dB by the strain-inertial combination. From 0.7 to 1 Hz, less suppression is observed. Beyond 1 Hz the microseisms appear to have added; however, the level of signal on the strain seismograph is low, approaching that of system noise. Tests to increase the signal-to-noise ratio by use of more sensitive 0.8 Hz galvanometers in place of the 3.0 Hz galvanometers were conducted at HN-ME in the period 17-20 April 1969. The inherent instability of the 0.8 Hz galvanometers, resulted in difficulties in phase matching, differences being as large as 17 degrees between the strain and inertial seismographs in the critical frequency range 0.5 to 2 Hz. Also, the galvanometers were very sensitive to wind-induced vibration of the PTA shelter.

The monitoring of subsequent strain records from HN-ME revealed the onset of wind noise caused in part by an unstable condition of the temporary phototube amplifier platform that developed when the ground thawed. A similar condition developed in the near surface section of the casing in the strain borehole. The PTA piers were reconditioned in May 1969, and the borehole casing reinforced in November 1969 by packing gravel around the top section of the pipe, including a 4-ft section above ground. The effect of the wind is now less; however, winds of 20-30 knots produce noise equal to the level of the microseisms, but at higher frequency (predominantly 3 Hz).

It is important, perhaps, to re-emphasize the fact that successful cancellation of microseisms has been accomplished at HN-ME. Although the microseisms at HN-ME are higher in level than at many interior sites, HN-ME is considered typical of sites where the detection of low-level signals can be enhanced.



SITE INFORMATION

Site No.	Geographic Coordinates North	Geographic Coordinates West	Nevada Grid North	Nevada Grid East	Elevation Feet	Elevation Meters
1	37°14′32″	116°27′52″	907,031	558,802	6260	1908
2	37°14′58″	116°30′16″	909,760	547,200	6230	1899
3	37°15′55″	116°31′38″	915,625	540,729	6010	1832
4	37°17′54″	116°32′53″	927,604	534,479	5880	1792
5	37°19′36″	116°32′58″	937,813	534,167	5560	1695
6	37°21′10″	116°32′13″	947,344	537,813	5300	1615

Figure 5. JORUM accelerometer locations

G 5778

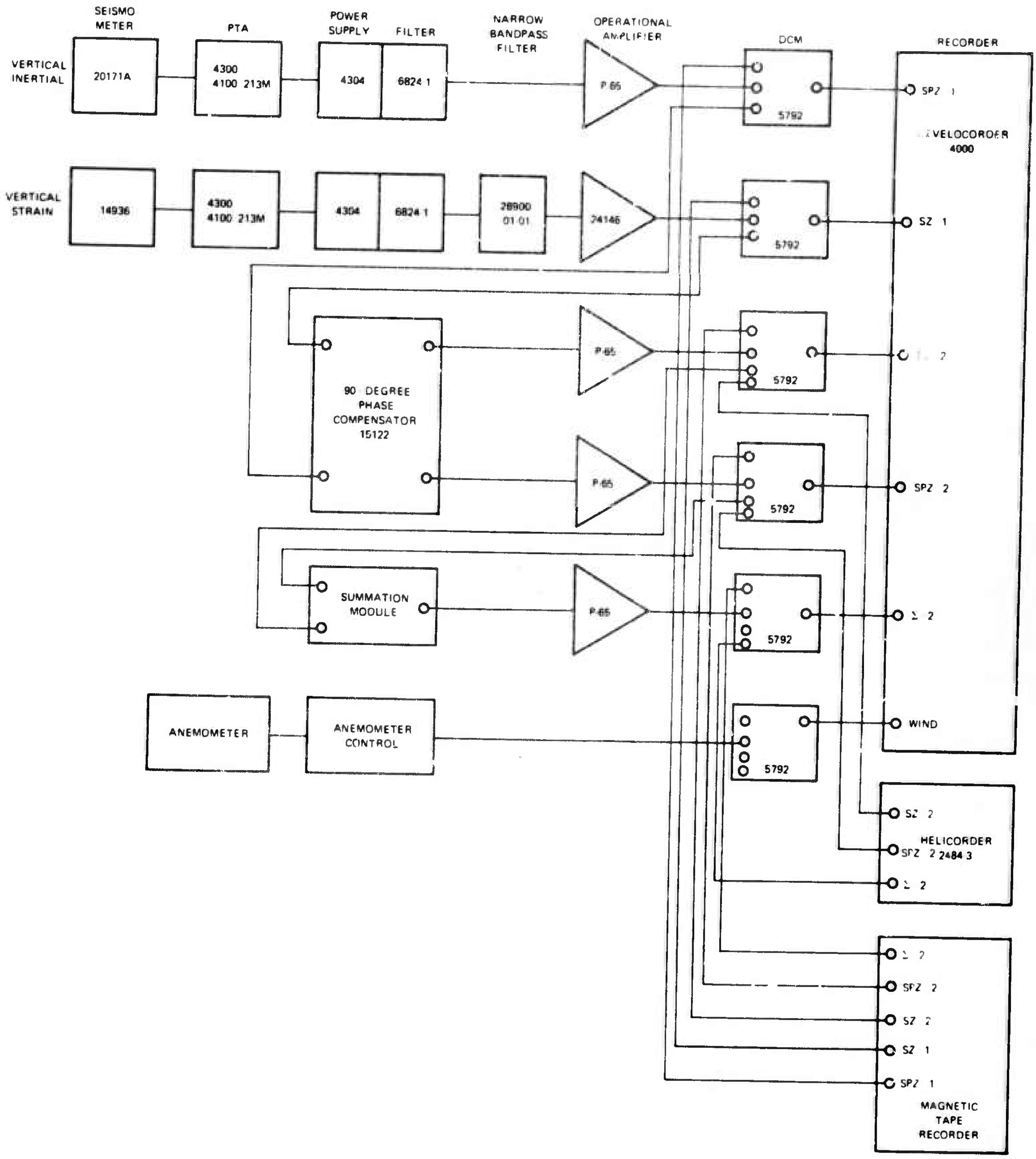


Figure 6. Block diagram of strain seismograph system at Houlton, Maine

G 5000

The strain and inertial seismometers have been operating in the boreholes at HN-ME for a full year without requiring maintenance. The excellent cancellation of microseisms has persisted without adjusting either the galvanometer responses or the response of the phase matching filters. Typical cancellation of microseisms and enhancement of P waves are demonstrated by the Helicorder record (figure 7) made after nearly a year of operation of the system during which no adjustments to maintain phase matching were necessary and during which no adjustment or maintenance of the vertical strain seismometer was needed.

3.2.3 Support was continued for the collection of LP triax data for Project VT/6706 near Fairbanks, Alaska. This project began operations on 11 October 1968 and requirements included the recording of standard LRSM SP, advanced LP, LP triax, and microbarograph data. Operations were discontinued on 10 October 1969. The van and all equipment remained on the site and will be reactivated for special monitoring assignments during the 1970 contract year.

3.2.4 The mobile observatories monitored and collected data from the RULISON, JORUM, and MILROW events. The RULISON event, near Rulison, Colorado, and the JORUM event at NTS, were detonated in September 1969. In early October 1969, the MILROW event was detonated on Amchitka Island in the Aleutian Islands.

3.2.5 The van and LRSM equipment at MN-NV were moved to Garland, Texas, after operations were discontinued on 15 January 1969. This van was later instrumented to record accelerometer data at NTS.

3.2.6 LC-NM discontinued operations on 16 July 1969. The equipment and van were left on the site for use during special events. The station was placed in operation again on 1 September 1969 and again on 26 September 1969. Operations were discontinued for the last time on 10 October 1969. The van and equipment were transferred on 22 December 1969 to the Civil Engineering Branch of the Air Force Weapons Laboratory, Sandia Base, Albuquerque, New Mexico. At the time of this writing, the equipment remains on site.

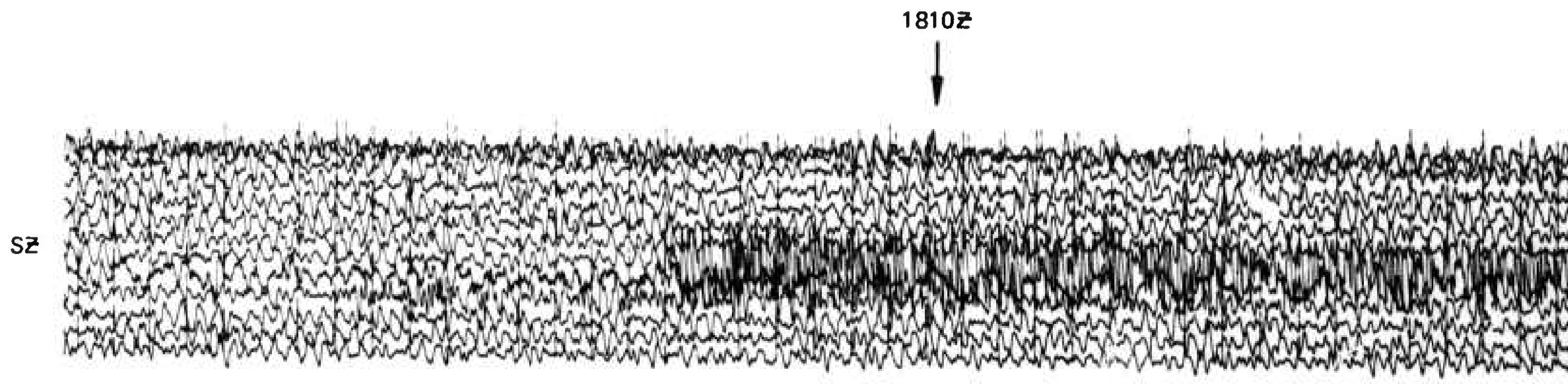
3.2.7 The KN-UT station was closed on 31 October 1969. This equipment was transferred on 19 December 1969 to the Civil Engineering Branch of the Air Force Weapons Laboratory, Sandia Base, Albuquerque, New Mexico.

3.2.8 During special recording periods, the teams at MN-NV and KN-UT operated, in addition to standard LRSM instrumentation, a SP vertical seismograph system in support of a special study for LRL. The recorder used was a four-channel, high-speed, 35-mm film recorder with each channel adjusted to a magnification assigned by LRL. These data,as well as copies of standard LRSM SP vertical 35-mm film records and logs, were air mailed to LRL immediately after processing.

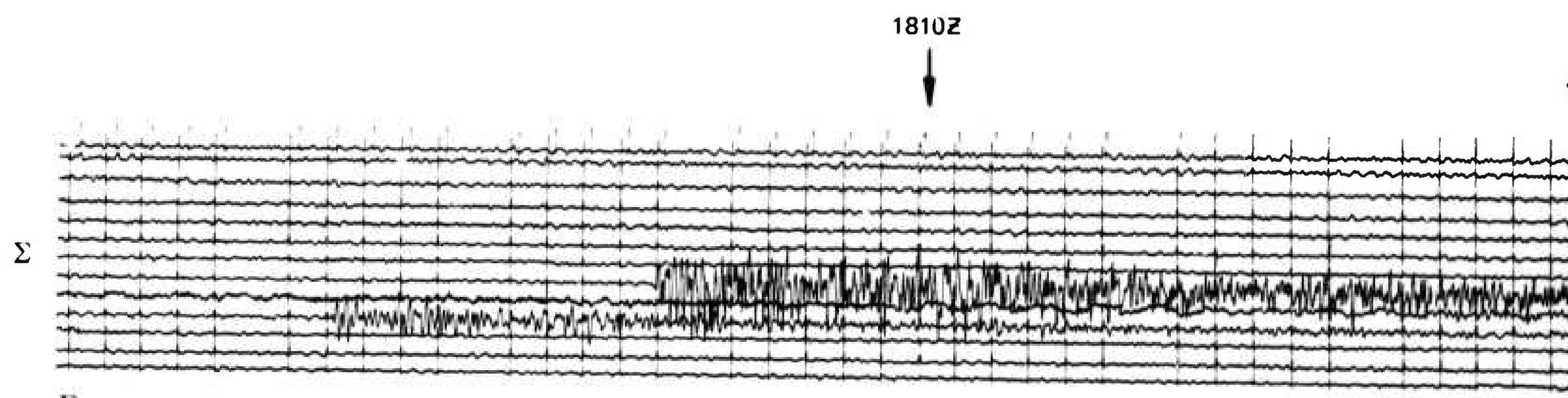
HNME
25 DECEMBER 1969

SPZ – VERTICAL INERTIAL

1810Z



SZ – VERTICAL STRAIN



Σ – SUMMATION OF SPZ AND SZ

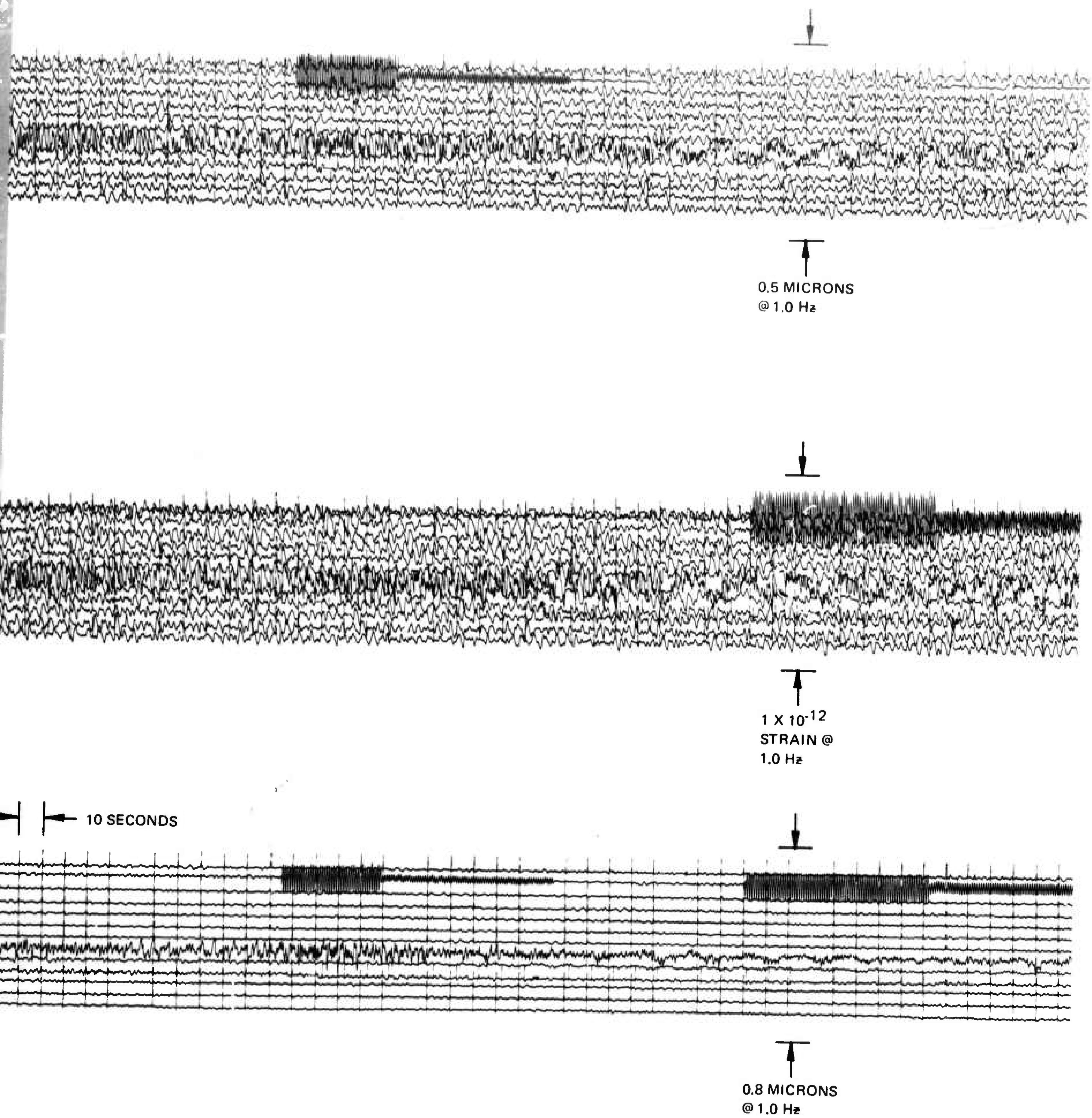


Figure 7. Helicorder record of microseisms recorded at HNME on 25 December 1969 showing typical cancellation of microseisms and enhancement of P-wave on the strain-inertial seismograph summation channel (bottom).

3.2.9 The WH2YK station was closed on 10 October 1969. The van and equipment were returned to Garland, Texas, and deactivated. This equipment was transferred on 10 December 1969 to the Air Force Office of Scientific Research (Office of Aerospace Research) Contract F44C20-69-C-0117 and delivered to the University of Washington in Seattle, Washington.

