FINAL REPORT

SUBARRAY E3 EXPANSION

PHILCO

Ford

PHILCO-FORD CORPORATION
MONTANA LASA

FINAL REPORT

SUBARRAY E3 EXPANSION

Prepared for

MIT LINCOLN LABORATORY
Lexington, Massachusetts

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under

SUB-CONTRACT 336 (P. O. No. BB-264)
W.B. Martin, Jr., Project Manager

PRIME CONTRACT AF 19(628)-5167

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ABSTRACT

An expansion and reconfiguration of a Montana LASA subarray was performed during the period October-December 1966. A description of the construction and installation of that subarray is presented. The evaluation of the array is reserved for a subsequent report.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

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FINAL REPORT

SUBARRAY E3 EXPANSION

1.0 INTRODUCTION:

"Long Legs" is the name given to the project of extending a Montana LASA subarray to maintain a minimum spacing between seismometers of three kilometers. The actual configuration was the result of studies conducted at MIT Lincoln Laboratory. Philco-Ford Corporation was requested to modify one of the subarrays in the E or F rings to verify that anticipated performance could be achieved.

2.0 PROJECT ACTIVITY:

2.1 Work Distribution:

Due to the nature of some aspects of the project subcontractors were used to accomplish parts of the expansion. Appendix I gives a list of the subcontractors and the work accomplished by each. The balance of the project was accomplished by LASA Maintenance Center (LMC) personnel.

2.2 Site Selection:

Site selection was based on several requirements which are listed in order of their importance:

A. Minimum existing cultural disturbances.

B. Favorable land-owner acceptance.

C. Access to new seismometer locations by means of existing county and ranch roads.

Site E3 was selected after aerial surveys and field visits determined that this site met the prescribed requirements more closely than any other site.

2.3 Surveying:

Prior to starting survey, permits to survey were obtained from landowners. Surveying commenced on 4 October 1966. Errors detected in the initial survey of Leg 2 resulted in the decision to re-survey all existing end-sensor locations to insure accuracy of new locations. Legal descriptions of land to be occupied were obtained on a day-to-day basis so that leasing agreements could be drawn up as quickly as possible. Figure 1 is the E3 subarray before expansion; Figure 2 is after expansion. Figure 3 compares the old and new configurations, the changes in geometry and spacing and the existing boreholes to be used in the new system.

Surveying accuracies were as follows:

Horizontal Distance-----1:5000
Elevation---------------±1/3 meter
Geographic Coordinates--±1 second

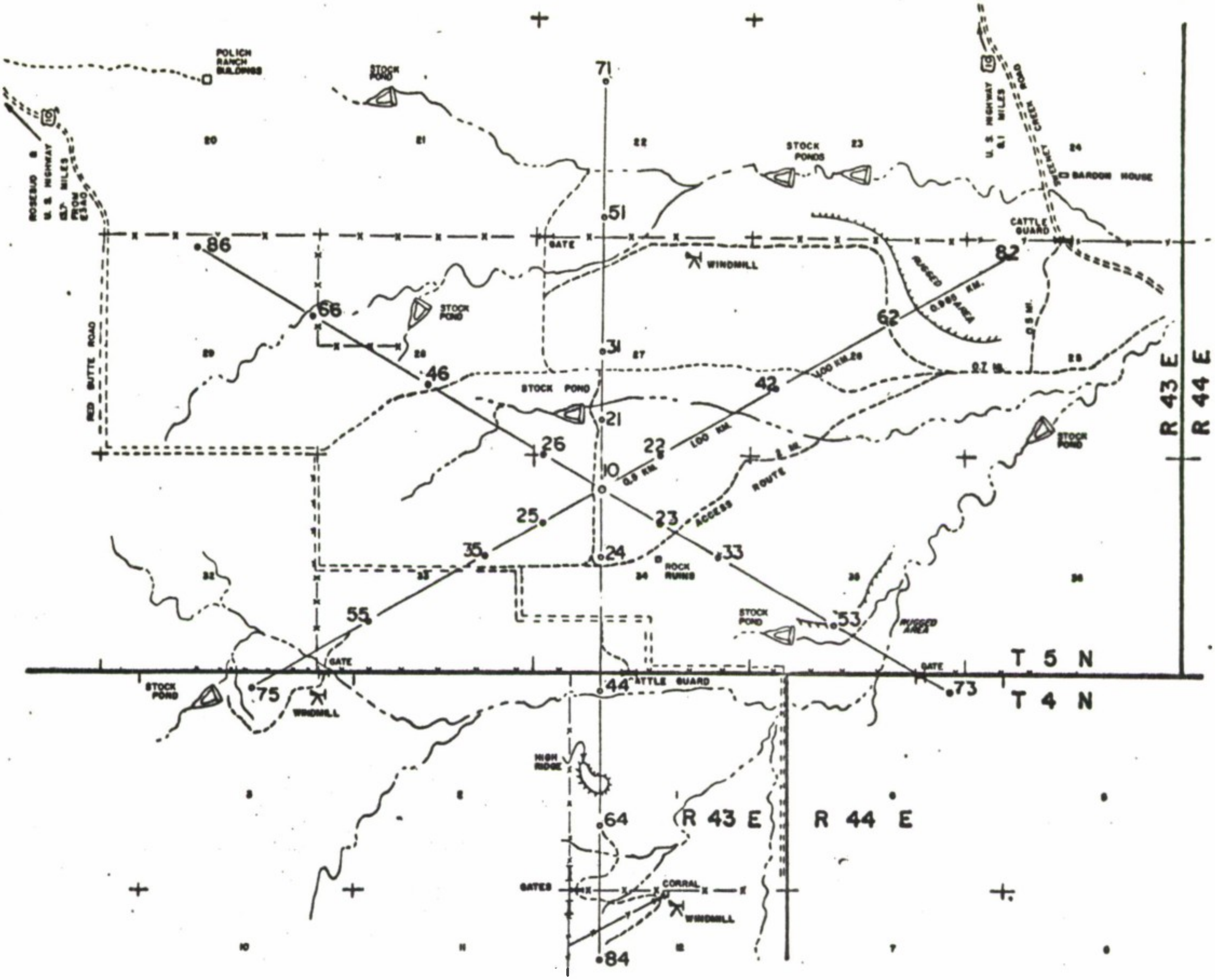
2.4 Drilling Operations:

