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THERMAL PROPERTIES OF SOILS.(U)
NOV 79 F04704-80-C-0006
UNCLASSIFIED FN-TR-29 NL

1 of 2
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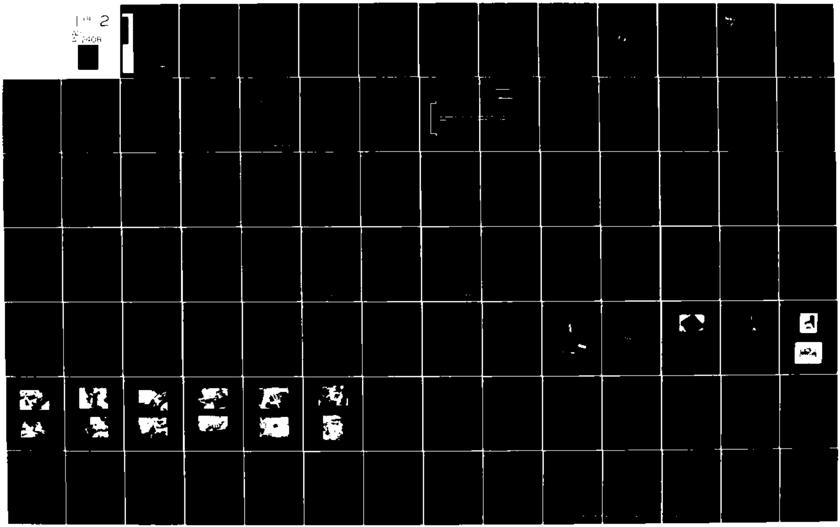

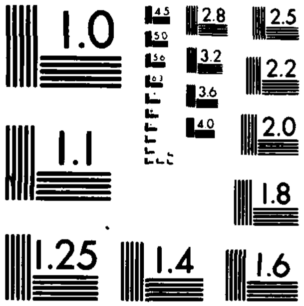

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963 A

MX SITING INVESTIGATION
GEOTECHNICAL EVALUATION

THERMAL PROPERTIES OF SOILS

PREPARED FOR
BALLISTIC MISSILE OFFICE (BMO)
NORTON AIR FORCE BASE, CALIFORNIA

FUGRO
NATIONAL, INC.
Consulting Engineers and Geologists

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

Investigation was performed in order to assist A.F. in evaluating heat flow characteristics of soils. Both field + lab tests were made. Studies [redacted] performed in south central Nevada showed that temperatures of the soil to a depth of 8 feet were affected by seasonal changes.

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FN-TR-29

THERMAL PROPERTIES OF SOILS
MX SITING INVESTIGATION

Prepared for:

U.S. Department of the Air Force
Ballistic Missile Office
Norton Air Force Base, California 92409

Prepared by:

Fugro National, Inc.
3777 Long Beach Boulevard
Long Beach, California 90807

23 November 1979

FUGRO NATIONAL, INC.

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1.0 INTRODUCTION

1.1 PURPOSE AND BACKGROUND

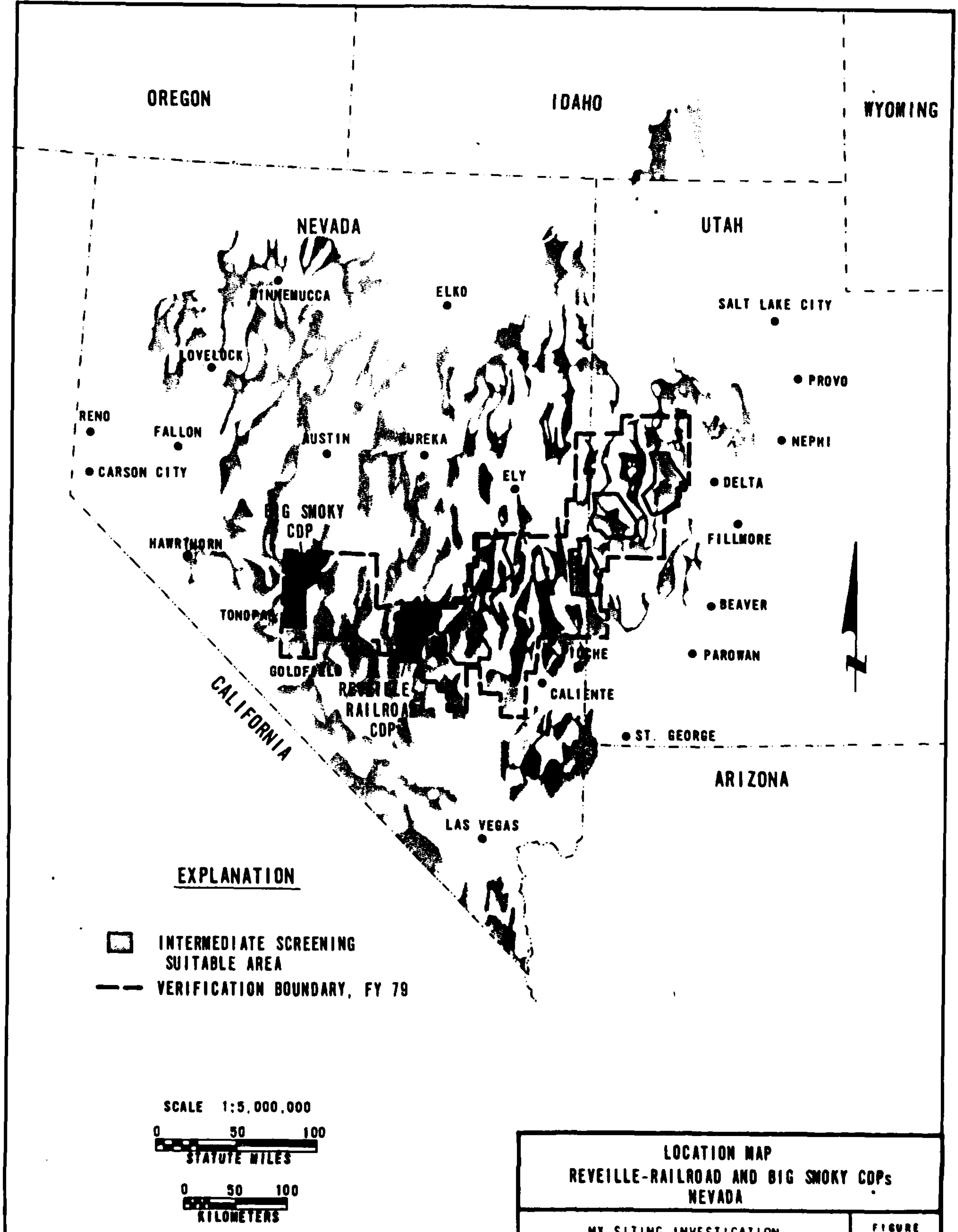
This report presents the results of Fugro National's investigation of thermal properties of subsurface soils in two valleys in Nevada. The investigation was performed in order to assist the Air Force in evaluating the heat flow characteristics of the soils. The investigation included a field program and a laboratory testing program. The field program consisted of installing thermal probes in borings and measuring in situ subsurface soil temperatures over a period of eight months; the laboratory testing consisted of determining thermal resistivity and volumetric heat capacity of soil samples obtained from borings.