3.3 OPERATIONS OF THE PORTABLE SYSTEMS

Portable system equipment is installed and operated by a single technician. With previous preparation of LP instrument vaults, an operator can initiate recording of both SP and LP data within three days of arrival at the site. Without advance preparation of the LP instrument vaults, full installation requires approximately six days. Operation of SP instruments can be accomplished within three hours, if requirements are such that this is necessary; calibration of the seismometers and the recording systems would be accomplished at a later date. Figure 8 is a sketch of a portable system site layout.

3.3.1 In January 1969, eight portable system teams were assigned to record data from DIODE TUBE, the first explosion in the Project MIRACLE PLAY series. Table 2 shows the team, station, designator, location, and operational dates. Figure 9 is a map showing the MIRACLE PLAY site locations.

Table 2. Project MIRACLE PLAY site locations.

Team No.	Station designator	Location	Operation dates	
			SP	LP
50	LL-MS	Laurel, Mississippi	17 Jan	17 Jan
51	LD3MS	Lucedale, Mississippi	18 Jan	18 Jan
52	LU-MS	Lumberton, Mississippi	16 Jan	17 Jan
53	RI-MS	Richton, Mississippi	14 Jan	18 Jan
54	PC-MS	Picayune, Mississippi	15 Jan	15 Jan
55	LD-MS	Lucedale, Mississippi	19 Jan	19 Jan
57	MB-MS	McComb, Mississippi	15 Jan	17 Jan
58	LD2MS	Lucedale, Mississippi	18 Jan	18 Jan

All teams discontinued operations on 2 February 1969 and returned to Garland, Texas. Figure 10 shows views of the site at Laurel, Mississippi (LL-MS).

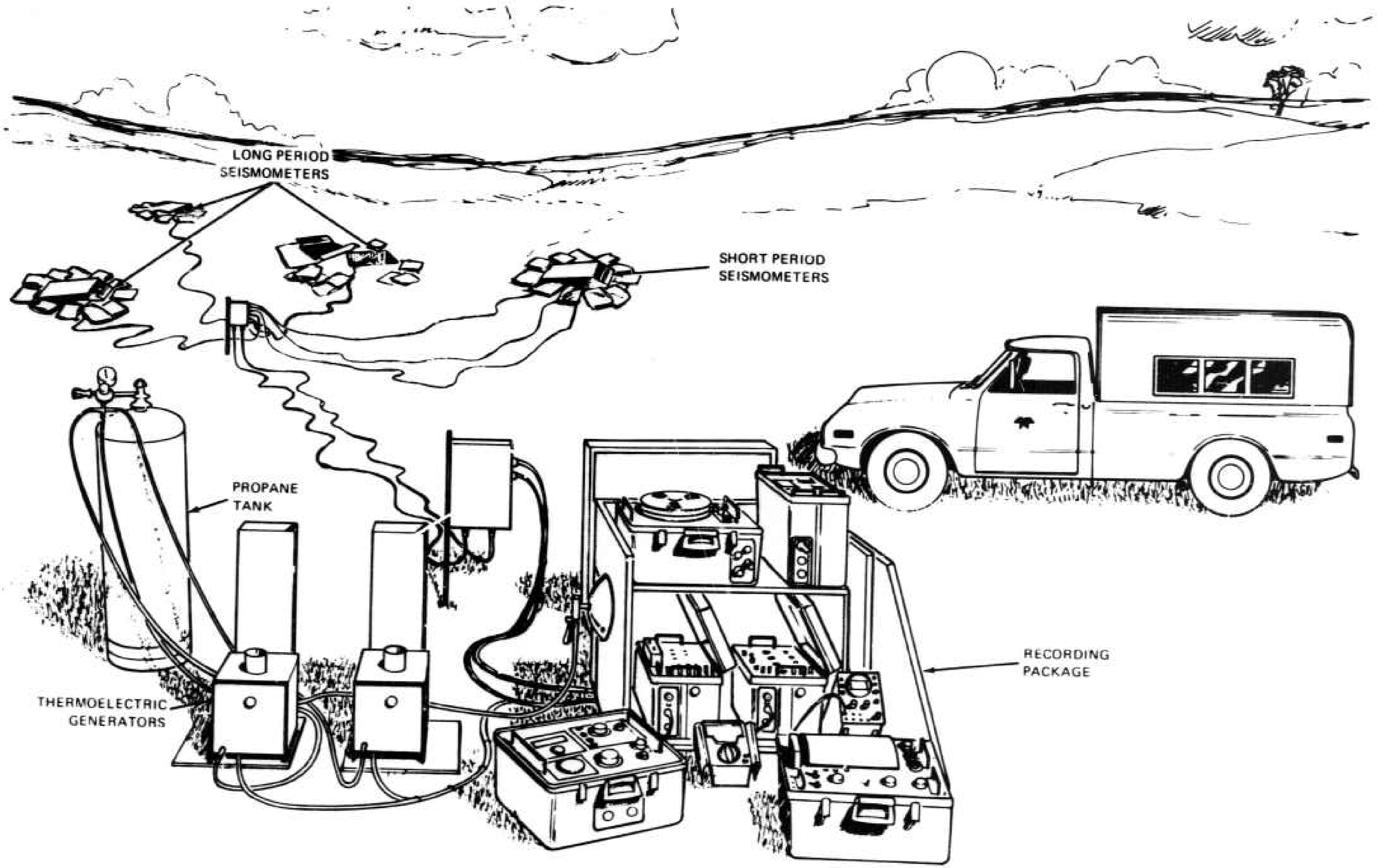
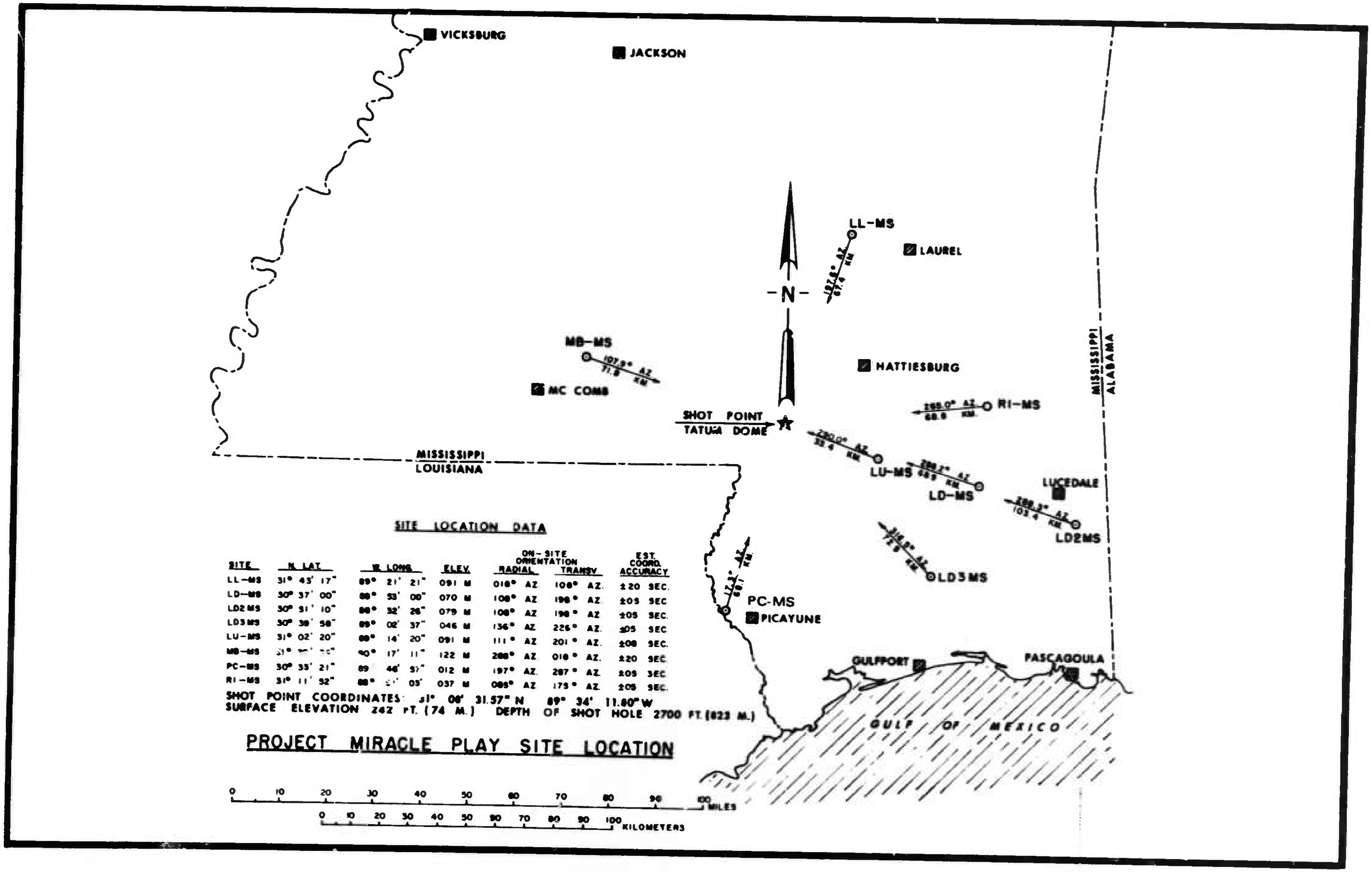


Figure 8. Portable systems site layout

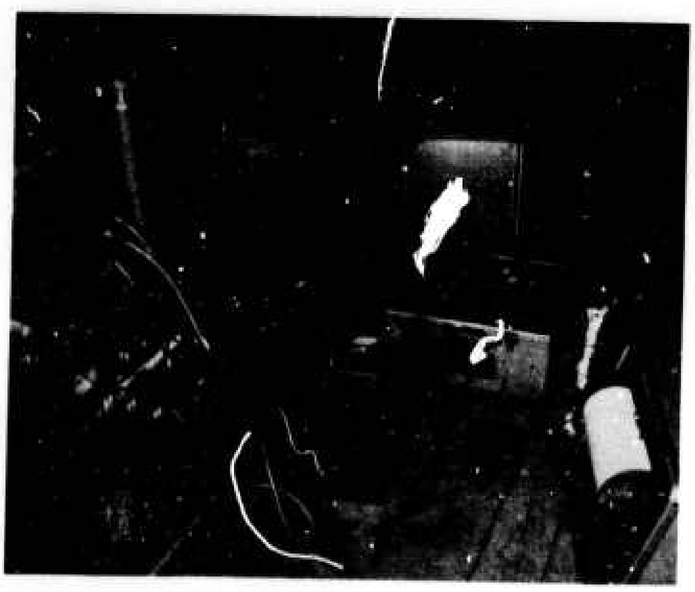
G 5779



SITE	N. LAT.	W. LONG.	ELEV.	ON-SITE ORIENTATION RADIAL	ON-SITE ORIENTATION TRANSV	EST. COORD. ACCURACY
LL-MS	31° 43' 17"	89° 21' 21"	091 M	018° AZ	108° AZ.	±20 SEC.
LD-MS	30° 37' 00"	88° 53' 00"	070 M	108° AZ	198° AZ	±05 SEC
LD2 MS	30° 51' 10"	88° 32' 26"	079 M	108° AZ	198° AZ	±05 SEC.
LD3 MS	30° 38' 58"	89° 02' 37"	046 M	136° AZ	226° AZ.	±05 SEC
LU-MS	31° 02' 20"	89° 14' 20"	091 M	111° AZ	201° AZ.	±08 SEC.
MB-MS	31° [illegible]	90° 17' 11"	122 M	288° AZ	018° AZ.	±20 SEC
PC-MS	30° 33' 21"	89 46' 37"	012 M	197° AZ.	287° AZ	±05 SEC
RI-MS	31° 11' 52"	88° [illegible] 03"	037 M	085° AZ	175° AZ	±05 SEC.

Figure 9. MIRACLE PLAY site locations

G 5780



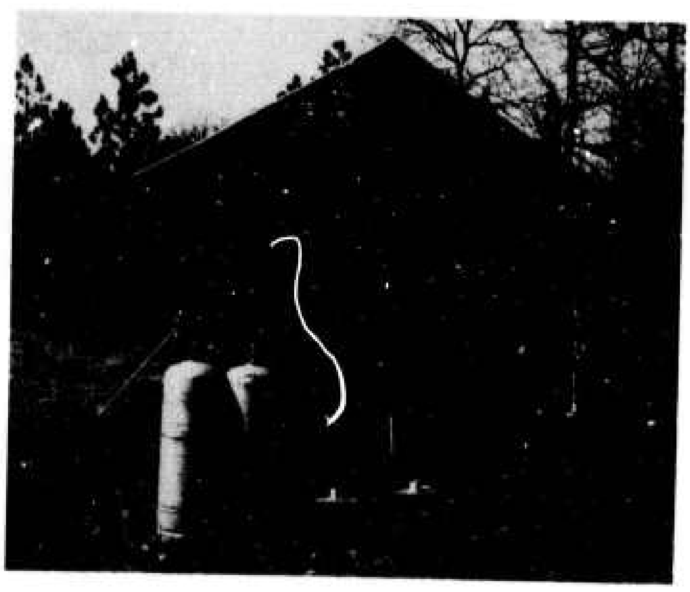


Figure 10. Views of the LL-MS portable system site during the DIODE TUBE experiment, January 1969.

3.3.2 In August 1969, eleven portable system teams were mobilized to monitor the RULISON event detonated near Rulison, Colorado, and the JORUM event detonated at NTS. Table 3 indicates the team, station designator, location, and departure, arrival, and operational dates, during the RULISON and JORUM data collection operation.

In early October 1969, MILROW was detonated on Amchitka Island in the Aleutian Islands. All portable teams monitored data from this shot at the sites shown in table 3.

Table 3. Portable system site locations during RULISON, JORUM, and MILROW

Team	Designator	Location	Date Departure	Date Arrival	Date Operational
50	GH-MS	*Greenville, Miss.	12 Aug 69	14 Aug 69	22 Aug 69
51	AS-PA	*Altoona, Pa.	11 Aug 69	17 Aug 69	26 Aug 69
52	SJ-TX	San Jose, Texas	15 Aug 69	15 Aug 69	21 Aug 69
53	CR2NB	Crete, Neb.	12 Aug 69	14 Aug 69	22 Aug 69
54	BE-FL	Belleview, Fla.	13 Aug 69	15 Aug 69	21 Aug 69
55	BP-CL	Bishop, Calif.	11 Aug 69	15 Aug 69	29 Aug 69
56	WQ-IL	*Watseka, Ill.	15 Aug 69	18 Aug 69	23 Aug 69
57	GZ-OH	*Galion, Ohio	15 Aug 69	17 Aug 69	23 Aug 69
58	EU2AL	Eutaw, Ala.	12 Aug 69	14 Aug 69	27 Aug 69
59	BY-IO	*Bloomfield, Iowa	12 Aug 69	15 Aug 69	26 Aug 69
60	PJ-PA	*Pottstown, Pa.	11 Aug 69	15 Aug 69	29 Aug 69

*New sites selected by team personnel.

All portable system teams discontinued recording on 10 October 1969 and returned to Garland, Texas.

3.3.3 During November and December 1968, portable instrumentation was installed at the Grand Saline, Texas (GA-TX) site and consisted of: (1) a three-component set of LP seismometers, as well as microbarograph and anemometer, on the surface; and (2) a three-component set SP and a three-component set LP seismometers 700 feet below the surface in a salt mine. All data were recorded by a single magnetic-tape recorder. Operations were discontinued on 23 April 1969. The surface vaults were left intact, and the cables running from the surface into the salt mine were left in place in order that the site can be reoccupied at a later date.

4. INSTRUMENTATION

4.1 GENERAL

This section describes the evaluation and modification of existing equipment and the characteristics of new equipment - the objective being to improve the capability and reliability of the various systems.

4.2 SEISMOMETERS

4.2.1 Sprengnether Horizontal and Vertical Seismometers, Geotech Models 100 and 201

The Sprengnether seismometers were used at all LRSM mobile observatories, except the FB-AK site. These seismometers require a well-controlled environment, usually provided by pressure sealing, heating, and insulating the vault. Under these conditions, the seismometers have provided adequate performance.

4.2.2 Long-Period Horizontal and Vertical Seismometers, Geotech Models 7505A and 8700C

These seismometers are used by six portable seismograph systems and the FB-AK mobile observatory. These instruments have given reliable service; however, it is difficult for the portable system operator to install the 160-pound instrument without assistance.

4.2.3 Portable Long-Period Vertical Seismometer, Geotech Model 28280 (SL 210)

This seismometer was developed because of the need for a truly portable LP seismometer; its volume of only 660 cubic inches and weight of 23 pounds makes it truly a portable instrument. The seismometer is somewhat more sensitive to temperature change than the Model 7505A, but performs satisfactorily when installed in a standard portable system vault and normal diurnal temperature variations exist. In order to provide the capability of operating the seismometer under extreme temperature variations, a remotely-controlled mass position adjustment is provided. The device is shown installed on the seismometer in figure 11. The seismometer was used during several field operations and performed satisfactorily.