Drilling and casing operations were begun as soon as leasing agreements were completed on location 62. Leg 2 was selected for starting of all construction due to the rough terrain. All boreholes were drilled to a depth of 210 feet and bottomed out in blue shale or blue shale mixed with sand layers. The type of drilling apparatus used was a Mayhew 1000 combination 20-foot rig, Figure 4. Eastman drift indicator readings, Figures 6 and 7, were taken on each hole by a Philco-Ford technician prior to removing the drill stem. The maximum allowable drift from vertical was 5 degrees. A new procedure for cementing borehole casing was developed on this first location. This was a departure from the procedure which had been used on all LASA boreholes prior to this time. This procedure called for installing a foot valve on the bottom of the casing and pumping cement slurry down through the casing, through the valve and up the outside of the casing. This is undesirable because it involves extensive cleanup operations to condition the casing interior for sensor installation. There is also the possibility of a malfunctioning foot valve allowing the cement to back up in the pipe. Many of the existing LASA boreholes cased in this manner now contain considerable water indicating that the cement does not make a good seal. The new procedure used in this installation was as follows:

1. The casing was tapped with a solid welded cap.

2. 320 gallons of cement slurry was pumped into the flushed borehole.

3. As it was lowered, the inside of the casing was loaded with drill stems for additional weight. After the flotation point of the casing was reached the casing was winched down.



SCALE

0 0.5 1 2 MILES

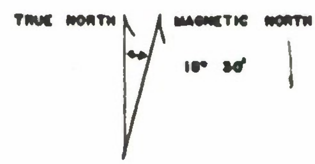
0 0.5 1 2 3 4 KILOMETERS

NOTE SPECIFICATIONS FOR SURVEYING SUB-ARRAY ARE AS FOLLOWS

HORIZONTAL ———— 1' in 3,000'
VERTICAL — nearest one-tenth (0.1) ft.
COORDINATES — nearest one (1) sec. for E3A0 location, all others computed.

Offset monument
E3 H2 15 m short, SW back along rep. F2 to H2 is thus 666 m.

SEISMOMETER LOCATIONS	TOP OF MONUMENT ELEVATION FEET	METERS	COORDINATES					
A0	2697.6	613.7	46°	08'	56"N	106°	20'	03" W
61	2846.4	699.0	46	09	14	106	20	03
C1	3002.4	615.1	46	09	30	106	20	03
E1	2843.5	566.7	46	10	03	106	20	03
61	2846.3	666.6	46	10	35	106	20	03
62	2981.1	908.6	46	09	06	106	19	43
02	2821.2	690.4	46	09	22	106	19	02
F2	2887.2	680.0	46	09	38	108	18	22
H2	2819.9	859.5	46	09	54	106	17	42
66	2960.0	611.4	46	08	50	106	18	43
C3	2960.6	602.5	46	08	42	106	19	23
E3	2965.0	604.6	46	08	26	106	18	42
63	2935.1	894.6	46	08	09	108	18	02
64	6013.0	616.4	46	08	42	106	20	03
D4	2809.0	856.7	46	08	09	106	20	03
F4	2956.6	601.2	46	07	37	106	20	03
H4	3016.2	619.3	46	07	05	106	20	04
65	3024.6	921.6	46	08	50	106	20	23
C6	3047.4	626.6	46	08	42	106	20	44
E6	6034.4	624.9	46	08	26	106	21	24
66	3050.6	626.6	46	08	10	106	22	06
66	2866.4	616.6	46	09	06	106	20	26
D8	2966.1	814.1	46	09	22	106	21	04
F6	2668.8	600.6	46	09	66	106	21	44
H6	3048.8	629.5	46	09	56	106	22	28



ORIENTATION OF SUB-ARRAY (H4 to 61)
00° 10' Azimuth

CENTER OF SUB-ARRAY IN SW¼ NE¼ NW¼ Sec. 34
T5N R43E Rosebud Co.

DATE OF SURVEY: Dec. 1964

RELIEF: E666 Minus E6H2 = 230.6 ft. or 70.3 m.