The thermal probes were installed in borings drilled during the Verification Program for the MX Siting Investigation. Soil samples for laboratory testing were obtained from these and other borings.

1.2 SCOPE

The scope of the investigation was as follows:

A. Installation of Thermal Probes: Thermal probes were installed in three borings to measure in situ soil temperatures. The probes consisted of a string of thermocouples at various depths below ground surface. One probe was installed in Reveille-Railroad Candidate Deployment Parcel (CDP) and two probes were installed in Big Smoky CDP. Both CDPs are located in Nevada (see Figure 1-1).



LOCATION MAP
REVEILLE-RAILROAD AND BIG SMOKY CDPs
NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE
1-1

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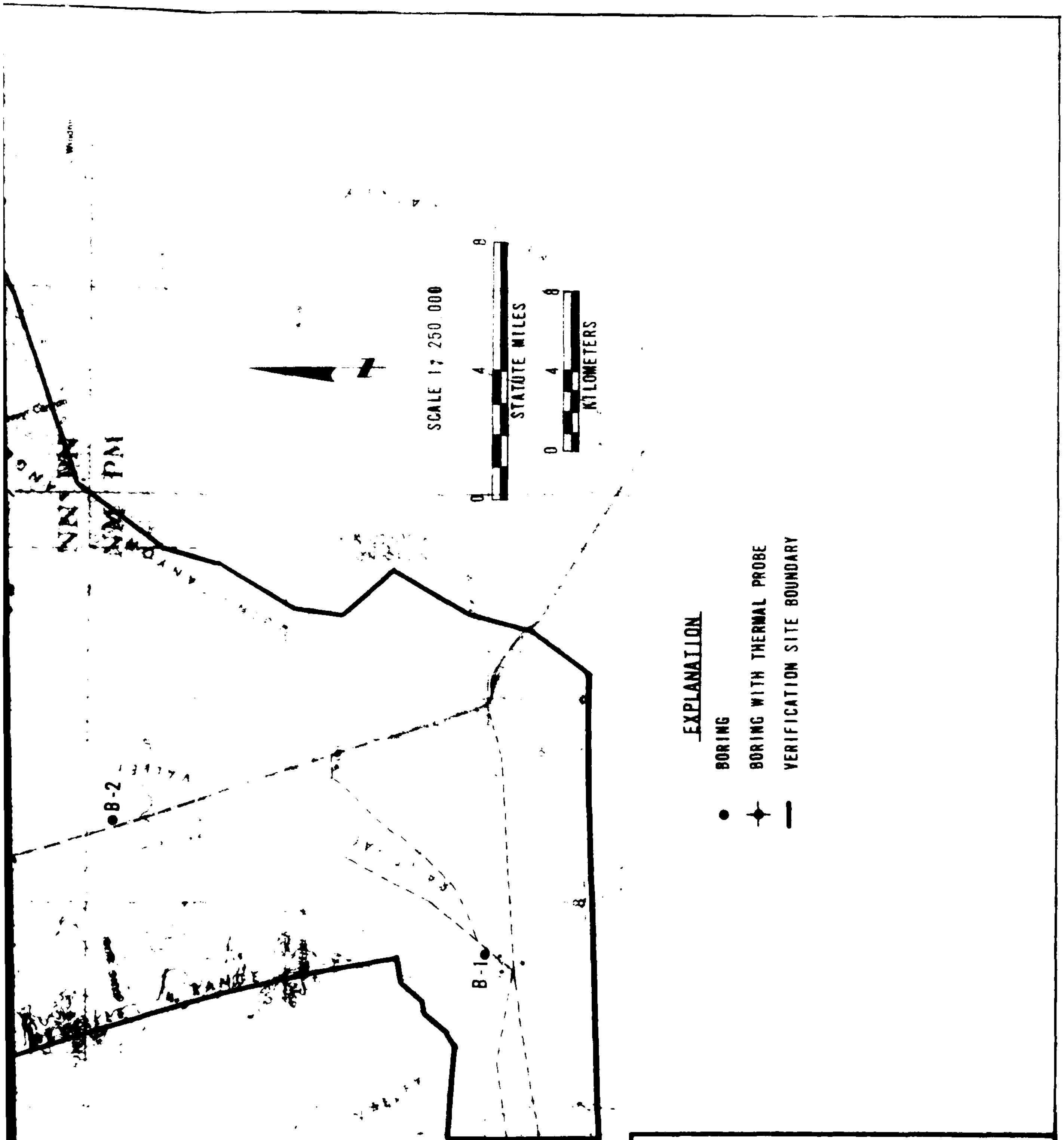
9 NOV 1979