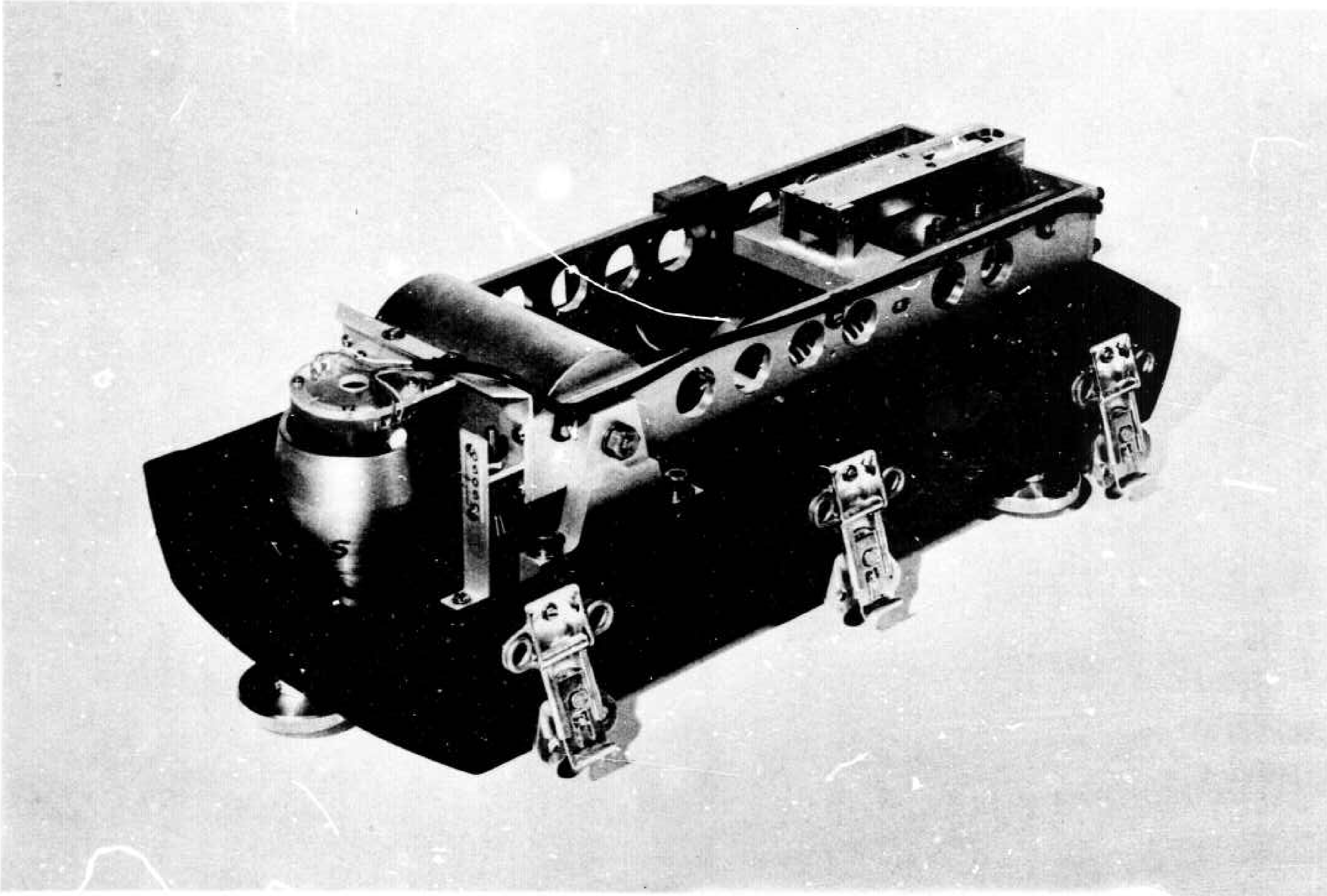


Figure 11. Portable Vertical Long-Period Seismometer, Geotech Model 28280, with remote mass position adjust

G 5781

4.2.4 Portable Long-Period Horizontal Seismometer, Geotech Model 28700 (SL 220)

This seismometer, shown in figure 12, has approximately the same volume and weight as the Model 28280. The instrument has exhibited good temperature characteristics during laboratory tests and field operations.

4.3 PORTABLE SYSTEM MODIFICATION

One portable seismograph system was modified to permit the use of the main battery power supply as a power source for the Model 19823 control monitor unit. The main batteries provide greater capacity and eliminate the requirement for separate battery packs for the control monitor. This modification will be performed on additional systems as the standard control monitor batteries require replacement.

4.4 NTS ACCELEROMETER PROJECT

Instrumentation was prepared to provide support to the University of California, Berkeley, in a special measurement program conducted at NTS. Two mobile recording vans were modified in order to record data from 18 accelerometers at both high and low gains. The modification basically consisted of the installation of one additional magnetic-tape recorder, with its associated calibration equipment, and two Model 22228C operational amplifier units in each van. The operational amplifier units were also modified before installation to meet the requirement for high- and low-gain channels.

4.5 STRAIN OPERATION AT HN-ME DURING JULY 1969

Three samples of HN-ME data recorded on 14 July were processed at Garland to determine whether the phase match between the vertical strain and inertial seismograph was suitable for operation following the re-insertion of the 3 Hz galvanometers into the system. Results of this processing indicate that no additional phase adjustments in the strain seismographs are considered necessary for the purpose of routine operation.

4.6 INVENTORY PROCEDURE

A computerized inventory control is used for all major equipment items subject to transfer between teams and to or from the warehouse. The computer playout shows stock number, nomenclature, equipment category, manufacturer, model number, serial number, original contract number, government I. D. number, if any, and location of the equipment. Updating of the computer tape is by punched card, and information can be retrieved either by equipment category or by location. Computer time required for the 42-page inventory ranges from 3 to 20 minutes, depending upon the number of changes made and the type of playout required. Updating is normally done once a month or after any major change in equipment disposition.

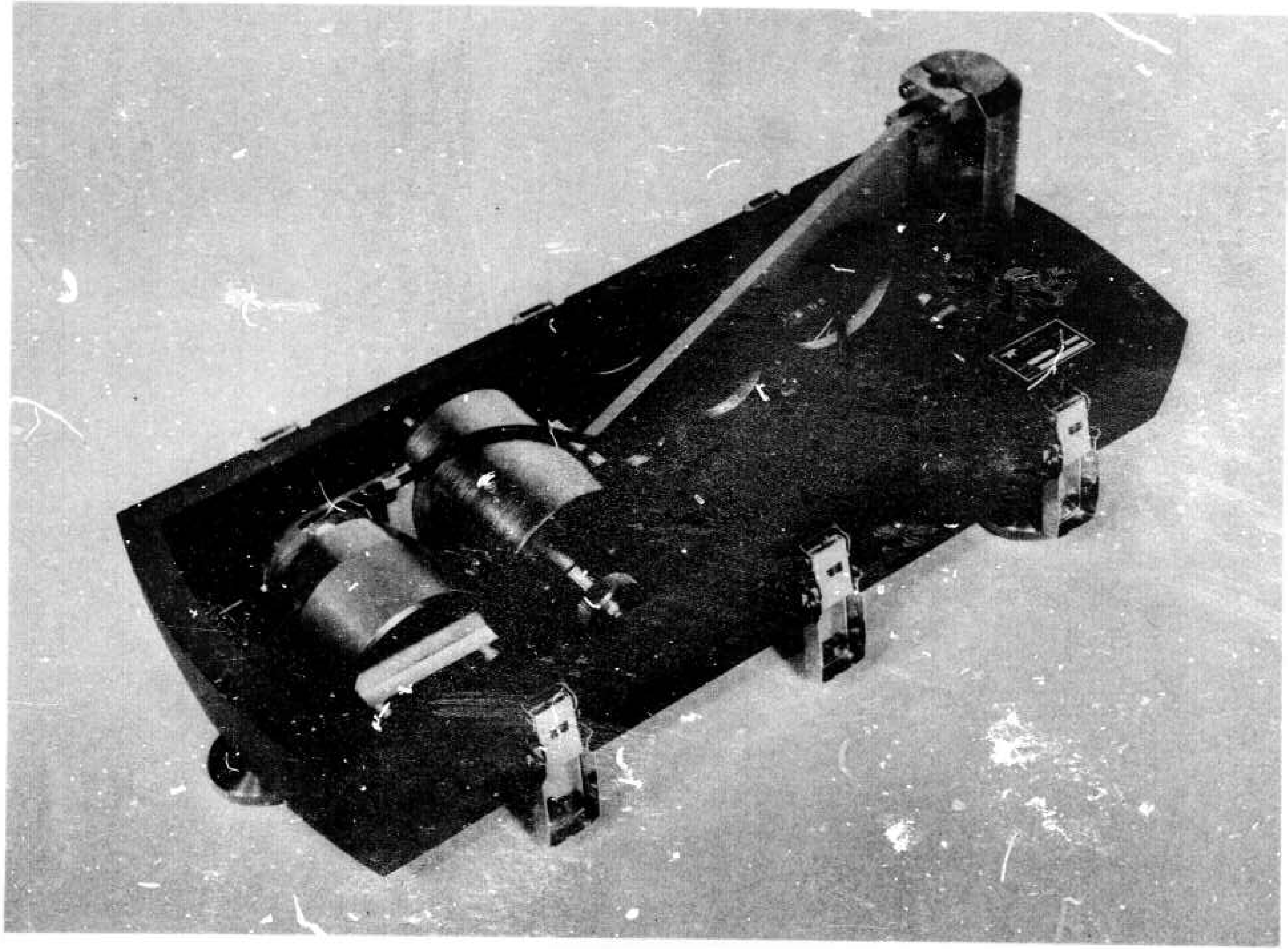


Figure 12. Portable Horizontal Long-Period Seismometer, Geotech Model 28700

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4.7 EXTENDED RANGE LP TESTS

Under the previous contract, an investigation was started to determine an LP frequency response that would be more suitable for recording surface waves than the standard LRSM LP frequency response. The initial investigation was performed at the LC-NM site, but it was decided to return the instrumentation to Garland in order to have better control of the tests. The instrumentation was returned to Garland during February 1969, but because of priority of other projects, testing was not resumed until July 1969.

Various combinations of system components and parameters were tested and the combination shown in figure 13 with its frequency response was determined to be the most promising. Acquisition of data using this system and a system that approximates the standard LRSM LP response, as shown in figure 14, was continued through December 1969. Figures 15 and 16 are samples of the data taken with the two systems. Observations made from the data, including histograms, percentage-of-occurrence of LP noise versus amplitude, and random sampling, indicated that the new response would aid in signal analysis. Additional data will be required, with analysis of numerous identified signals, before a complete evaluation of the benefits of the extended range LP system can be made.

4.8 TIMING SYSTEM, MODEL 19000, MODIFICATION

Four Model 19000 timing systems used in the portable seismograph systems were modified by removing the lower half of the mother board and replacing it with hard wiring. This modification reduces the susceptibility to open and short circuits.

4.9 INSTRUMENTATION FOR ATMOSPHERICALLY-GENERATED SEISMIC NOISE PROJECT

The purpose of this effort is to investigate the correlation between surface atmospheric pressures and earth noise at the surface and at depth in the period range of 20 to 100 seconds. Special active filters to shape the response were designed, fabricated, and tested. Installation of the equipment at the Grand Saline, Texas, salt mine was started in December 1969, and the acquisition of data will be conducted during early 1970.

4.10 PORTABLE STRAINMETER SYSTEM

4.10.1 Introduction

Work on the portable strainmeter system was authorized by Amendment Nos. 6 and 7 of the Statement of Work to Be Done, AFTAC Project Authorization No. VELA T/8703/ASD.

The system design concept and proposed field installation techniques for six portable strainmeter systems were submitted by Geotech on 20 August 1969 and were approved by the Project Office on 28 August 1969.

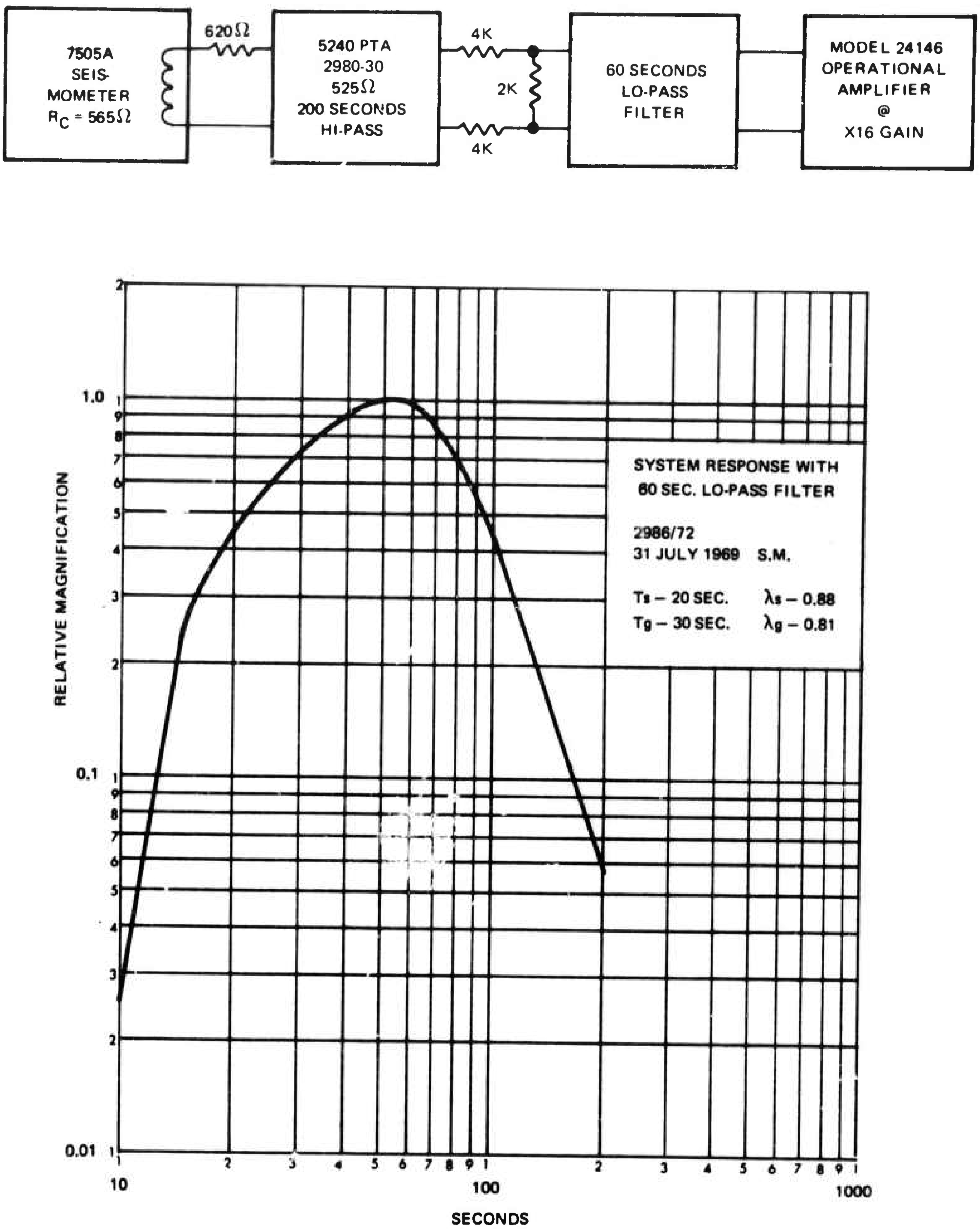

Figure 13 Extended range LP frequency response

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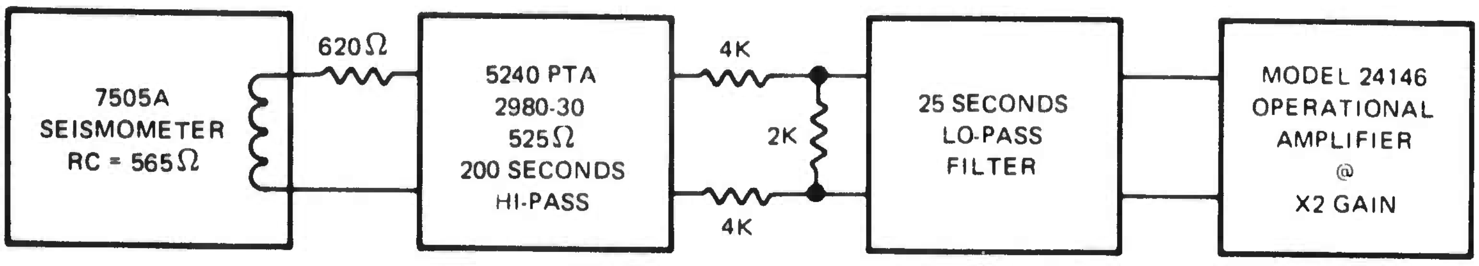