Figure 1
Subarray E3 Original Configuration
Sept. 1966

LASA
SUB-ARRAY E3
SOUTHEASTERN MONTANA

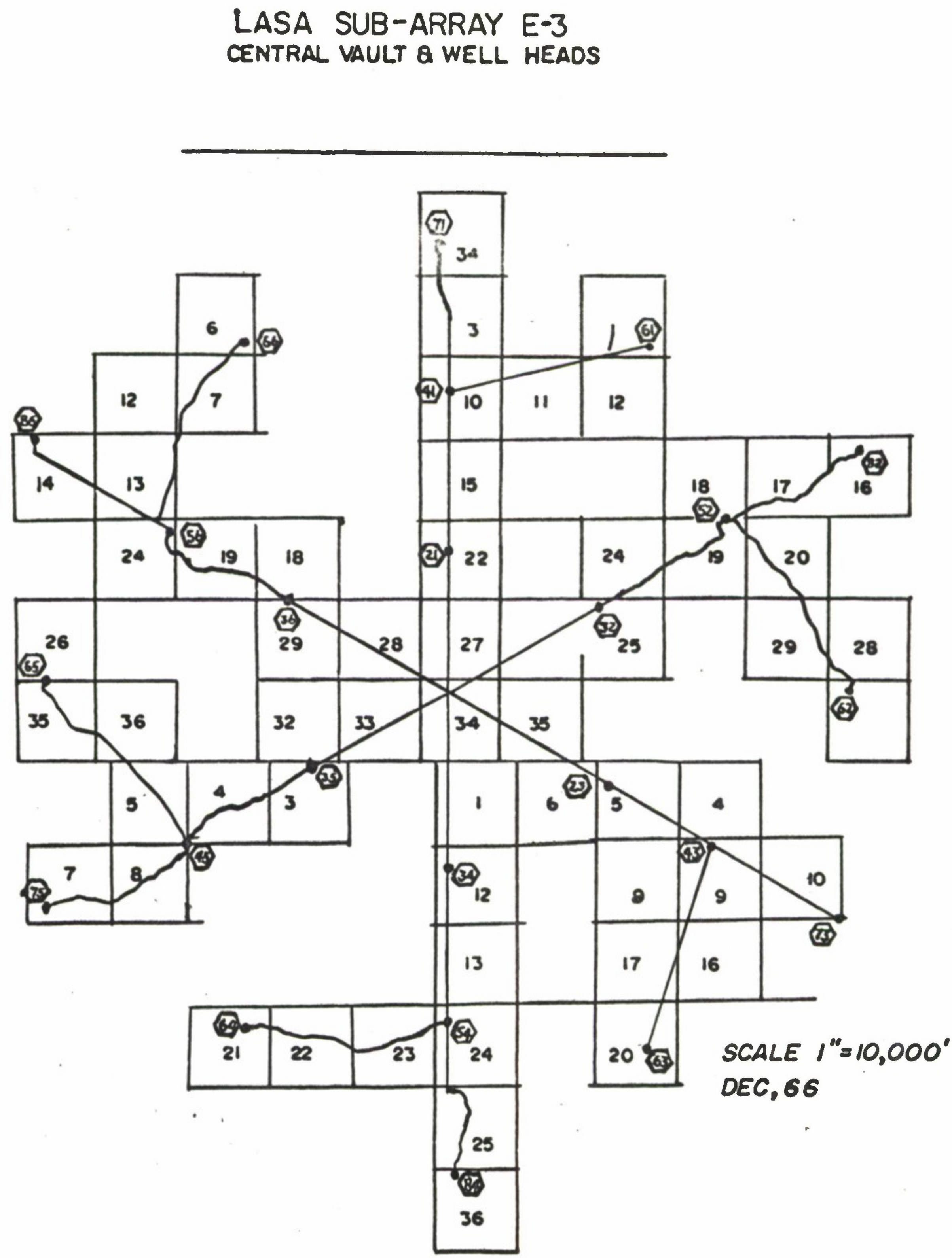


Fig. 2 Subarray E3 Final Configuration

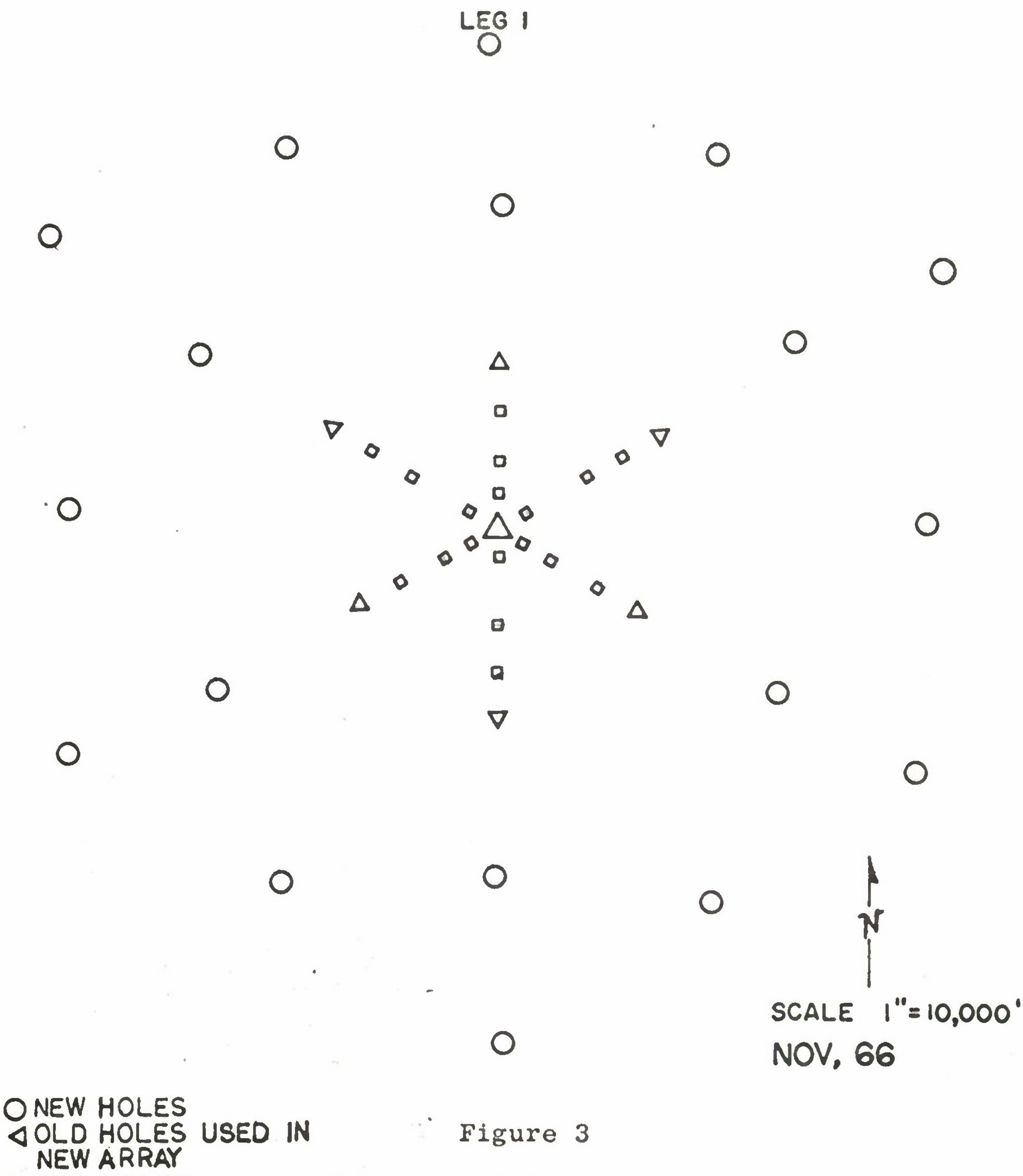


Figure 3

Subarray E3 Comparison of Configurations

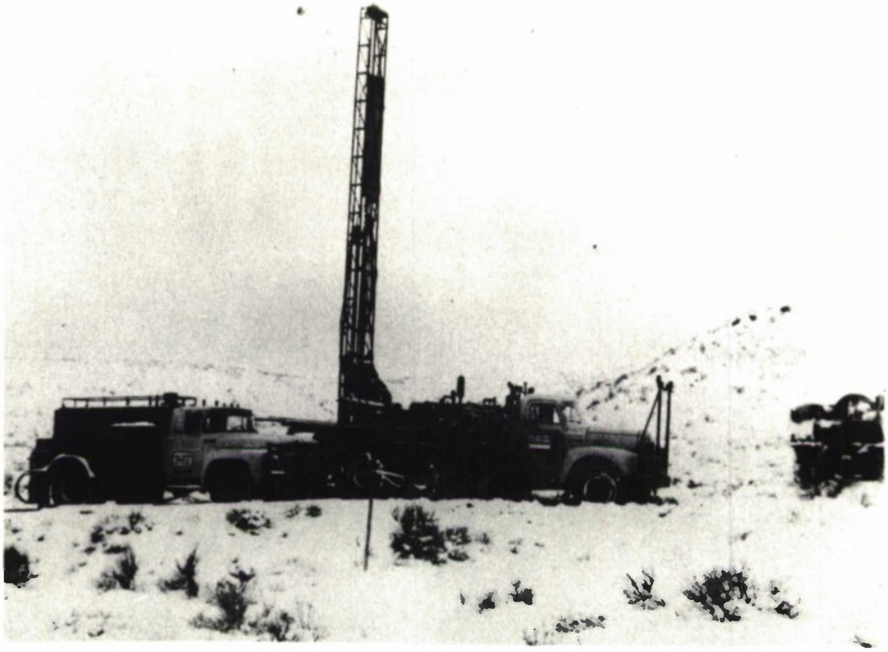


Figure 4   Drilling Rig in Operation at E3-66

Figure 5 Cable Route Preparation at E3 Leg 1

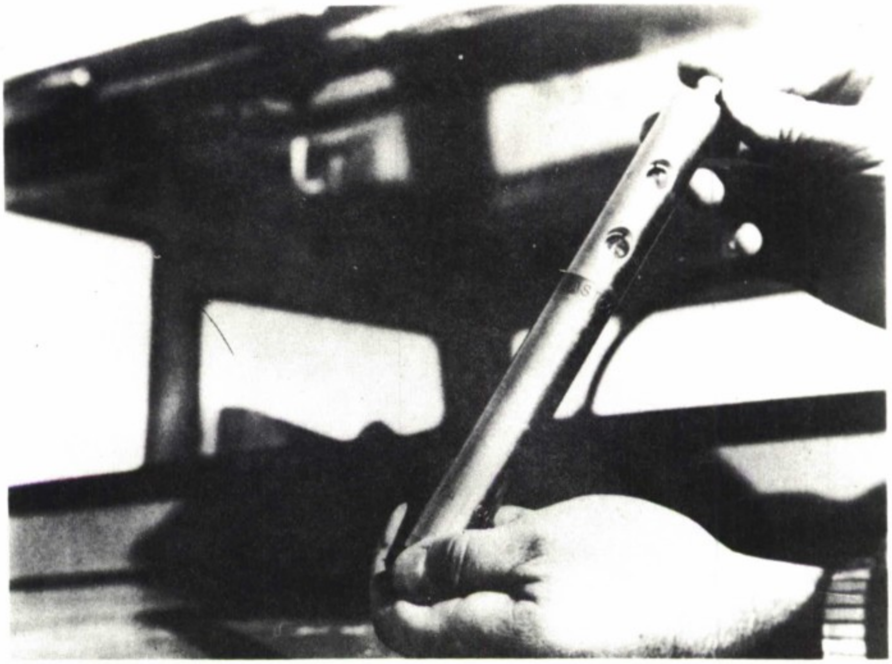


Figure 6 Eastman Drift Indicator

Figure 7 Eastman Drift Indicator Being Prepared For Use

4. The casing joints were made up as casing was lowered into the borehole. Joints were handmade using four-foot chain wrenches and each joint was coated with pipe joint compound.

5. The borehole was topped off with cement slurry to insure that the casing was cemented to the top of the ground.

This procedure proved to be very effective and quite fast. A well could easily be drilled, cased and cemented in one day's time. This procedure left a clean and dry borehole with its rust preventive lubricant intact in which to install the sensor.

Drilling specifications were as follows:

Hole depth--------	200 ft. ±5 ft. as cased
Hole size---------	7 7/8" O.D.
Casing size-------	5" I.D.
Casing thickness--	.244" wall
Casing type-------	Range I H-40 grade

2.5 Trenching Operation:

Cable was trenched (Figures 8 and 9) into the ground by means of a ripper tooth (Figures 10 and 11) through which the cable was fed. The cable was buried to a depth of 36 inches. Some of the ground had to be pre-ripped prior to laying the cable. The trenches were partially leveled by dragging two sections of railroad track behind the cable-laying ripper tooth. The trenches were not "back-dragged" with the dozer blade as in previous construction since this completely destroys the grass coverage allowing erosion to take place. These trenches were inspected and restored in the spring of 1967. The cost per mile to restore the cable trenches was less than had been incurred prior to this time. In certain areas, some leveling of terrain (Figure 5) was necessary before the trencher could lay cable. This work was held to a minimum to reduce land damage.