B. Laboratory Testing: Laboratory tests were performed to determine thermal resistivity and volumetric heat capacity of soil samples obtained from seven borings drilled in Reveille-Railroad CDP and six borings drilled in Big Smoky CDP. The locations of the borings drilled in the two CDPs are shown in Figures 1-2 and 1-3.

The details of the thermal probes and laboratory testing are explained in the following sections.


B-1
B-2
B-3
B-3A
B-4
B-5
B-6
REVEILLE
RANGE
HUMBOLDT NATIONAL FOREST
PM
SCALE 1: 250 000
STATUTE MILES
0
4
8

9 NOV 1979



BORING LOCATION MAP
REVEILLE-RAILROAD CDP, NEVADA

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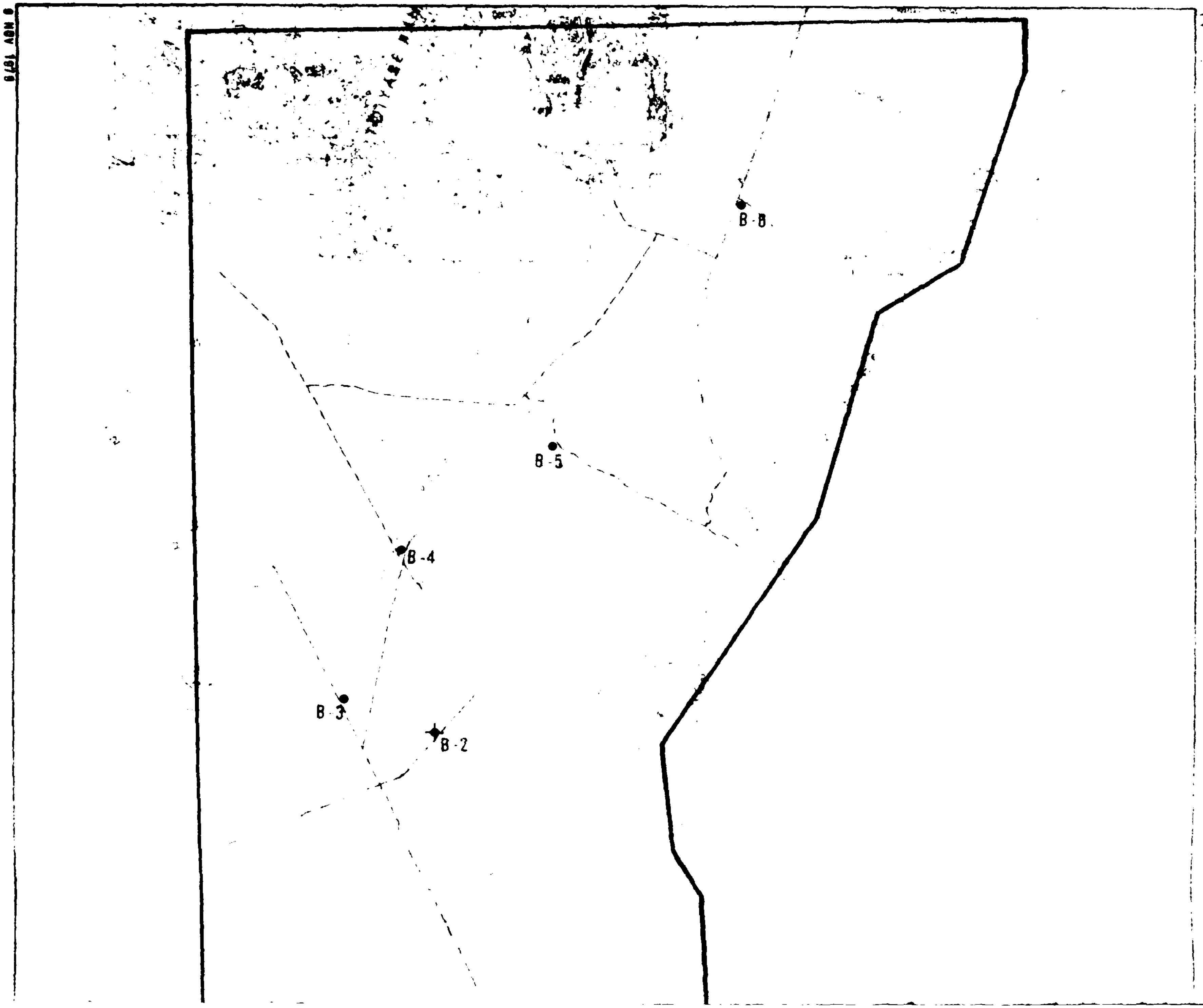
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE
1-2

FUGRO NATIONAL, INC.