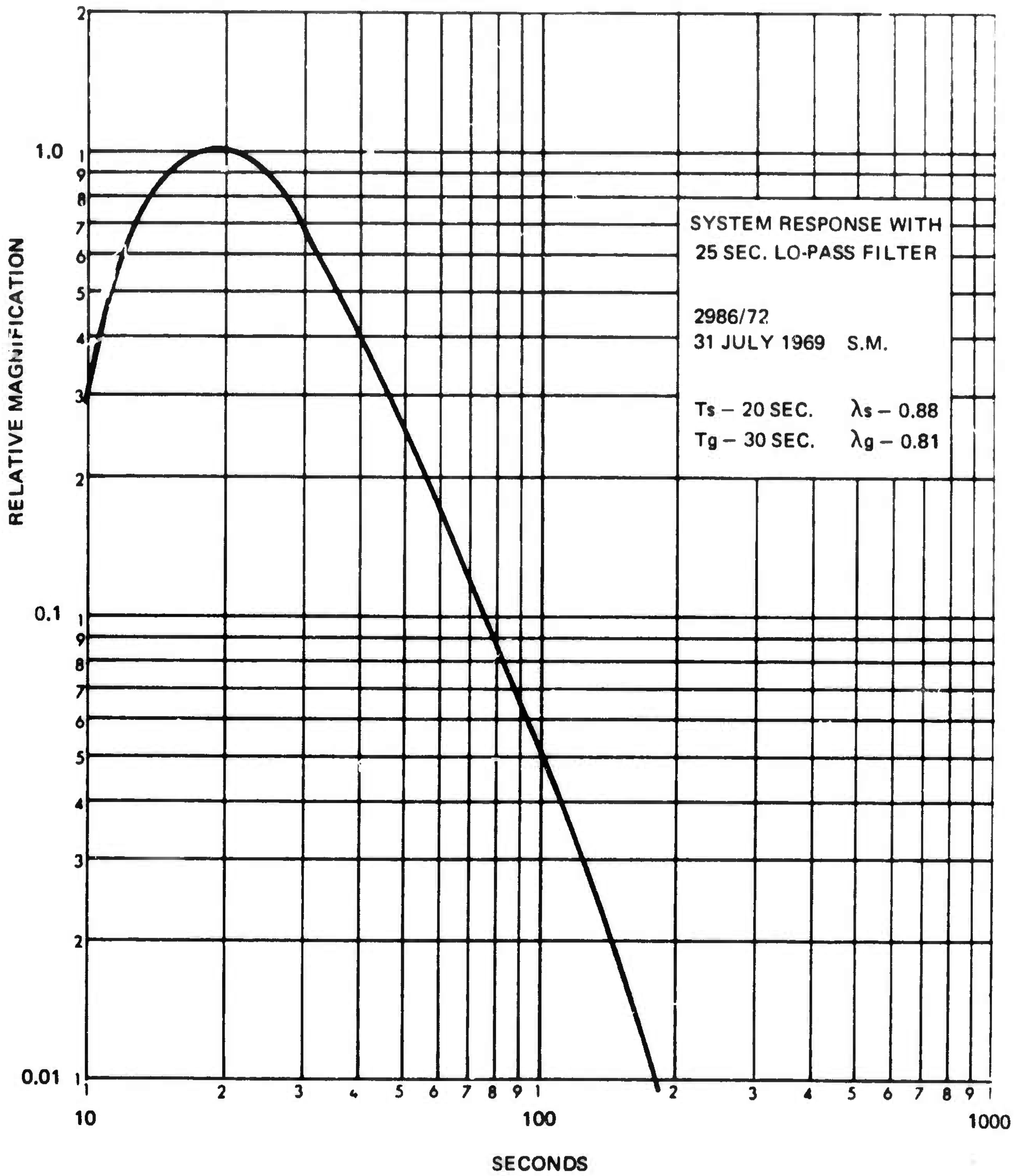

Figure 14. LP frequency response using a 25-second low-pass filter

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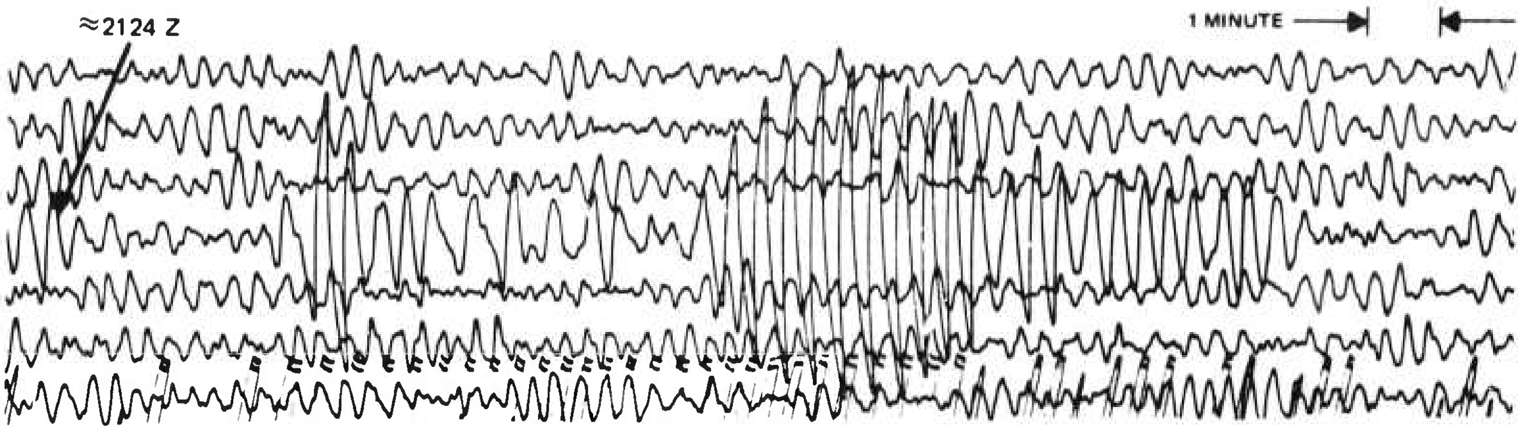

Figure 15. Reproduction of a portion of a Helicorder record showing data recorded by a long-period seismograph with a frequency response approximating the LRSM response. Magnification 167 K at 20 seconds. Recording made at Geotech facilities, Garland, Texas, 3 August 69.

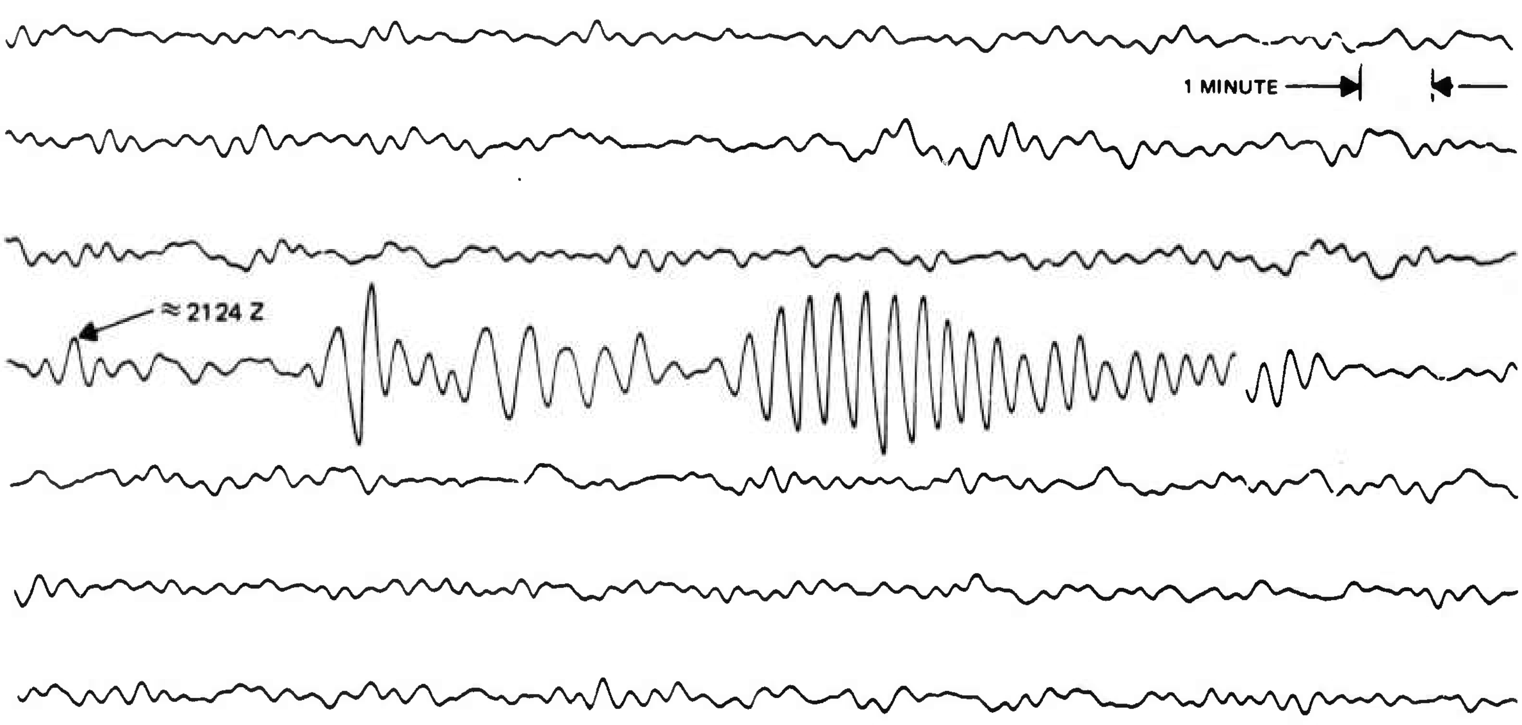

Figure 16. Reproduction of the same portion of a Helicorder record shown in figure 15, with data recorded by a long-period seismograph with a frequency response peaked at 50 seconds (magnification 100 K).

G 5789

The systems were designed, fabricated, and assembled in the period 28 August through 21 December 1969. System tests were completed on the first system, and it was shipped to Site No. 1 (RH-NV) on 8 December 1969. Figure 17 shows the location of the portable strain sites. Table 4 gives the detail of the portable strain site locations. The last system was shipped on 21 December 1969. The first data from Site No. 1 (RH-NV) were obtained on 23 December 1969.

4.10.2 System Capability

On the basis of both component and system tests in the laboratory, design criteria for the portable strainmeter system are satisfied. The portable strainmeter is capable of resolving earth strains of 5×10^{-10} or smaller over an interval of 6 meters in the period range from 10 seconds to dc; recording the signals on magnetic tape; and operating unattended for a period of at least one week. The resolution is limited by noise in the capacitance detector circuit, which is less than 50 microvolts in the frequency range 0.001 to 1 Hz. Long-term drift occurs at a rate of 150 μV/°C. The strain interval (6 meters) is limited by environmental effects. The maximum period of unattended operation is limited by the propane fuel supply. The 100-lb tank in present use will last at least 2 weeks. The recorder will operate 33 days on one reel of tape. The system design allows strains over a 66 dB range to be recorded on a high-gain channel in a range 5×10^{-10} to 1×10^{-6} and over a 34 dB range on a low-gain channel from 2.4×10^{-7} to 1.2×10^{-5}.

4.10.3 Design Features

4.10.3.1 Variable-Capacitance Transducer

A new variable-capacitance transducer based on the design of a Geotech Model 33377 I/C detector has been developed. Dual capacitor plates are used in each detector circuit to obtain maximum linearity of displacement, and dual detectors are used in a configuration that cancels temperature-induced differential movement of the capacitor plates. Each capacitor with the plate centered has a capacitance of 100 pF. Movement of the center plate causes an unbalance of capacitance which is converted to a corresponding voltage by a pulse-width modulator, a pulse-width detector, and an averaging filter. The dual detector has a nominal sensitivity of 40 millivolts per micron. The outputs of the two I/C detectors are summed to provide a high-gain and a low-gain output from the summation. The low-gain circuit not only preserves large signals that exceed the range of the high-gain system, but serves more or less as a backup system, particularly since the two circuits are operated from different voltage regulators.

4.10.3.2 Coarse Adjustment

The coarse-adjust mechanism, which displaces the central capacitor plate of both dual-capacitance detectors simultaneously, is designed to center the central plate during initial installation to avoid consuming the adjustment range of the fine-adjust unit. It also may be necessary to actuate the coarse

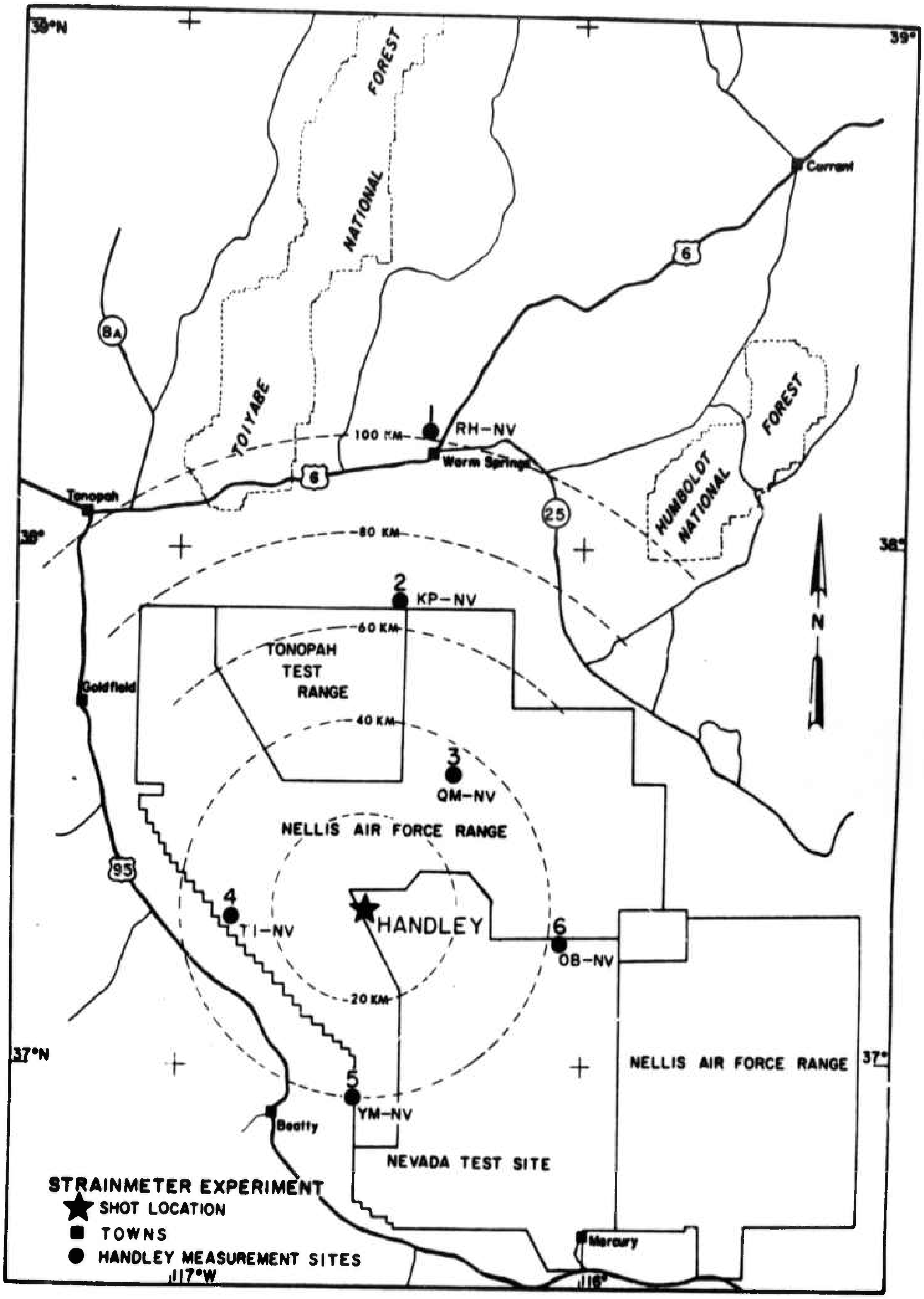

Figure 17. Location of portable strainmeter sites

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Table 4. Portable strainmeter site locations

Site No.	Site name	Site designator	Geographic coordinates N. Lat.	Geographic coordinates W. Long.	Elevation Feet	Elevation Meters	Approximate azimuthal orientation of strainmeter	HANDLEY radial thru site	Distance from HANDLEY (km)	Approximate deviation of strainmeter from HANDLEY radial
1	Rawhide Mtn., Nevada	RH-NV	38°13'36"	116°22'53"	5800	1768	325°	007.5°	103.6	43°
2	Kawich Peak, Nevada	KP-NV	37°53'51"	116°27'33"	7000	2134	356°	005.7°	066.5	10°
3	Quartzite Mtn., Nevada	QM-NV	37°33'47"	116°19'04"	6160	1878	020°	033.4°	034.8	13°
4	Tolicha Peak, Nevada	TI-NV	37°17'07"	116°52'01"	5000	1524	266.5°	266.5°	029.6	in-line
5	Yucca Mtn., Nevada	YM-NV	3[illegible]°55'53"	116°33'15"	4400	1341	182.5°	182.5°	041.1	in-line
6	Oak Spring Butte, Nevada	OB-NV	37°14'09"	116°03'09"	5680	1731	081°	099.8°	043.3	19°

adjust unit to counteract seasonal temperature change in near-surface tunnels and in the trench installations. A stepper motor and micrometer head provide a predicted displacement sensitivity of 0.347 microns per step. A backlash of approximately 1.0 micron occurs when the motor is reversed.