All cable splicing was done by Philco-Ford technicians. Sixty-five (65) splices were made using SCOTCHCAST COMMUNICATION splicing kits. No problems were encountered with either cable or cable splices. The splices were buried, mapped and marked with a metal marker flush with the ground.

Figure 8 Completed Cable Trench at E3

Figure 9 Trenching Rig in Use at E3

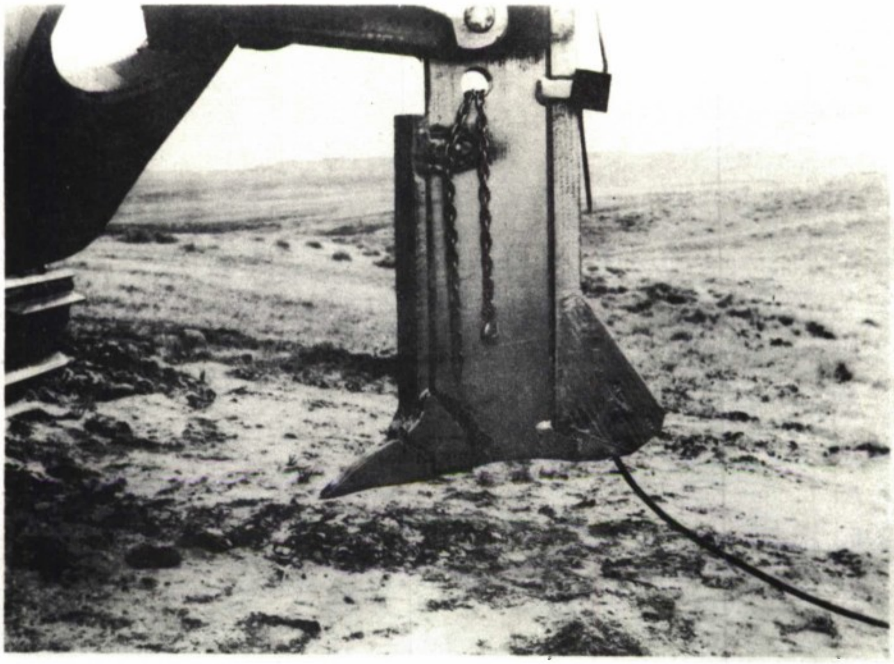


Figure 10 Cable Laying Ripper Tooth Ready for Use

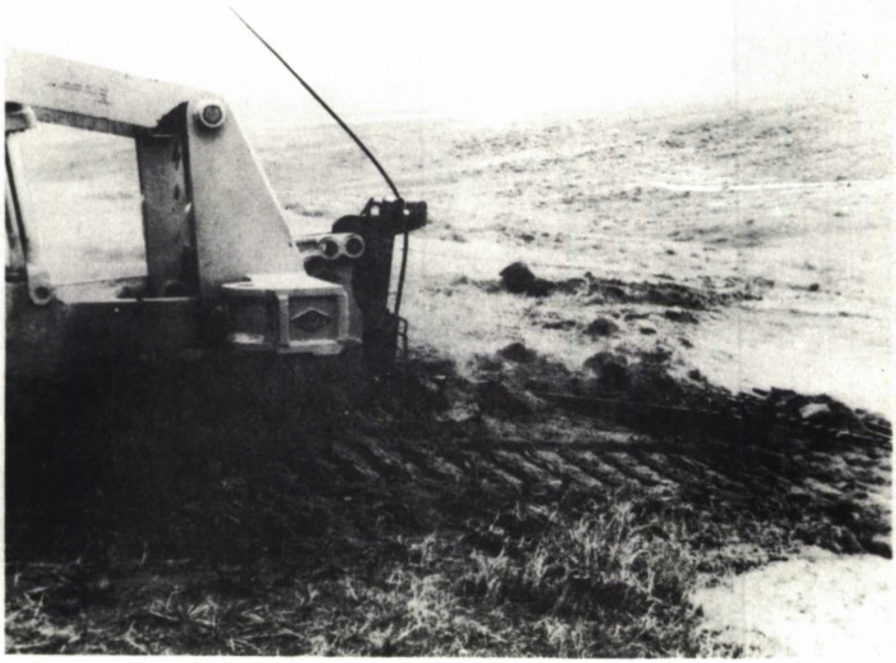


Figure 11 Cable Laying Ripper Tooth in Operation

2.6 Wellhead Vault Installation:

The wellhead vaults (WHV) were locally fabricated from standard 55-gallon drums (Figures 12 and 13). They were installed by welding them to the top of the casing. The excavation made for the WHV was filled with "pea" gravel to provide better drainage. One major change was made to the WHV in the way the cables entered the vault. Rather than using a large, single-pipe entrance, each cable was brought in through an individual conduit and sealed with a Thomas and Betts connector. The WHV's were coated with mastic on the outside and painted with rust preventive paint on the inside.

2.7 Project Cost:

Appendix II presents a table of costs for each major job division in the project.

3.0 SENSOR AND ELECTRONICS EQUIPMENT INSTALLATION:

Concurrent with the expansion of the subarray certain changes were made in the sensor and electronic equipment to provide more reliable operation and to minimize future in-field repairs.

The operations necessary to accomplish this were carried out in the following order:

A. Removal of sensor equipment
B. Rehabilitation of seismometers
C. Modification of RA-5 amplifiers
D. Installation of sensor equipment
E. Installation of central terminal housing equipment
F. Checkout and calibration

3.1 Removal of Sensor Equipment:

The initial effort for removal of the sensor equipment was to remove the WHV amplifier panel from the WHV and pull the seismometer with its cable from the borehole.

Several boreholes were partially filled with water and two seismometers in the outer ring were stuck in the borehole casing and could not be removed. Because they were located in boreholes which formed part of the new configuration, they were checked electrically, found to be satisfactory and reused without rehabilitation.