2



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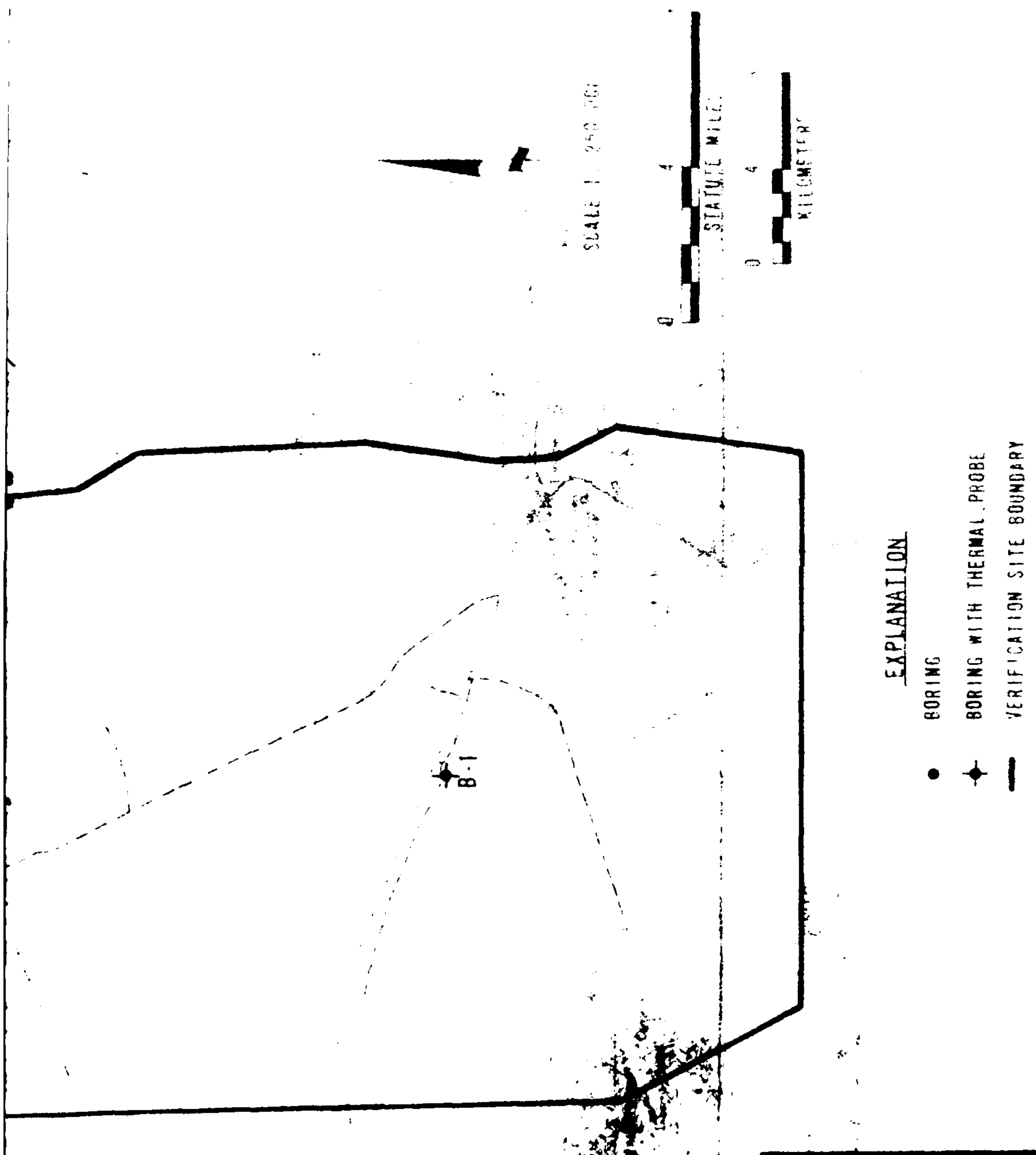


BORING LOCATION MAP
BIG SMOKY CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
1-3

FUGRO NATIONAL, INC.