4.10.3.3 Fine Adjustment

Particular effort was given to the problem of recentering the capacitor plates within a strain equivalent of 5×10^{-10}. The problem was resolved by designing a fine adjust mechanism that adjusts the capacitor plates in 5-millimicron increments by use of a stepping motor, a micrometer head, and a lineal motion reducer. The stepper motor provides a precise rotational motion of 0.000985 revolution per step to a 500-micron per revolution micrometer. The motion is then reduced to a nominal 0.493 revolutions per step by a 100:1 lineal motion reducer. The reduction factor of the reducer is known to an accuracy of 0.5 percent. Thus, the position of the capacitor plates is adjustable in steps of 4.93 millimicrons within an accuracy of 1 percent over a range of approximately 15 microns. The latter value is the operating range of the lineal motion reducer. A backlash equivalent to 13 $\pm$3 millimicrons occurs when reversing the direction of the stepper motor.

4.10.3.4 Electromagnetic (EM) Calibrator

An electromagnetic calibrator that compresses a short section of the strain standard at the fixed-end of the strainmeter provides calibration signals at a nominal motor constant of 46 millimicrons per ampere. The EM calibrator consists essentially of a coil and ring-magnet assembly that compresses or extends an 18-cm section of aluminum tubing connected to the quartz standard. The aluminum tubing is temperature compensated by a nearly-equal length of aluminum in a foldback arrangement. At a practical coil current of 3 milliamperes and a predicted equivalent noise level of less than 3 millimicrons of differential ground displacement, less than one percent inaccuracy in calibration measurement is possible by averaging five cycles of calibration signal. A 0.5 percent meter is used to measure current.

4.10.3.5 Signal Control Center

The high-gain primary strain channel with a strain resolution of 5×10^{-10} and the high-gain temperature channel with a resolution of 0.001°C are maintained within the linear range of the tape recorder by an offset-biasing technique using a precision level detector and a 12-bit digital-to-analog converter (DAC). The initial design plan for the DAC called for use of a 14-bit ladder. A compromise between optimum design and delivery schedule resulted in the use of a 12-bit ladder. With less dynamic range in the 12-bit ladder, the capacitor plates must be reset when secular strains exceed 7×10^{-7}. The drift range can be doubled by lowering the system sensitivity; however, the minimum resolvable strain level is increased proportionally.

The system has been carefully designed to provide optimum signal levels at each point in the system. Although the system is capable of resolving strains of 5×10^{-10}, environmental conditions will probably be the ultimate limitation on operating sensitivity. Consequently, provision has been made for the use of optional gain cards in a signal control center. The optional gain cards with 1% precision components also permit accurate reduction of voltage to preserve the dynamic range of the signal control center in the event that the fine adjust mechanism has been displaced to the limit of its operating range.

In a typical trench installation where the average seasonal rate-of-change of temperature is expected to be of the order of 0.1°C per day and the coefficient of expansion of the rock of the order of 2.5×10^{-6} per °C, strain rates of the order of 1×10^{-7} per day are predicted. In order that dynamic range is not consumed entirely by seasonal temperature drift, it may be necessary to operate with an optional gain card of X1 (12 dB below the optimum gain) which will permit strains of 2×10^{-9} to be resolved with a S/N ratio of 2. In this case, the system could operate 12 days and still tolerate a signal of 5×10^{-7} without clipping. By resetting the capacitor plates 6×10^{-6} meters with the fine adjust mechanism, an additional 10 days of operation can be achieved. An additional 29 days of operation can be achieved by reducing the gain by 6 dB using a new pre-set optional gain card.

4.10.4 Test Facility

Shown in figure 18 is a prototype model of the strain transducer and electromagnetic calibrator connected by a 0.85-meter length of quartz tubing. Also, shown is a 2.6-meter deep vault constructed at the Geotech facility in Garland to simulate temperature conditions in a trench installation. Development of the capacitance transducer was also carried out in part by operating the transducer in a 16.4-meter deep vault in Garland.

4.10.5 Installations

To confine diurnal temperature changes to the order of 0.001°C, mine tunnels were designated for strainmeter vaults. Trenches 2.7 meters deep in competent rock were excavated in areas where mines were not available. Mine tunnels at Site Nos. 2 (KP-NV) and 6 (OB-NV) will probably meet the desired standards for the temperature environment of the strainmeter; whereas, mine tunnels at Site Nos. 1 (RH-NV) and 3 (QM-NV) are, at best, marginal. Trench installations at Site Nos. 4 (TI-NV) and 5 (YM-NV) are being evaluated.

The mine tunnel and partially installed strainmeter at Site No. 1 (RH-NV) are shown as figure 19. A view of the trench installation at Site No. 5 (YM-NV) before enclosing the quartz standard with styrofoam is shown as figure 20. A photograph taken just prior to backfilling is shown as figure 21.

4.10.6 Reports

A report (Technical Report No. 70-6) on the design of the portable strain system is being prepared under separate cover. A later report (70-10) will cover an evaluation of the strainmeter installation.

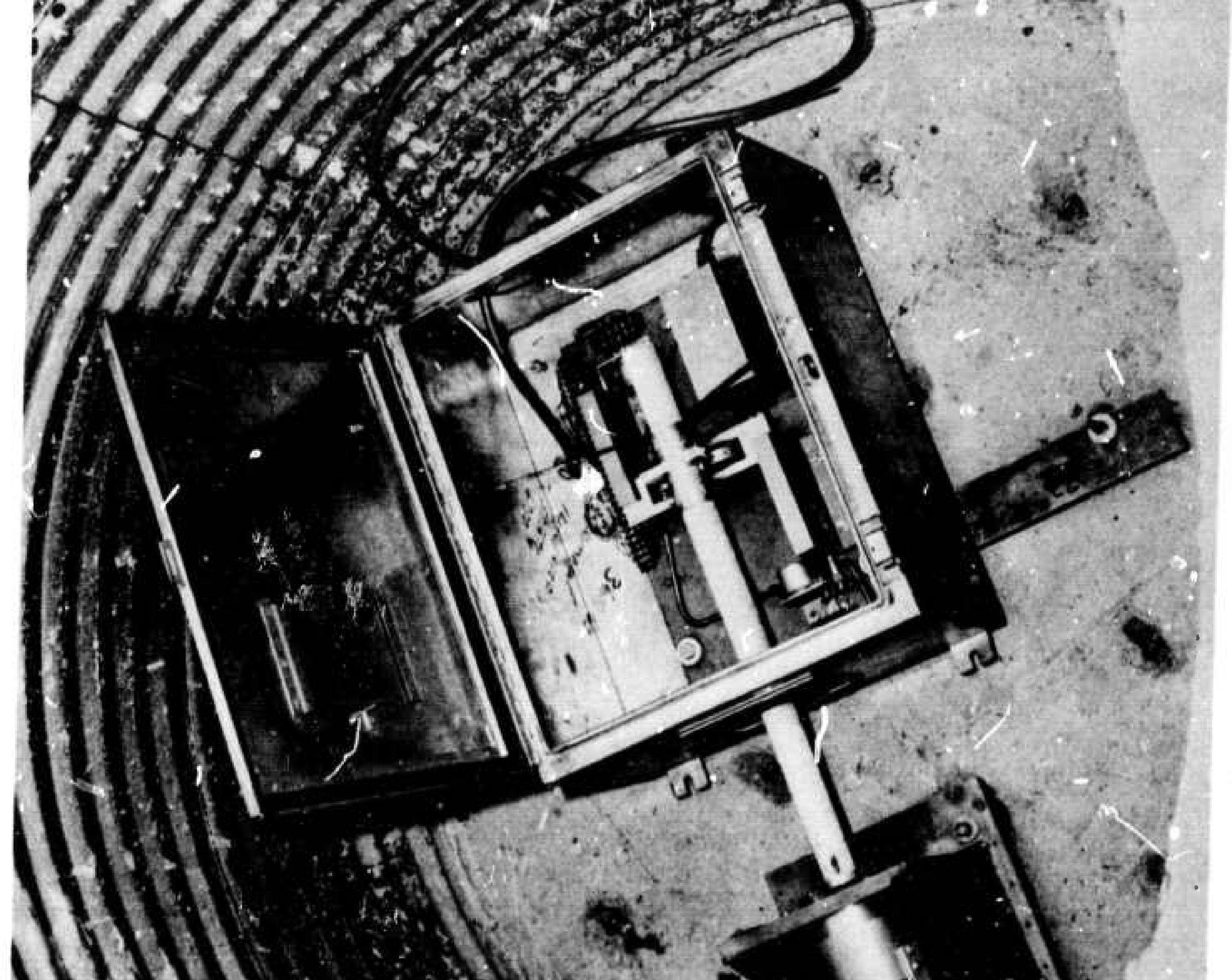

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Figure 18. Prototype strainmeter in 2.6-meter deep test vault in Garland, Texas

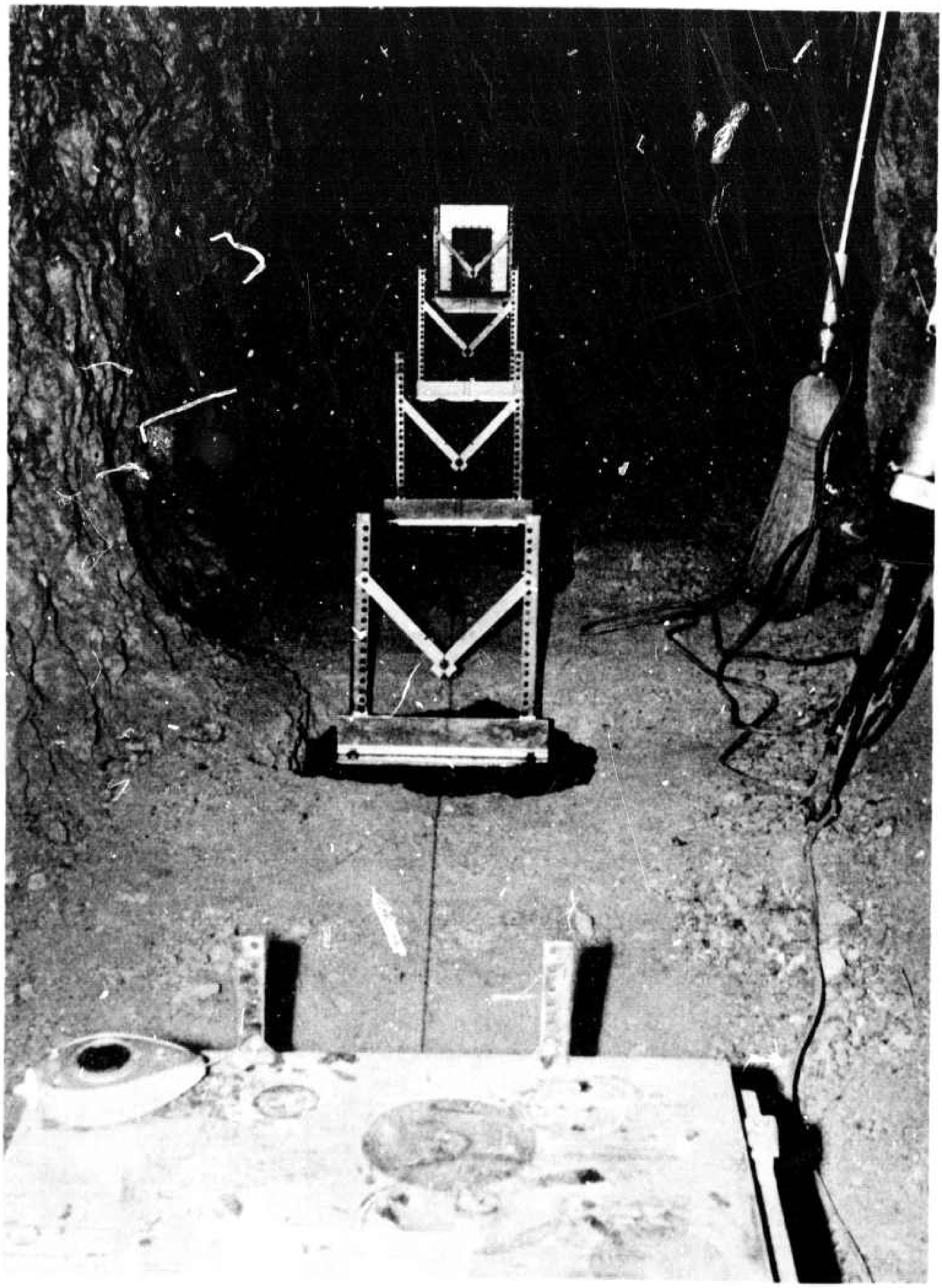

Figure 19. View of mine tunnel installation at Site No. 1 (RH-NV).

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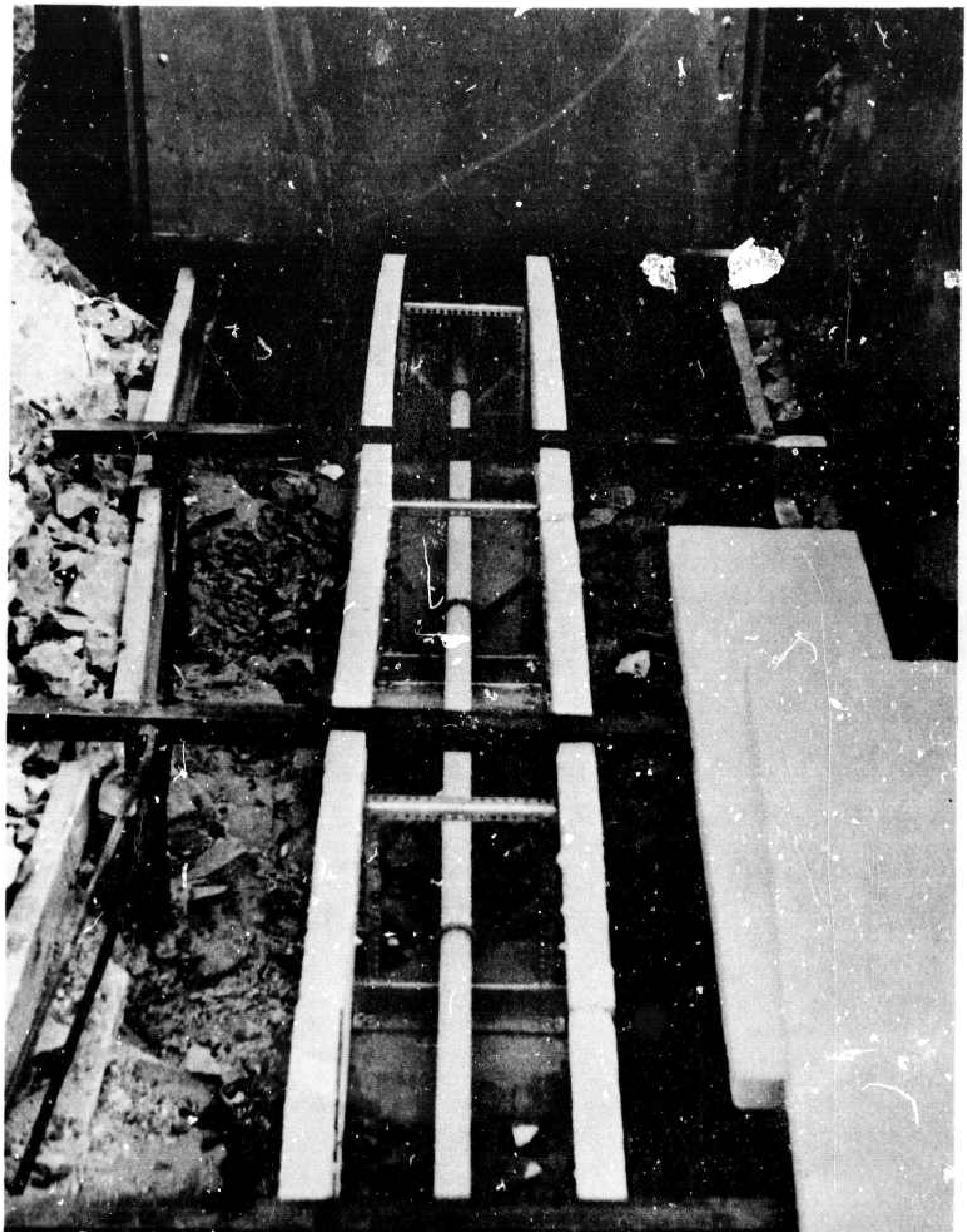

Figure 20. View of trench installation at Site No. 5 (YM-NV) before enclosing the quartz standard with styrofoam

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Figure 21. View of the trench installation at Site No. 5 (YM-NV) taken just prior to backfilling the trench.

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5. EVALUATION OF SUPPORT EQUIPMENT

5.1 GENERAL

The support equipment includes the instrumentation shelters, vehicles, trailers, and generators utilized during LRSM field operations. The support equipment is discussed in Final Report Project VT/6703, LRSM Program.