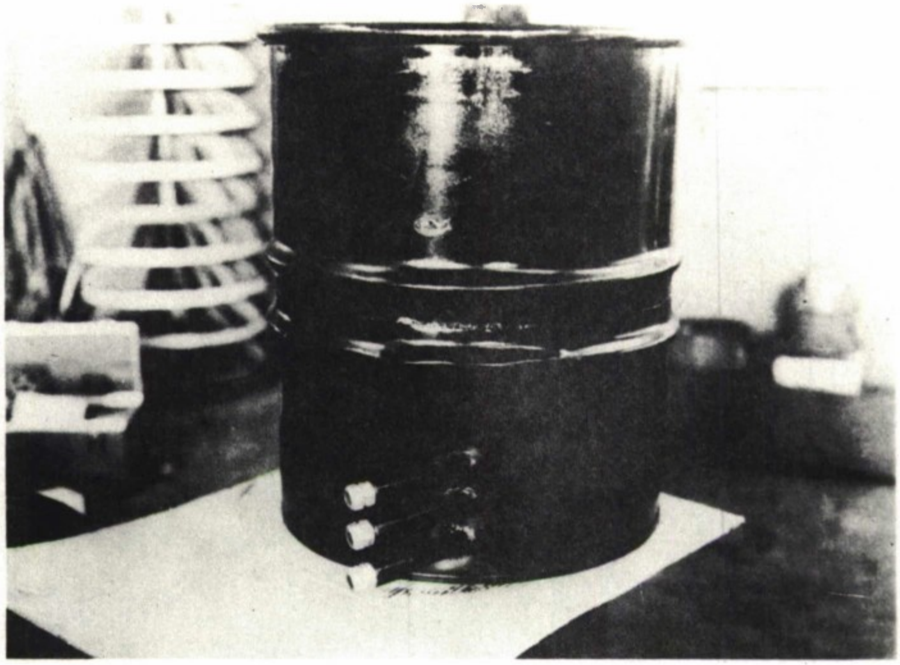


Figure 12 E3 WHV showing Cable Entrances

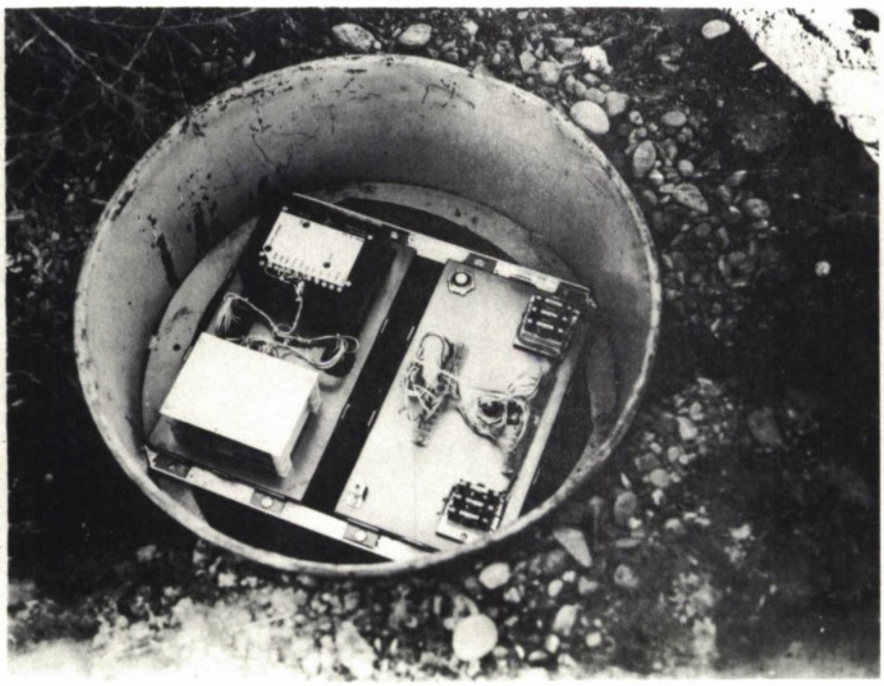


Figure 13 E3 Type WHV with Panel Exposed

3.2 Rehabilitation of Seismometers:

Seismometers used in the Long Legs Project are the HS-10-1/A type which are employed throughout the Montana LASA. The HS-10-1/A seismometers removed from E3 were returned to the LASA Maintenance Center (LMC) for refurbishment prior to use in the expanded array.

The seismometers were checked for physical damage, given an electrical resistance check and then cleaned of all mineral deposits and rust (Figure 14). They were repainted with two coats of water and chemical resistant primer and paint (Figure 15).

Electrical tests made consisted of resistance measurements of coils, high-potential test of case insulation (500 volts), natural frequency and damping measurements (Appendix III). The units were then subjected to water pressure (Figure 16) of 250 psi for one hour while resistance checks were taken again to determine if any signs of moisture leakage were present.

To facilitate replacement of the seismometer in the future a quick disconnect plug (Amphenol Part No. KPT 06J16-23PW) was added to the seismometer cable prior to reinstallation (Figure 17).

3.3 Modification of RA-5 Amplifiers:

Modified RA-5 amplifiers were used in this expanded subarray. Twenty-five (25) spare RA-5 amplifiers were sent to MIT Lincoln Laboratory for modification. This modification was designed to minimize gain variation due to temperature extremes and eliminate the distortion problem relating to detector voltage variation. Subsequent to the modification and return to the LMC, the amplifiers were checked, adjusted to normal operating specifications and tested in the environmental chamber. Gain variation reduction should result from the addition of feedback to the preamp. An entirely new output stage was added with sufficient gain to make up for the signal loss caused by the added feedback in the preamp. This output stage includes a separate gain control and a band width limiting filter.

3.4 Installation of Sensor Equipment:

Installation of sensor equipment was carried out in two phases. The first phase included assembly and checkout of materials, the second involved field installation.