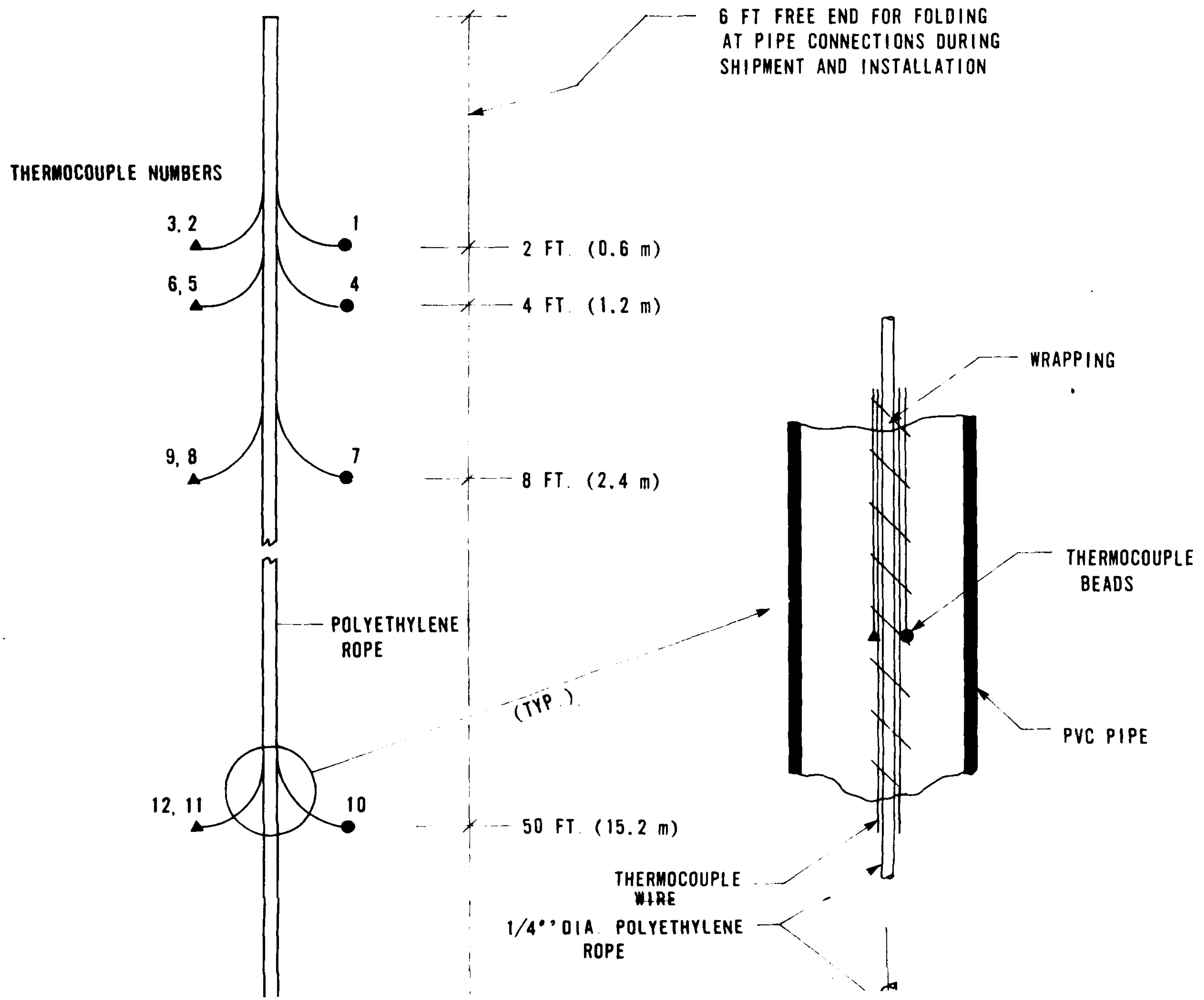
2

2.0 IN SITU SOIL TEMPERATURES

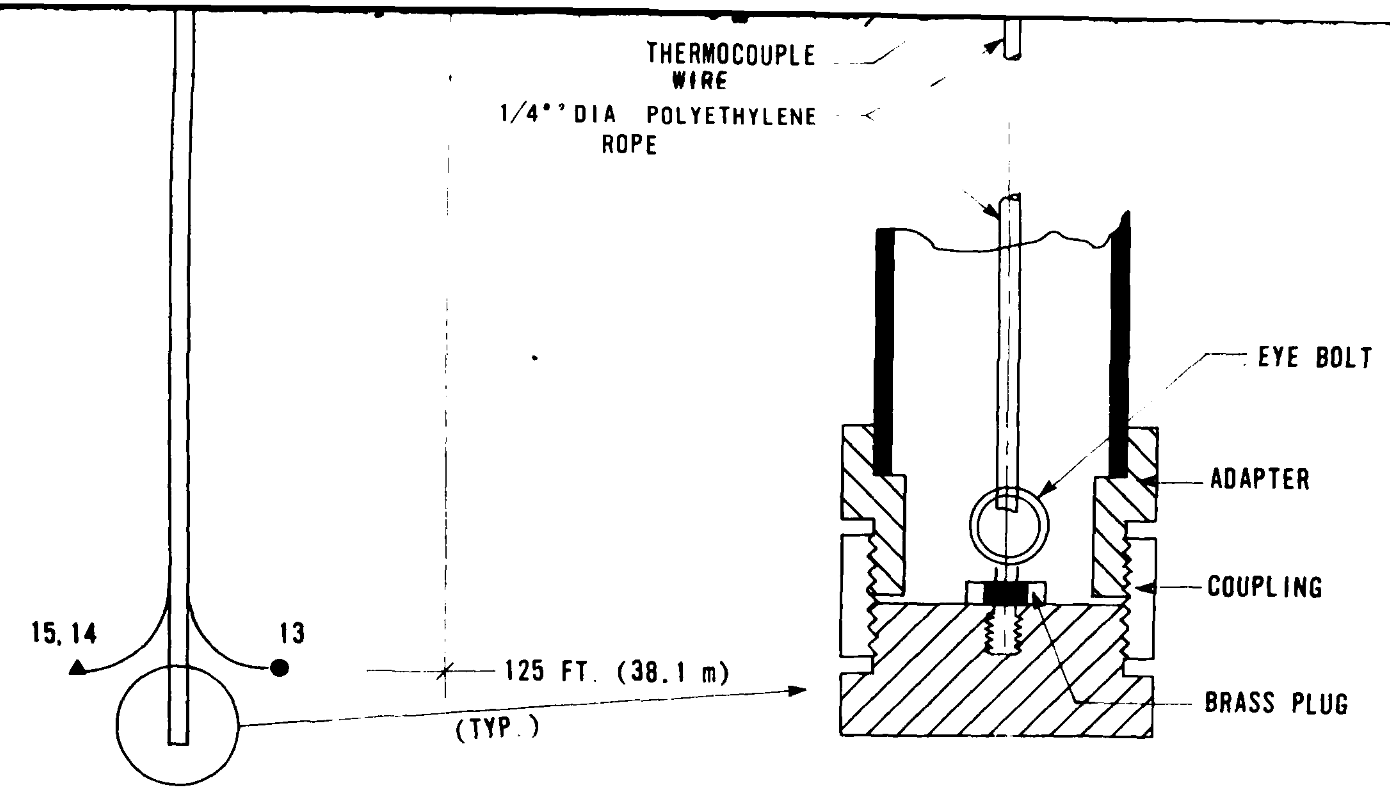
In order to measure in situ soil temperatures at various depths below ground surface, thermal probes consisting of thermocouples at various intervals were assembled in the laboratory, checked, transported to the field, and installed in borings. The thermocouples measured the in situ temperatures, and they were monitored periodically. Details regarding the type of thermocouples, their calibration, various components of the probe, assembly of the thermal probe, and field installation are presented in Appendix A.