5.2 INSTRUMENTATION SHELTERS

The instrumentation vans, phototube amplifier shelters, and seismometer vaults continued to provide adequate service. However, when conditions permit, bunker-type enclosures for the vaults have been constructed for the sites in arctic or sub-arctic regions.

5.3 VEHICLES

Vehicles used by the LRSM teams during this report period were as follows:

a. Heavy-duty trucks used for transporting the mobile observatories during station moves;

b. Special-purpose vehicles used when the normally-assigned vehicles are inadequate for the task;

c. Utility trailers used for transporting generators and equipment in the field.

5.3.1 Heavy-Duty 3/4-Ton Pickup Trucks

During the report period, four of the heavy-duty 3/4-ton pickup trucks were transferred from the LRSM program. Of the original 40 pickup trucks, five remained in active service at the end of December 1969. The average mileage per unit is 63,000 miles. Most of this mileage has been accumulated on unimproved roads. This type of driving subjects these vehicles to a great deal of abuse from vibration and damage from gravel thrown by passing vehicles.

In June 1967, six 3/4-ton heavy-duty Chevrolet pickup trucks were purchased under a lease contract for the portable system teams; and in March 1968, five more were received for the new portable systems teams. The vehicles have the capacity to carry all instrumentation and associated equipment and have enclosures mounted over the beds of the trucks. The enclosure serves a dual purpose: it protects equipment while traveling and personnel can work under cover during times when weather conditions would otherwise hamper operations.

5.3.2 Heavy-Duty 1/2-Ton Pickup Trucks

Ten 1/2-ton pickups were acquired in August 1965 to replace the personnel carriers that, because of their high mileage, had become unreliable or uneconomical to maintain. On 31 December 1969, all were salvaged but three, and the average number of miles per pickup truck was 72,000 - the greater part accumulated on unpaved roads.

5.3.3 Two and One-Half Ton Truck

In October 1964, a 2-1/2 ton truck was obtained to move instrumentation vans; and at the close of this report period it had been driven 95,445 miles with few mechanical breakdowns. A second unit was leased in March 1966 and has been driven more than 47,000 miles. During this report period, these vehicles were driven 18,183 miles.

5.3.4 Snow Vehicle

A Kristi Snow Vehicle, Model KT-3, was purchased in October 1962 to provide transportation for personnel during severe weather conditions. This vehicle has been assigned to several teams located in areas that have an abundance of snow. When Schefferville, Quebec (SV3QB), closed in September 1968, this vehicle was shipped to Red Lake, Ontario, Canada (RK-ON). The use of this vehicle is restricted to times when other vehicles cannot operate due to the heavy snow conditions.

5.3.5 Utility Trailers

The LRSM program is currently using two utility trailers to transport generators and instrumentation in the field. These units were used extensively during portable system operations, prior to the acquisition of the new 3/4-ton trucks. The operational cost for the utility trailers has been low, with the major expenses being incurred for tires.

5.4 GENERATORS

At the close of this report period, two Caterpillar diesel generators and two U. S. Motors generators were in service at field locations. Five additional units are being maintained at the Garland plant in an operationally-ready status. The generators have performed satisfactorily under many different climatic conditions. However, as may be expected, repairs have become more frequent with increased operating time.

Generators were used as both primary and standby power sources at some stations, and as the standby power source at others. A summary of the sites at which generators were maintained as of 31 December 1969 follows:

Team	Type of generator
RK-ON	Caterpillar - primary U. S. Motor - standby
FB-AK	U. S. Motor - standby
NP-NT	Caterpillar - standby

6. DATA EVALUATION

6.1 GENERAL

Data critiques were performed on data recorded by LRSM seismograph teams, for the purpose of maintaining quality and accuracy. The critiques also provided support personnel with the information needed to stay current with the progress of each team and to react quickly to newly developed problem areas. All data and operations logs were reviewed periodically, using critique check lists and the LRSM Field Operations Manual as the standards on which acceptance of performance is based.

6.2 FILM QUALITY CONTROL

6.2.1 Quality control analysts monitored the records of each team by careful examination of the physical and technical appearance of selected film seismograms and operations logs.

The analysts examined the following items and procedures:

a. Record Shipment - promptness and packaging

b. Logs - neatness, completeness, and accuracy of computations

c. Film - photography, handling, and accuracy of measurements

d. Data Quality - maintenance of operational schedules and tolerances, recording WWV and station time, and a general category for irregularities, which affect data quality.

The field team supervisors were provided with a copy of each critique. With this information, supervisors were able to work directly with each team to find solutions for reported problems.

6.3 MAGNETIC-TAPE QUALITY CONTROL

The Special Presentations group is responsible for the quality control checks of the magnetic tapes that are recorded by the LRSM field teams. The purpose of this critique is to aid the field teams in maintaining the professional quality of their data tapes. In order to provide a valid check, quality control technicians randomly select one tape each month from every operational site. The selected tape is reviewed using a magnetic-tape critique check list, the results of which reflect the usability of the data on the magnetic tape. The completed critiques are then sent to the field teams and their supervisors. This prompt review, followed by a magnetic-tape critique summary, which is published each month, assisted the field personnel in detection and correction of data recording problems not readily apparent in the field.

During this report period, the critique results revealed that dc offsets on data channels and varying background levels were problems requiring close attention at the field sites.

6.4 INTERIM LIBRARY

The Interim Library continued to perform the following support services for LRSM:

a. Received data from field teams, established accountability for and stored data to ensure against its loss, and provided easy access by data users;

b. Reviewed operations logs and film wrappers and monitored team shipping schedules. Notified the Data Control Group when deficiencies occurred;

c. Made monthly data shipments to Seismic Data Laboratory (SDL) in Alexandria, Virginia;

d. Prepared and shipped film and tape records in response to data requests approved by the Project Officer;

e. Coordinated the processing, accountability, and shipping of the magnetic-tape and 35-mm film playouts of portable systems data;

f. Reviewed Electronic Data Processing (EDP) operations logs for completeness and accuracy, and transferred the data to punched cards.

6.5 EDP OPERATIONS LOGS

For the period from 1 January 1969 to 31 January 1969, the operations logs for both the mobile observatories and the portable systems were produced by EDP techniques. Beginning with 1 February 1969, all operations logs were manually generated.

6.6 TELEPHONE STATUS REPORTS

An LRSM telephone status report, a single-page summary of a special event, was prepared and mailed to the Project Officer within 24 hours of each event. This report listed the operational status of each team and indicated the presence of a signal, or lack of it, on each seismogram.

7. DATA PROCESSING

7.1 GENERAL

During the period covered by this report, the work performed by this group was:

a. Processing magnetic-tape data

b. Conducting seismic noise surveys

c. Conducting special studies in support of the quality control function.

7.2 PROCESSING MAGNETIC-TAPE DATA

The Special Presentations group continued to provide professional quality data transcriptions from magnetic tapes during this reporting period. Some of the visual records produced for the numerous routine and special studies are: 16-mm and 35-mm photographic film, as well as 7-inch and 12-inch photographic paper. A direct-writing paper is also available when a quick evaluation of magnetic-tape data is necessary. The Geotech Model 512 analog-to-digital converter is used frequently to provide the digital records that are required for computer analysis. This instrument is pictured in figure 22. Equipment improvements in the lab are continually being made to extend the versatility of the instruments and the quality of the data.

7.3 SEISMIC NOISE SURVEYS

A typical LRSM noise study gives an indication of the properties of the seismic noise found in a given area. A noise survey for a given LRSM site includes:

a. A curve showing cumulative probability distribution of amplitudes;

b. A histogram showing percentage of occurrence of indicated periods;

c. A noise spectrum curve showing the average noise amplitude in millimicrons, corrected for the system response, and plotted as a function of period.

Technical Report 69-42, Seismic Noise Survey, Volume 4, Long-Range Seismic Measurements Program, was distributed in October 1969.

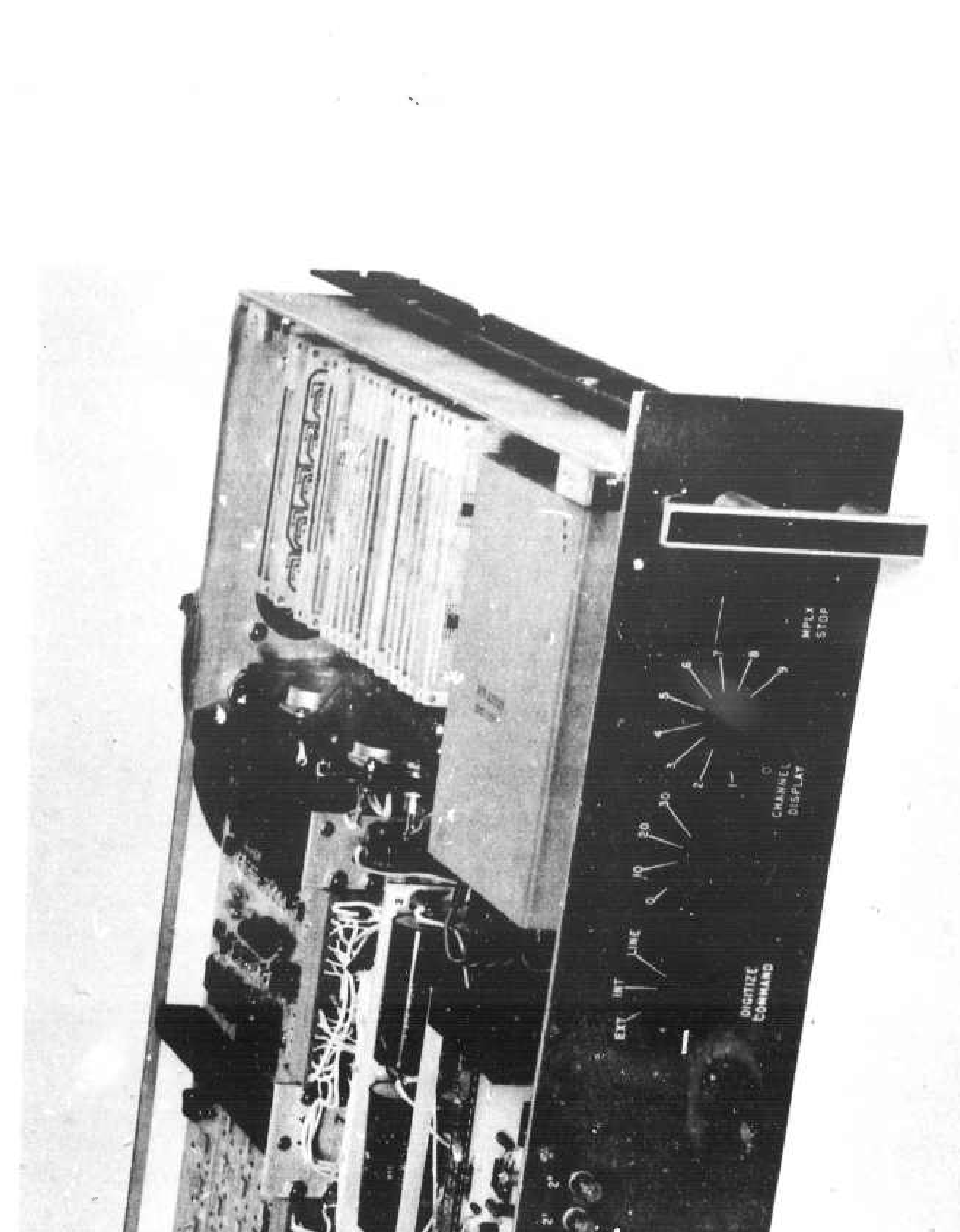

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Figure 22. Geotech Model 512 analog-to-digital converter

7.4 DATA CATALOG

The contract requirement for the task of compiling and publishing a data catalog was completed during this report period, with the publication of the December 1968 catalog.

8. SPECIAL PROJECTS

8.1 GENERAL

Studies conducted during the report period were directed toward: (1) the analysis of data from portable and mobile systems (see section 8.2); (2) the investigation of LP data (see section 8.3); and (3) theoretical studies on atmospheric loading (see section 8.4). The following technical report and notes were published.

Robertson, Herbert, 1969, Preliminary report on long-range seismic measurements participation in Project MIRACLE PLAY - DIODE TUBE: Geotech Tech Report No. 69-10.

Sorrells, G. G., 1969, Long-period seismic noise and atmospheric pressure variations, Part 1: The response of an isotropic halfspace to a plane pressure wave: Geotech Tech Note 3/69.

Der, Z. A., 1969, Long-period seismic noise and atmospheric pressure variations, Part 2: Static loading of a layered elastic halfspace by atmospheric pressure variations: Geotech Tech Note 4/69.

8.2 INTERPRETATION OF LRSM PORTABLE AND MOBILE SYSTEMS DATA

8.2.1 Preliminary Report on Long-Range Seismic Measurements Participation In Project MIRACLE PLAY - DIODE TUBE, TR 69-10

The MIRACLE PLAY - DIODE TUBE gas explosion in a cavity in Tatum Dome, Mississippi, was monitored by eight LRSM teams operating three-component SP and LP seismographs. Four teams encircled the salt dome and occupied approximately the same sites as were occupied during the STERLING experiment. Four more teams encircled the Lucedale, Mississippi (LD-MS), site where an anomalous signal was recorded from the STERLING shot. High winds during the time of the arrival of the DIODE TUBE signal at LD-MS resulted in a record with a low signal-to-noise ratio. Spectrum analysis and coherence measurements indicate that the DIODE TUBE signal was recorded at LD-MS by the radial seismograph. The DIODE TUBE signal amplitude was about one-third the STERLING amplitude according to measurements of the largest waves in the STERLING and DIODE TUBE recordings of the radial seismographs.

8.2.2 Statistics of LP Noise Recorded at LRSM Mobile Van Sites

Average LP ground noise displacements were determined every day that film records were available at Geotech during the period from March to December 1968 for mobile va . sites at KN-UT, MN-NV, HN-ME, WH2YK, PG-BC, PG2BC, LC-NM, RK-ON, and SV2QB. The following period bands of interest as recorded on vertical and radial seismographs were sampled: the 6-sec band, which included wavelets having periods from 4 to 8 sec; the 15-sec band, which included wavelets having periods from 13 to 17 sec; and the-20-sec band. Means, x, variances, s^2, and standard deviations, s, were calculated from these data on a monthly basis. Sites were then ranked on the basis of lowest means and standard deviations. The quietest site was found to be RK-ON followed by LC-NM, KN-UT, PG-BC, and PG2BC, SV2QB, HN-ME, MN-NV, and WH2YK. Mean amplitudes in the 6-sec band are at least 6 dB greater than mean amplitudes in the 15-sec band. A large increase of the mean amplitudes in the -20-sec band as recorded by horizontal seismographs in October indicates an increase in tilt noise caused by local atmospheric conditions. Similar amplitudes in the "quiet" summer months indicate virtually no effect due to site geology.

8.3 LP STUDIES

8.3.1 Preliminary Measurements of the LP Noise Field at Grand Saline, Texas

Two sets of LP seismographs and a LP microbarograph were operated in the vicinity of the Kleer Mine, Grand Saline, Texas, during the winter of 1968. Each set consisted of a vertical and two horizontal seismographs that were characterized by the displacement response shown in figure 23. One set was operated on the surface in close proximity to the microbarograph system. The other set was located in the mine at a depth of approximately 700 feet. The basic objective of the experiment was to quantitatively describe the contribution of atmospheric turbulence to the LP seismic noise field. In order to achieve this objective, data segments, approximately 30 minutes in length, were taken during intervals typified by various atmospheric conditions ranging from calm to turbulent. Each set of data segments included samples simultaneously taken from all six seismographs and the microbarograph. Power density spectra were computed for each member of the set and coherency spectra were computed for selected pairs of records. The principal results of the investigation are summarized in the following paragraphs.