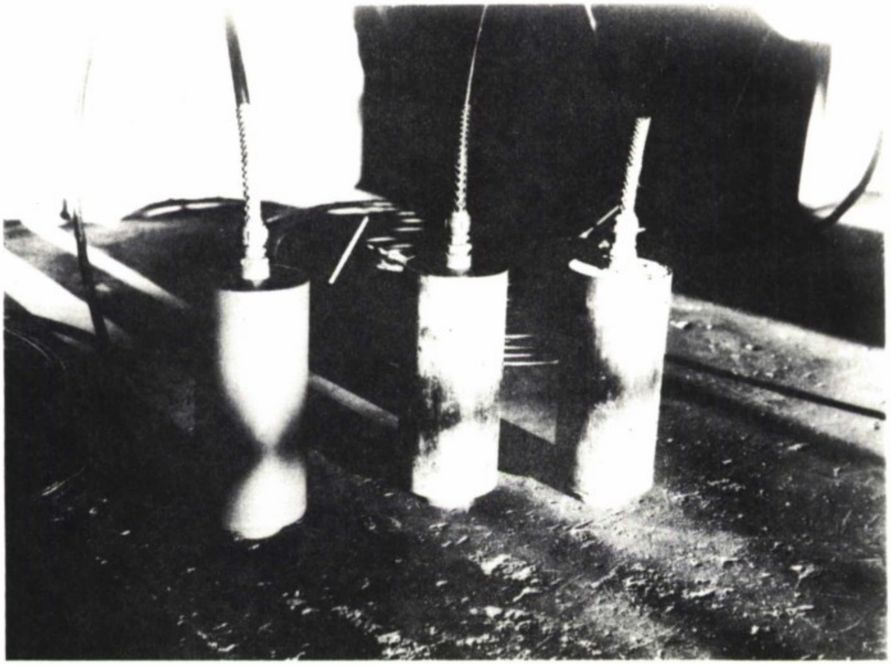


Figure 14 Seismometer Before Refurbishing

Figure 15 Seismometer After Refurbishing

Figure 16 Seismometer Being Placed in Pressure Test Chamber

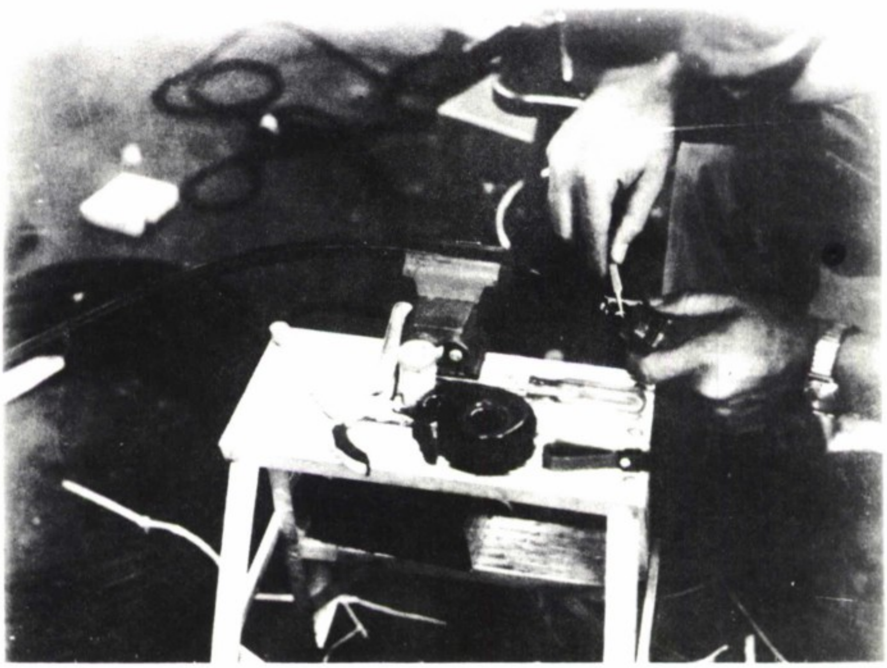


Figure 17 Quick Disconnect Plug Being Installed on Seismometer Cable

3.4.1 Assembly and Checkout of Materials:

In conformance with the research and experimental aspect of Montana LASA, several changes were included in the installation of WHV components. These changes are dedicated to the improvement of the field system as well as to simplify future maintenance and operational procedures.

The changes included:

1. A quick disconnect plug on the seismometer cable (Figure 17), in lieu of taper pins, to facilitate removal and replacement of the seismometer.

2. Incorporation of two WHV junction boxes in place of the one used previously (Figure 13). One new box, designated as the WHV junction box (WHV "J" Box), contains all the cabling into and out of the WHV. This change will involve less disturbance of cabling during future seismometer changes and thus result in fewer cable problems. The second box, designated as the WHV amplifier box (WHV "amp" box), contains the RA-5 amplifier, associated remote calibration and lightning protect circuitry.

3. Quick-disconnect jacks and mounting hardware were provided so the amplifier could be replaced with a minimum of disturbance to other units.

4. A telephone jack was installed on the WHV "J" Box to allow telephone communication, via EE-8 field phones, with the CTH or other WHV's in the subarray.

The modified WHV boxes were fabricated at MIT Lincoln Laboratory. Upon arrival at the LMC, the boxes were prepared for field installation. The RA-5 amplifiers were installed in the WHV "amp" box with lightning protect gas tubes. Thorough shop testing of the WHV package was accomplished prior to field installation.

3.4.2 Field Equipment Installation:

Installation was carried out by five two-man crews. Four field crews installed the equipment in the

WHV's and one crew installed the CTH equipment and served as coordinator between field crews. The procedure consisted of installing the seismometer, mounting the new WHV "J" Boxes, tailoring and connecting the cables and making checks with the crew at the CTH (paragraph 3.6).

Due to the rough terrain (Figure 18), 4-wheel-drive pickup trucks were used. These trucks are specially equipped for LASA operations of this sort. Two-way radio telephones and EE-8 field phones were used for communication between the WHV, CTH, LMC and LASA Data Center (LDC). Near blizzard conditions were encountered during the latter days of this installation. During this time these improved vehicular and communication facilities proved essential.