2.1 THERMAL PROBE ASSEMBLY

The in situ thermal probe consisted of a string of 15 beaded thermocouples (T-type) situated at five different depths in groups of three each. The thermocouples were placed at depths of 2, 4, 8, 50, and 125 feet (0.6, 1.2, 2.4, 15.2, and 38.1 m) below ground surface. Of the three thermocouples at each depth, two were branched and one was single. In order to protect the assembly from damage during installation, the string was placed inside a series of unconnected 10-foot (3-m) sections of PVC pipe [0.75-inch (19-mm) diameter] with compression couplings. The details of the assembly are shown in Figure 2-1. The assembled thermocouple string was folded back and forth to facilitate transportation to the field.


6 FT FREE END FOR FOLDING AT PIPE CONNECTIONS DURING SHIPMENT AND INSTALLATION
THERMOCOUPLE NUMBERS
3, 2
1
2 FT. (0.6 m)
6, 5
4
4 FT. (1.2 m)
9, 8
7
8 FT. (2.4 m)
POLYETHYLENE ROPE
(TYP.)
12, 11
10
50 FT. (15.2 m)
WRAPPING
THERMOCOUPLE BEADS
PVC PIPE
THERMOCOUPLE WIRE
1/4'' DIA. POLYETHYLENE ROPE

2



SYMBOL	THERMOCOUPLE TYPE
●	SINGLE
▲	BRANCHED

NOT TO SCALE

TYPICAL THERMAL PROBE ASSEMBLY
REVEILLE-RAILROAD AND BIG SMOKY CDPs. NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
2-1

FUGRO NATIONAL, INC.

2.2 INSTALLATION OF THERMAL PROBES

2.2.1 Drilling of Borings

Before installation of thermal probes, borings were drilled to the required depth using a Failing 1500 drill rig with hydraulic pulldown and rotary wash techniques. The borings were 4-7/8 inches (124 mm) in diameter, and a bentonite slurry was used to stabilize the hole. Soil samples at various intervals were obtained from these borings. Both relatively undisturbed [Fugro Drive samples; 2.5-inch (64-mm) diameter] and undisturbed [Pitcher samples; 2.87-inch (73-mm) diameter] soil samples were obtained for laboratory testing. Seven borings in Reveille-Railroad CDP and six borings in Big Smoky CDP were drilled.

Drilling procedures, sampling techniques, field visual soil classification, and logging procedures are presented in Appendix B. In addition, logs of all the borings drilled in the two CDPs are also included in Appendix B.

2.2.2 Field Installation

Upon completion of drilling, the borings were flushed with water until the return water was clear. The thermal probe was assembled section-by-section using pressure couplings and lowered into the boring until the bottom of the probe was 125 feet (38.1 m) below the ground surface. The annular space between the PVC pipe and the wall of the boring was backfilled with Monterey No. 1 sand by pouring it from the sacks. The top 10 feet of the boring was backfilled with native soil. The lead wires of the thermocouples were then connected to a junction box at the ground surface. A manhole with cover was installed around the junction box and both structures were sealed with concrete. A schematic drawing of a typical thermal probe installation is shown in Figure 2-2. The details of the field installation procedures are included in Appendix A.