Figures 24 and 25 are representative of the range of variations encountered in the power density spectra of the vertical seismograms. The spectra shown in figure 24 were taken during an interval when microbarographic activity was at a minimum. Notice that for periods less than about 20 seconds the spectra observed in the mine and on the surface are virtually the same. This was to be expected since in this range the LP noise spectrum is known to be dominated by microseisms with wavelengths much greater than the vertical distance separating the two observation points. At longer periods, the noise observed in the mine and on the surface are virtually the same. This was to be expected since in this range the LP noise spectrum is known to be dominated by microseisms with wavelengths much greater than the vertical distance separating

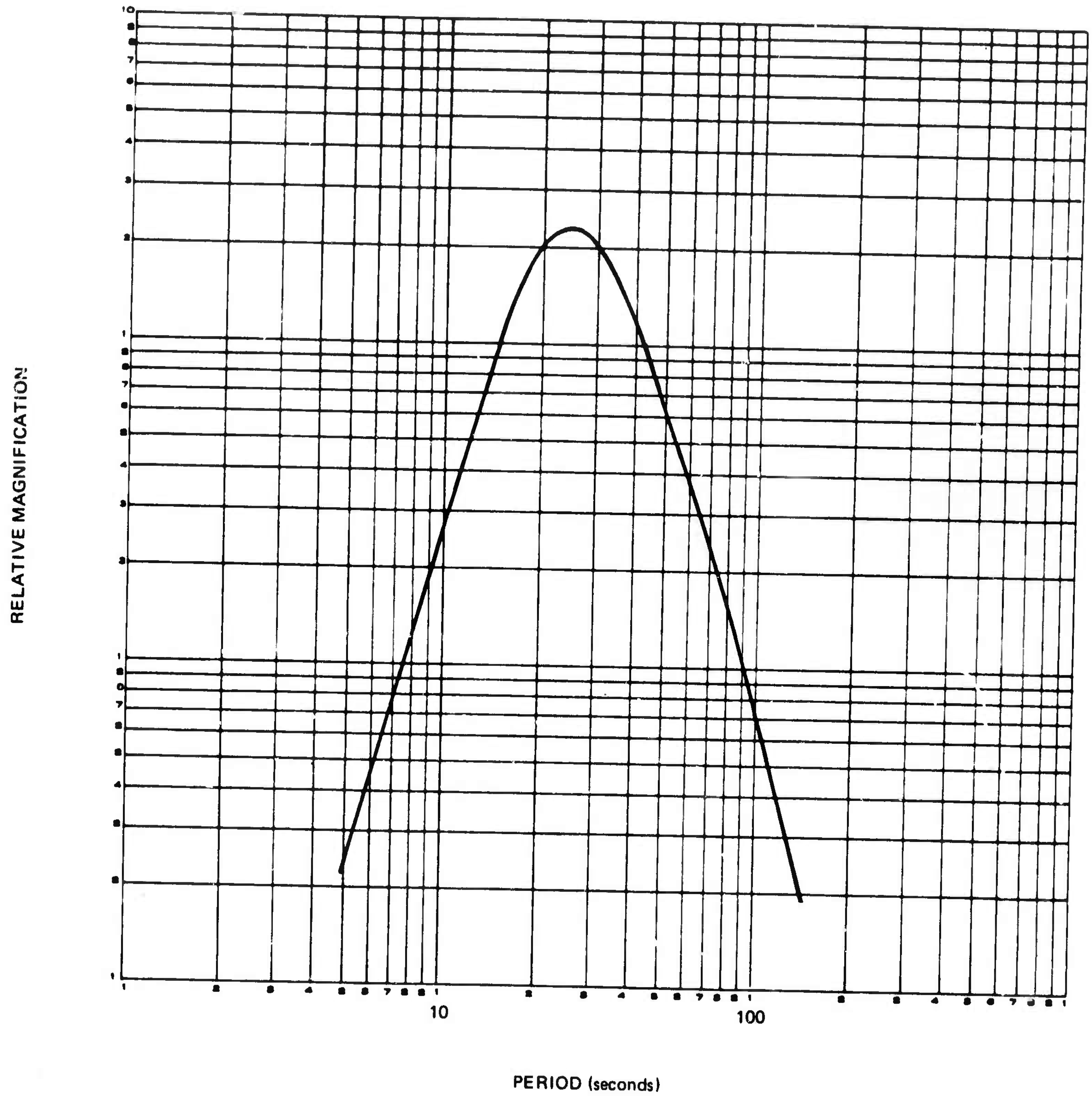

Figure 23. Frequency response of the long-period seismograph, Portable System Model 19282A

G 5784

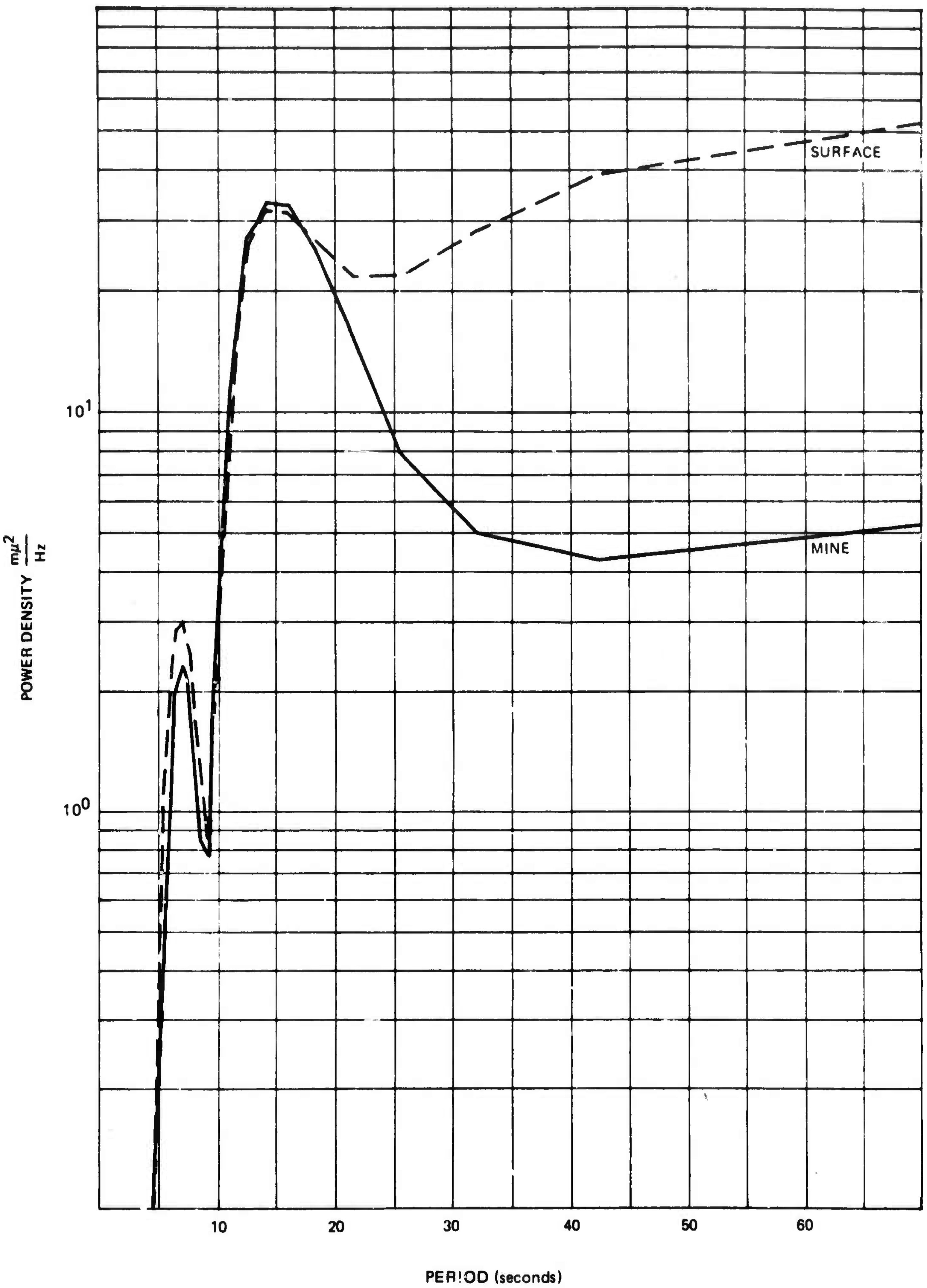

Figure 24. Example of long-period seismic noise spectra observed on vertical seismographs located at the surface and in the mine during a calm period

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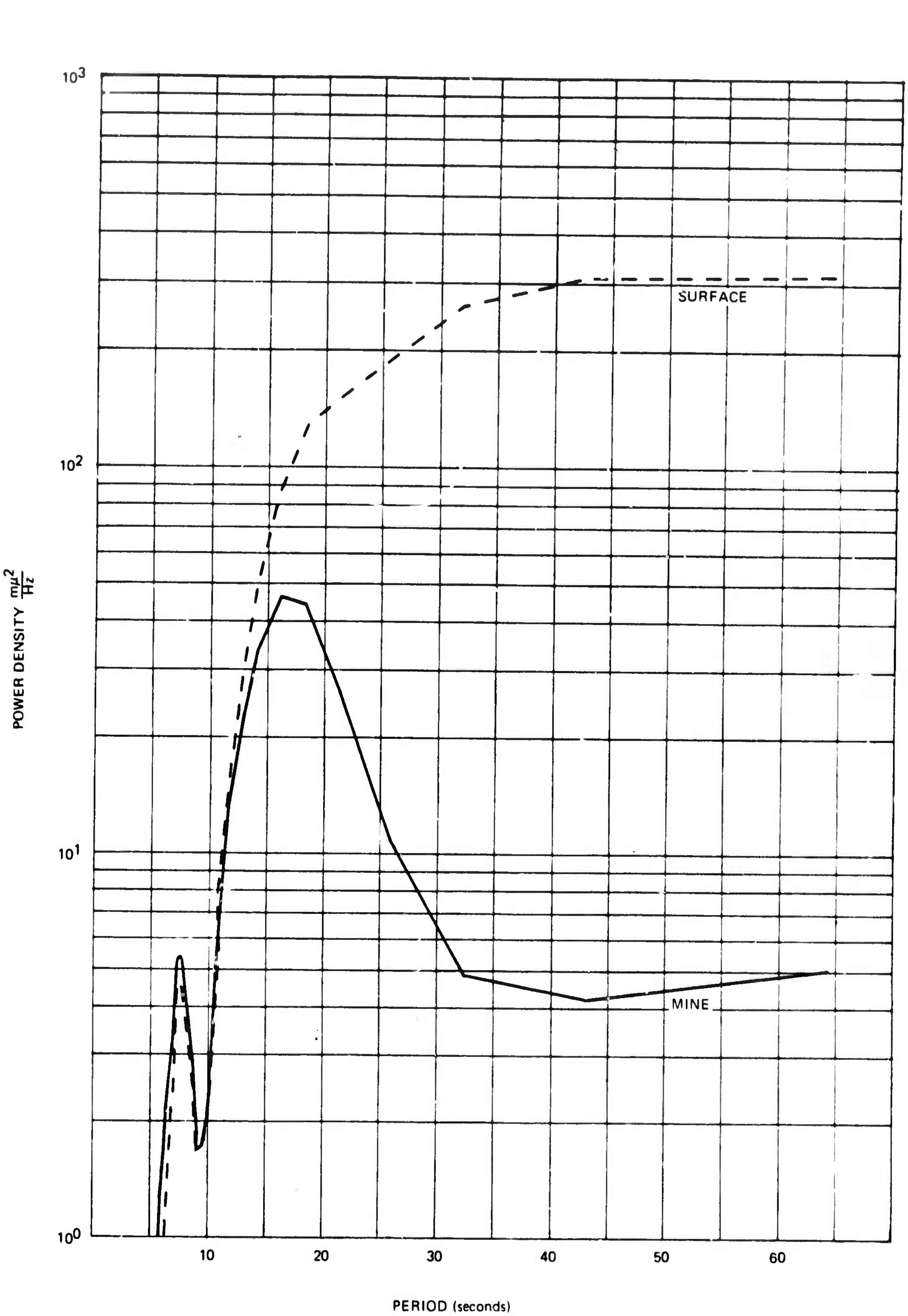

Figure 25. Example of long-period seismic noise spectra observed on vertical seismographs located at the surface and in the mine during a period of atmospheric turbulence

G 5786

the two observation points. At longer periods, the noise observed at the surface increases relative to that observed in the mine. The sources of the noise in this period range are not presently known and this subject will be given more careful scrutiny in future studies.

The spectra shown in figure 24 are representative of the noise observed during periods of moderate atmospheric turbulence. During this interval, the mean microbaric noise power increased by about 20 dB in the period range 20-40 sec relative to the power observed during the previously discussed interval. Notice that while the surface spectrum has been increased dramatically for periods greater than 20 seconds there has been very little change in the noise spectrum observed in the mine. This is in qualitative agreement with the theory developed by Sorrells[1], which showed that the seismic disturbance caused by atmospheric pressure fluctuations attenuates very rapidly with increasing depth.

The LP noise field observed by the horizontal seismographs show similar variations in power. Examples of the noise spectrum observed by the horizontal seismographs located in the mine and on the surface are shown in figures 26 and 27. The samples intervals are the same as those discussed previously. From figure 26, it can be seen once again that even though the atmospheric conditions are calm, the noise observed at the surface is considerably higher than the noise observed in the mine. As shown in figure 27, an increase in atmospheric turbulence leads to an increase in the seismic noise spectrum observed at the surface, but has virtually no effect on the spectrum observed in the mine. In figure 28, the square of the coherence between the surface transverse and the microbarographs is plotted as a function of period. These computations were made from the records taken during the period of atmospheric turbulence. The results presented in this figure clearly indicate the existence of a linear relationship between the horizontal component of the seismic noise field and the atmospheric pressure field.

In summary, the results shown above give clear indications that for periods greater than about 20 seconds the LP seismic noise spectrum observed at the surface of earth is significantly influenced by the state of the atmospheric pressure field while the seismic noise observed at a depth of 700 feet is virtually independent of this source. These results are considered to be quite significant to the problem of increasing surface wave signal-to-noise ratio especially in the ultra LP range and a more detailed investigation is presently underway.

[1]Sorrells, G. G., 1969, Long-period seismic noise and atmospheric pressure variations, Part 1, The response of an isotropic halfspace to a plane pressure wave: Geotech Tech Note 3/69.

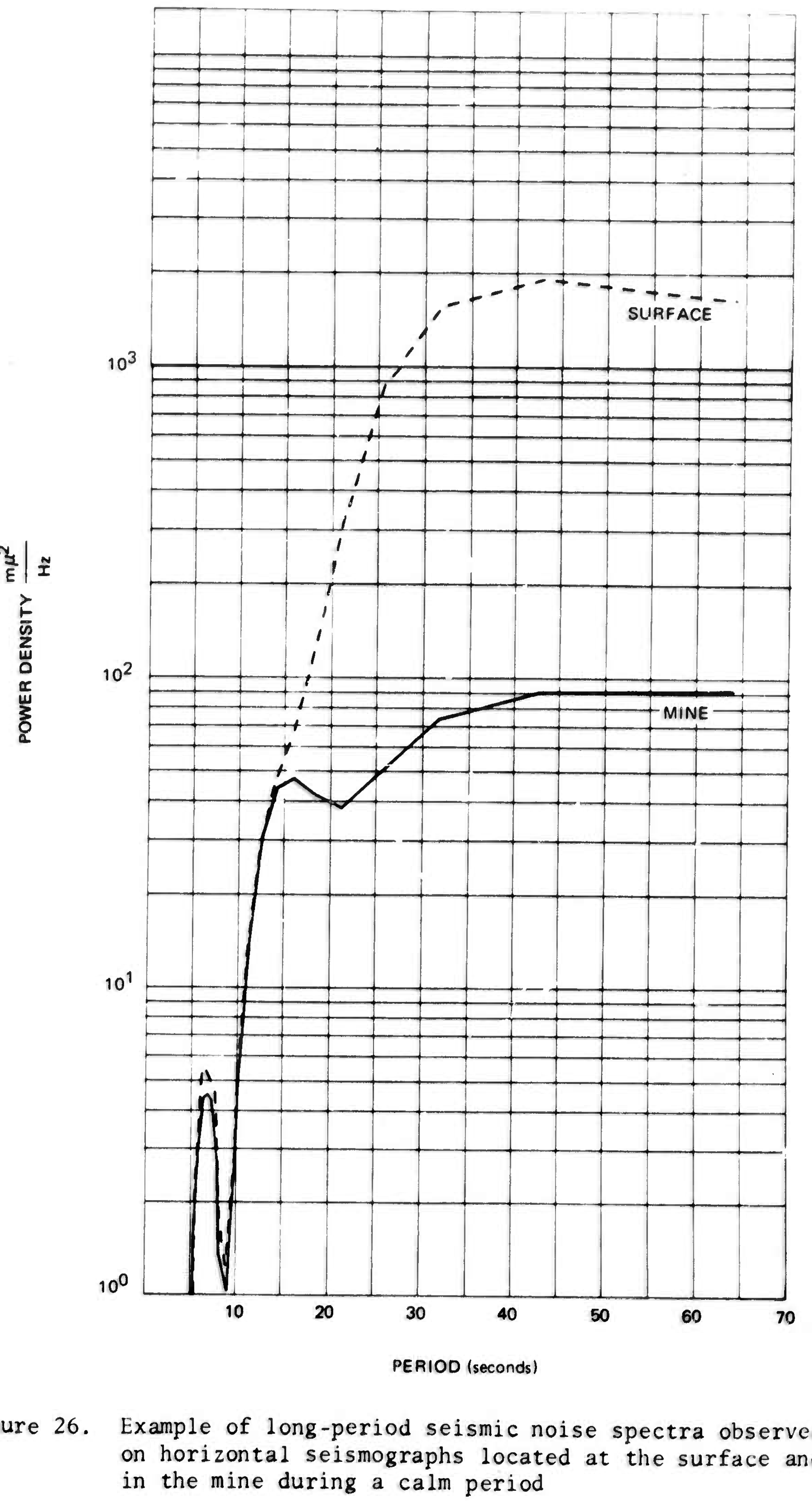

Figure 26. Example of long-period seismic noise spectra observed on horizontal seismographs located at the surface and in the mine during a calm period