3.5 Installation of Central Terminal Housing (CTH) Equipment:

While field crews were installing the WHV equipment, other equipment was installed in the CTH. An amplifier power supply, specially modified for the Long Legs Project, modified power protect cards and associated wiring were installed in the CTH. These cards provide for trimming of each WHV amplifier output at the CTH thus eliminating visitation at each wellhead. With termination of the RA-5 output now on this modified card, removal of the terminating resistor on the Input Protection Card in the SEM input drawer was necessary to avoid double-termination of the RA-5 output signal.

3.6 Field Checkout and Calibration:

As each amplifier was installed, the signal pair to the CTH was checked for continuity and proper polarity.

The amplifier power supply was set to the proper operating level (43 Volts). The power supply current was recorded as each amplifier was connected in order to detect any malfunction that would result in excessive current being drawn from the power supply. The total power supply current with all subarray amplifiers operating normally was found to be 510 milliamperes. When the seismometers are bypassed and the calibration signal is fed directly to the RA-5 amplifier, the relays draw additional current and raise the power supply current to 740 milliamperes.

The RA-5 amplifiers were allowed 24 hours to stabilize before final gain trim settings were made. During this interval the gain trim potentiometers were adjusted to their high and low limits to establish the range of trim

Figure 18   Typical Terrain Encountered at E3

available. With the RA-5 amplifiers adjusted for a gain of 10K and with a 20V p-p cal signal applied to the subarray, the average trim range for the subarray was from a low of 6 volts peak-to-peak to a high of 15 volts peak-to-peak as measured at the SEM multiplexer input.

After the 24-hour stabilization period, the gains were trimmed to give the proper calibration outputs at the Billings LDC. After a complete system checkout by the LDC, the subarray was returned to service on December 13, 1966.

4.0 CONCLUSIONS AND RECOMMENDATIONS:

This installation was completed in a very short period of time necessitated by climatic considerations. It should be pointed out that the early completion was a direct result of exceptionally favorable landowner relationships and extended efforts on the part of the subcontractors. In any future installations of this type it would be advisable to begin leasing and surveying well ahead of actual construction since these are the areas of most unforeseen difficulties.

The procedures developed for borehole cementing proved to be very effective and should be considered for future operations on holes up to 250 feet in depth. It should be noted, however, that soil conditions encountered will have a direct bearing on its effectiveness.

A P P E N D I X

Subcontractors	Job Description
L.P. Anderson Contractors, Inc. P.O. Box 209 Miles City, Montana	Constructing wellhead vaults, cable trenching and laying.
Atlas Engineering, Inc. 1739 Grand Avenue Billings, Montana	Survey of all 25 wells and cable trenches.
Buell & Edlund Drilling Co. P.O. Box 154 Miles City, Montana	Drilling and casing the 18 new wells.
Eastman Oil Well Survey 1437 Avenue East Houston, Texas	Rental of Eastman Drift Indicator

APPENDIX I

TABLE OF COSTS

Trenching operation	$32,929.22
Surveying	11,671.00
Drilling operation	19,186.00
Eastman Drift Indicator (rental)	270.00
Material and Installation at WHV	4,866.15
Miscellaneous Hardware	406.23
Land restoration	429.94
TOTAL COST	$69,758.54

APPENDIX II

DATA ON SEISMOMETERS

SER. NO.	COIL RE-SISTANCE	COIL CT RE-SISTANCE	CAL COIL	LKG.TO CASE	f_o	OVERSHOOT RATIO UNDAMPED	1 MEG	240K	180K
Unk.	50K	25K	18	∞	1.045	1:2.75	1:5.0	1:23	--
165	50K	25K	18	∞	1.000	1:3.14	1:9.33	1:60	--
586	48K	24K	23	∞	.945	1:2.69	1:9.0	1:40	1:10.4
582	50K	25K	20	∞	1.000	1:3.12	1:6.91	1:55	--
524	49K	24.5K	21	∞	1.011	1:3.28	1:8.0	1:63.75	--
430	50K	25K	25	∞	.9875	1:3.15	1:7.0	1:38.6	1:450
474	49K	24.5K	22	∞	1.1625	1:2.48	1:4.37	1:10.66	1:21.0
592	50K	25K	28	∞	.9725	1:3.5	1:8.0	1:73.33	--
541	50K	25K	24	∞	.975	1:3.57	1:5.88	1:44.3	--
503	50K	25K	19	∞	1.170	1:2.5	1:5	1:16.3	1:30
583	50K	25K	17.5	∞	1.275	1:2.37	1:4.1	1:13	1:23.5
562	50K	25K	29	∞	1.057	1:3.2	1:7.1	1:70	--
Unk.	50K	25K	18	∞	.920	1:3.75	1:11.11	1:290	--
586	50K	25K	23	∞	.990	1:3.14	1:7.8	1:50	1:440
440	50K	25K	19.5	∞	1.0425	1:3.43	1:7.8	1:54.3	1:230
497	50K	25K	18.5	∞	.994	1:3.42	1:8.88	1:260	1:560
Unk.	50K	25K	23.5	∞	1.112	1:3.3	1:6.1	1:28	1:60
373	48K	24K	22	∞	1.035	1:3.4	1:5.4	1:29.1	1:130
Unk.	50K	25K	19.25	∞	1.03	1:3.222	1:4.8	1:29	1:65
561	48K	24K	24	∞	.962	1:3.37	1:4.9	1:20	1:44
429	50K	25K	20.5	∞	1.02	1:3.53	1:5.33	1:29	1:343
424	48K	24K	20	∞	1.02	1:2.5	1:4.11	1:52	1:27

APPENDIX III

DOCUMENT CONTROL DATA – R&D

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13. ABSTRACT

An expansion and reconfiguration of a Montana LASA subarray was performed during the period October-December 1966. A description of the construction and installation of that subarray is presented. The evaluation of the array is reserved for a subsequent report.

14. KEY WORDS

LASA	seismology
seismic array	seismometer