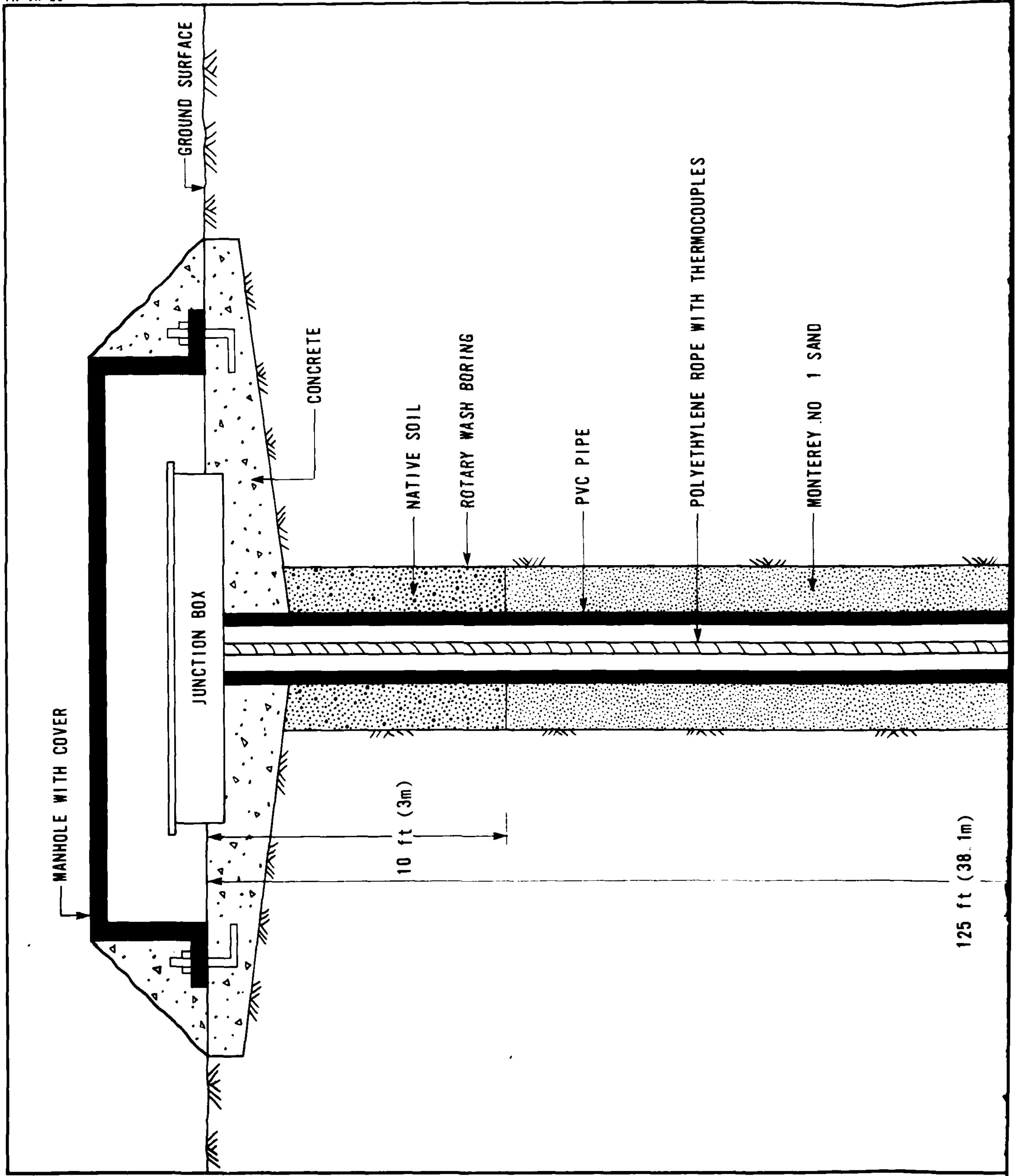
2.3 RESULTS

Using a digital readout unit, the thermocouples were read daily for a few days following the installation of the thermal probes. After thermal equilibrium was reached (approximately one week after installation), the in situ soil temperatures were measured at intervals of approximately one month. The thermal probe in Reveille-Railroad CDP is identified as RR-B-3A, and the two probes in Big Smoky CDP are identified as BS-B-1 and BS-B-2.

The in situ soil temperatures measured by the three probes from April to November 1979 are presented in Table 2-1. Plots of soil temperatures, as a function of time for the three probes, are presented in Figures 2-3, 2-4, and 2-5. A review of these plots indicate that:

1. Soil temperatures at depths of 2, 4, and 8 feet (0.6, 1.2, and 2.4 m) are affected by the seasonal changes in air temperatures;
2. Soil temperatures at depths of 50 and 125 feet (15.2 and 38.1 m) are not affected by seasonal changes in air temperatures; and