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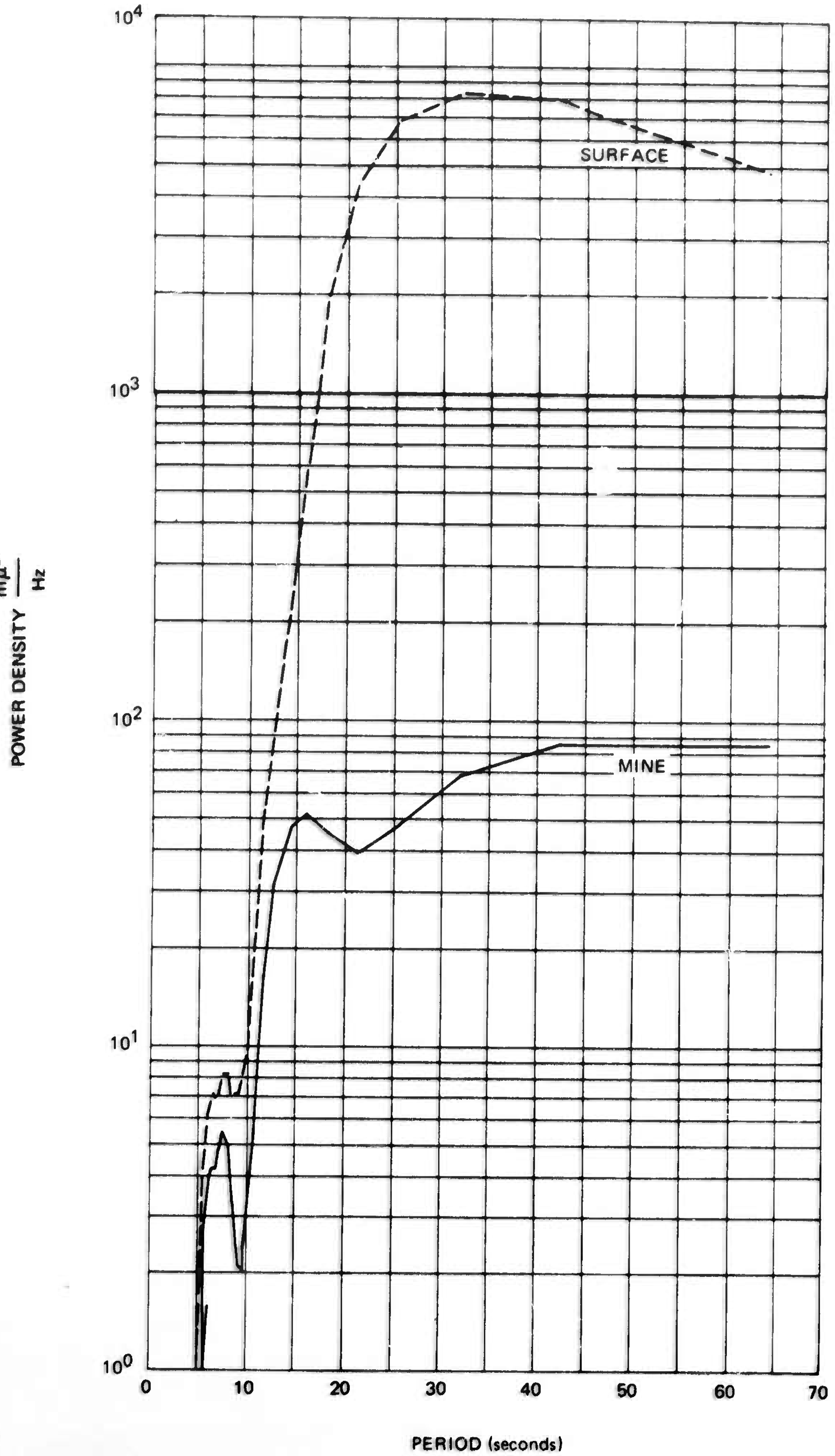

Figure 27. Example of long-period seismic noise spectra observed on horizontal seismographs located at the surface and in the mine during a period of atmospheric turbulence G 5792

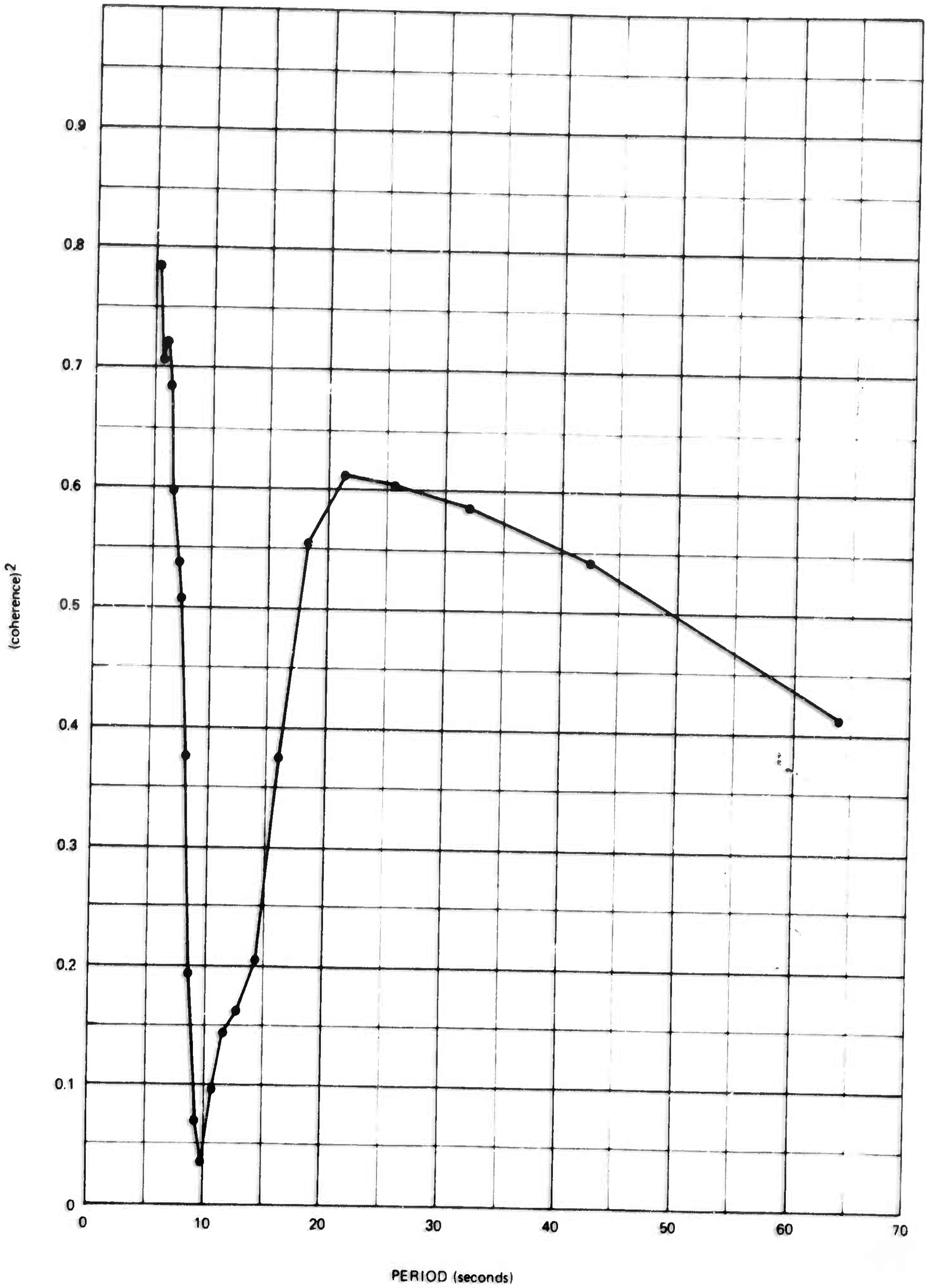

Figure 28. The square of the coherence between the outputs of the microbarograph and the surface transverse seismograph. Sampled interval was during a period of atmospheric turbulence.

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8.3.2 Power Variations in LP Seismic Noise with Changing Weather Situations at KN-UT

LP vertical data taken during "quiet" and "stormy" periods at KN-UT as determined from weather maps were spectrum analyzed. The purposes of this analysis was to determine if power spectra are stationary during calm periods and to determine if there is any relationship between storm intensity and power spectra.

Daily weather maps published by ESSA were used to select "quiet" and "stormy" periods at KN-UT. Quiet periods were selected on the basis of calm conditions at Cedar City, Utah (about 55 miles from KN-UT), as determined from the station model. Stormy periods were selected on the basis of low pressure systems approximately centered in the KN-UT area. The following days, weather conditions, and intervals of interest for data processing were selected.

Date	Weather condition	Interval of interest
30 Aug 68	Calm	1130Z - 1230Z
24 Sept 68	Calm	1130Z - 1230Z
8 Jan 69	Stormy	1130Z - 1230Z
27 Jan 69	Stormy	1130Z - 1230Z
29 Jan 69	Stormy	1130Z - 1230Z
8 Feb 69	Calm	1130Z - 1230Z
16 Feb 69	Stormy	1130Z - 1230Z
26 Feb 69	Stormy	1130Z - 1230Z
4 Mar 69	Stormy	1130Z - 1230Z

The noise samples as recorded by the vertical LP seismograph at KN-UT were sampled at a rate of 2 samples per second. The lengths of the noise samples were 1900 seconds, and power spectra were computed using 190 lags (5%). Three spectral types resulted from the spectral analysis as shown in figure 29. The first type has greater power in the 15-sec peak than the 7-sec peak as denoted by the spectra taken during a calm period in the fall (24 September 1968); the second type has about equal power in the 15-sec and 7-sec peaks as denoted by the spectra taken during a calm period in the winter (8 February 1969); and the third type has greater power in the 7-sec peak than the 15-sec peak as denoted by the spectra taken during a stormy period in the winter (24 January 1969).

Based on the results of this study, it appears that there is no long-term stationarity during calm periods; however, spectra in general appear to be similar when seasonal weather conditions are similar. There also appears to

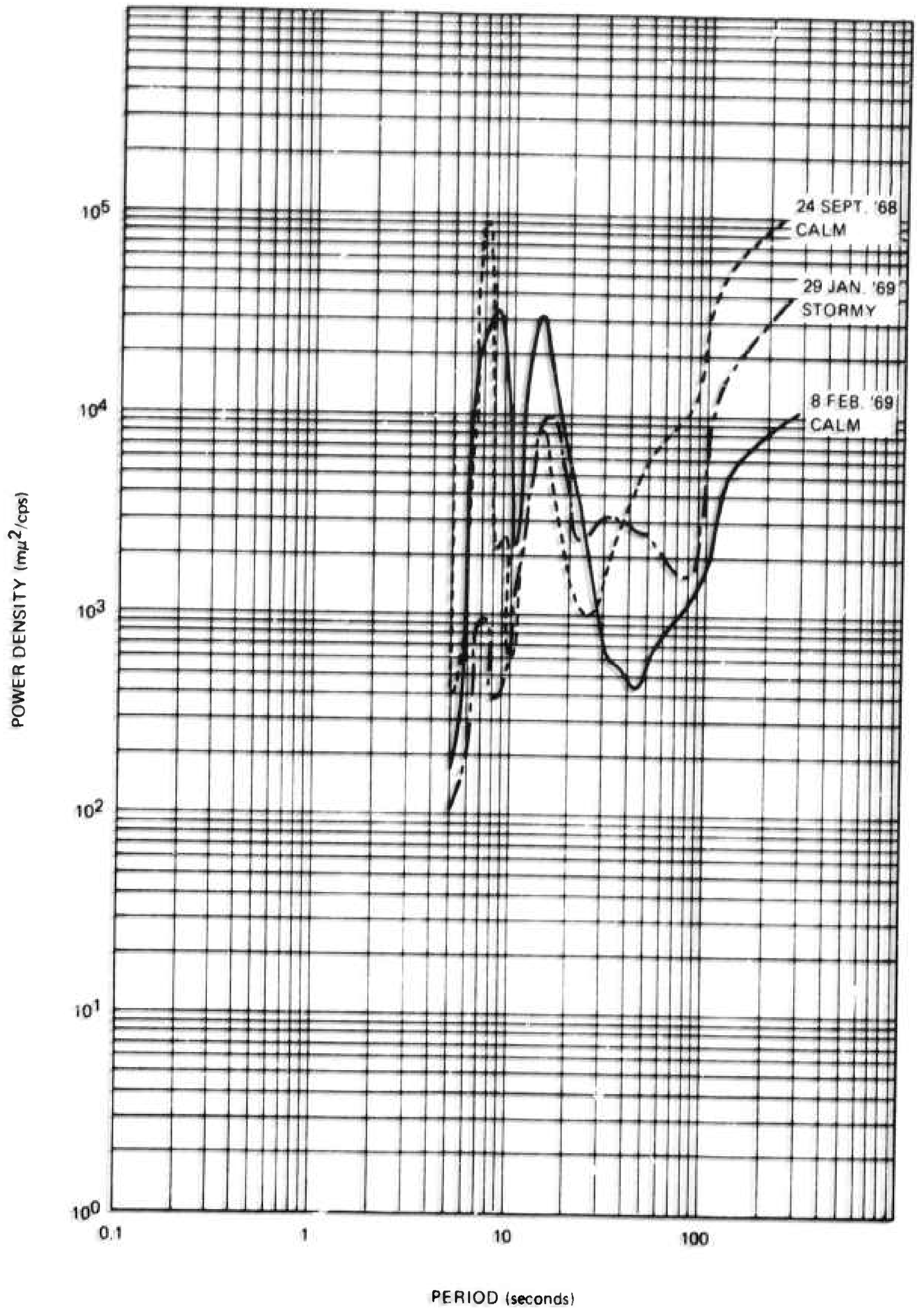

Figure 29. Composition spectra of background noise recorded on a vertical long-period seismograph at KN-UT during a calm period in the Fall (24 Sept 68), a calm period in the Winter (8 Feb 69) and a stormy period in the Winter (29 Jan 69).

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be an increase in power of the 7-sec spectral peaks during stormy periods. The weather maps for all the stormy periods, except one (29 January 1969), showed a cold front associated with the low pressure system that extended into the Pacific Ocean off either California or Baja, California. For the one exception (29 January 1969), a low pressure system and front were centered off the Washington coast.

8.4 THEORETICAL STUDIES ON ATMOSPHERIC LOADING

8.4.1 Long-Period Seismic Noise and Atmospheric Pressure Variations, Part 1: The Response of an Isotropic Halfspace to a Plane Pressure Wave, Tech Note 3/69

The displacement response of an elastic halfspace to a plane pressure wave that moves at a rate well below the seismic wave speeds is derived. Numerical studies of the response indicate that pressure waves with amplitudes of 100 microbars or more can contribute significantly to the LP vertical seismic background observed at the surface, provided that the detectors are located on thick units of alluvial fill or poorly to moderately indurated sandstones and shales. These same waves can create significant tilt noise on LP horizontal seismographs regardless of the rock type, provided that the detector is located at or near the surface. The seismic disturbance created by pressure waves decays rapidly away from the surface. Therefore, it appears likely that the effects of atmospherically-generated noise may be eliminated by placing the detectors at moderate depths.

8.4.2 Long-Period Seismic Noise and Atmospheric Pressure Variations, Part 2: Static Loading of a Layered Halfspace by Atmospheric Pressure Variations, Tech Note 4/69.

In this technical note, expressions are derived for the response of a horizontally layered elastic halfspace to atmospheric loading. The atmospheric pressure variation is described as a space-time stationary random process that exerts stresses on the free surface. For the LP part of the spectrum, the dynamical effects are negligible and the deformations can be considered as static for any given time. The static loading response of an elastic-layered halfspace is described in terms of larger matrices using the Thompson-Haskell method for the two-dimensional case. Formulas are given for the computation of the elastic response to loads of arbitrary shape in terms of this two-dimensional response. Expressions for the power spectra of seismometer tilt noise and the microbarograph outputs are derived in terms of these response functions and the frequency wavenumber spectra of the atmospheric pressure variations. Some sample calculations are also presented.

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13. ABSTRACT

The progress of the Long-Range Seismic Measurements (LRSM) Program during the period 1 January through 31 December 1969 is described.

At the beginning of this report period, there were nine mobile observatories and eleven portable seismograph systems in the LRSM program. These seismograph systems participated in related programs and experiments such as MIRACLE PLAY, RULISON, JORUM, and MILROW. The portable seismograph systems continue to demonstrate their versatility and effectiveness during all field assignments. Six portable strain systems were designed, prefabricated, and deployed to the Nevada Test Site. The site selection was completed in late September and site preparation and installation was started during November 1969.

A review of the studies and evaluations made is included in this report. Studies conducted were directed toward: 1) the analysis of data from portable and mobile systems and 2) the investigation of long-period and short-period data.

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KEY WORDS	LINK A		LINK B		LINK C	
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VELA-Uniform						
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