FN-TR-29



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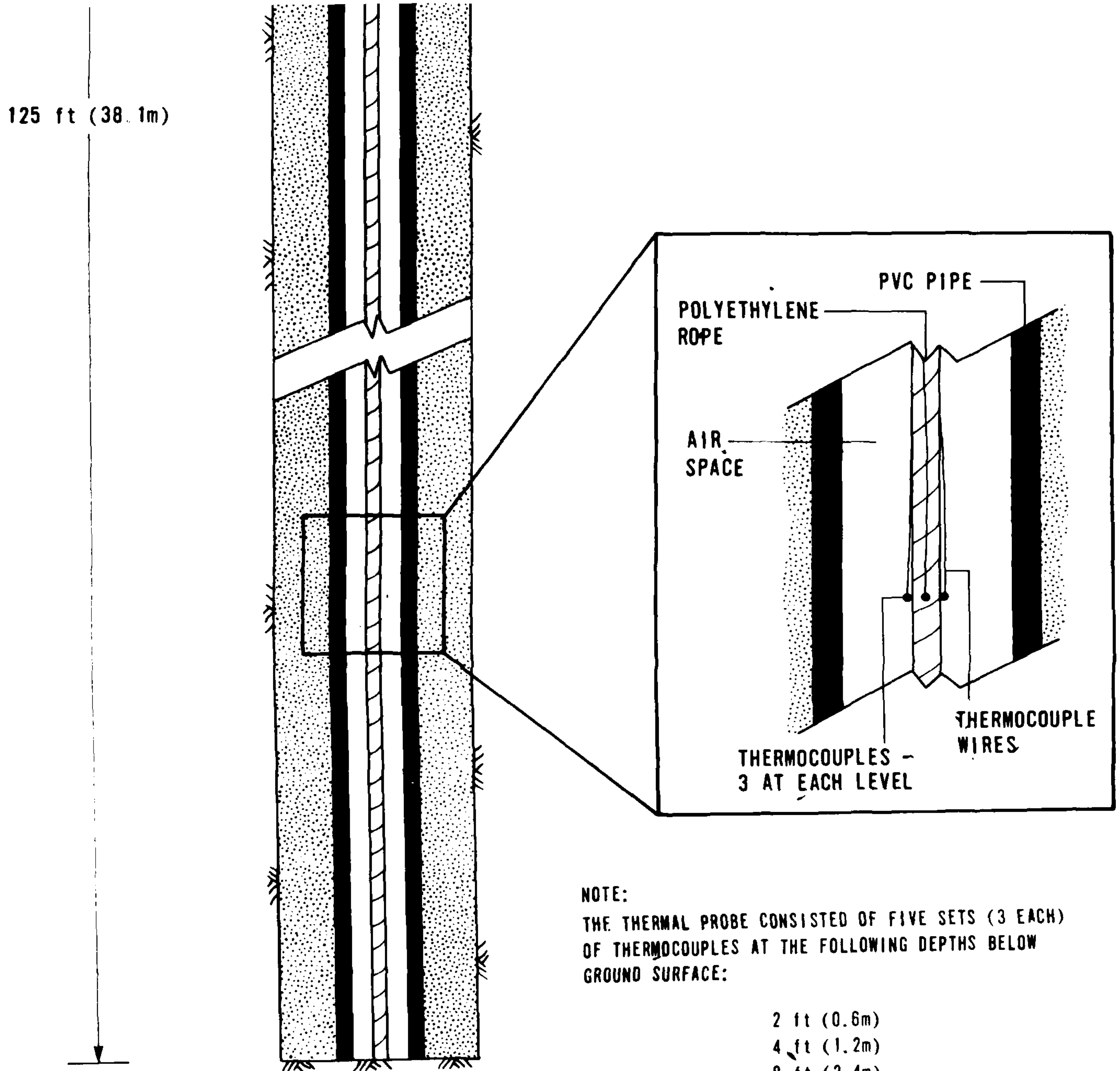

* NOT TO SCALE

NOTE:
THE THERMAL PROBE CONSISTED OF FIVE SETS (3 EACH) OF THERMOCOUPLES AT THE FOLLOWING DEPTHS BELOW GROUND SURFACE:

2 ft (0.6m)
4 ft (1.2m)
8 ft (2.4m)
50 ft (15.2m)
125 ft (38.1m)

TYPICAL THERMAL PROBE INSTALLATION
REVEILLE-RAILROAD AND
BIG SMOKY CDPS, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
2-2

FUGRO NATIONAL, INC.

THERMAL PROBE NUMBER	DATE AND TIME OF READINGS	TEMPERATURE,* °F					
		AIR	DEPTH BELOW GROUND SURFACE				
			2 ft (0.6m)	4 ft (1.2m)	8 ft (2.4m)	50 ft (15.2m)	125 ft (38.1m)
RR-B-3A	8 APR 79/3:40 PM	NDA	51.2	47.2	48.1	58.5	61.0
	20 APR 79/2:50 PM	NDA	53.4	50.8	49.1	59.2	61.5
DATE OF INSTALLATION	9 MAY 79/11:00 AM	54.2	58.6	55.5	51.0	58.6	61.0
4 APRIL 1979	6 JUN 79/12:20 PM	95.7	69.2	63.5	55.6	58.8	61.3
	10 JUL 79/12:30 PM	97.2	75.9	70.1	61.2	58.8	61.2
	7 AUG 79/3:05 PM	94.5	81.8	75.7	65.2	58.9	61.2
	2 SEP 79/12:30 PM	84.0	75.0	72.3	66.9	59.2	61.5
	5 OCT 79/5:00 PM	62.9	69.8	69.7	67.3	58.9	61.3
	10 NOV 79/3:30 PM	51.1	53.6	59.4	64.8	59.3	61.6
BS-B-1	10 APR 79/6:20 PM	NDA	52.2	49.1	50.1	59.4	63.4
	22 APR 79/6:25 AM	NDA	52.8	50.4	50.1	59.2	63.2
DATE OF INSTALLATION	9 MAY 79/3:30 PM	55.5	57.9	55.4	51.8	59.4	63.5
5 APRIL 1979	7 JUN 79/6:30 AM	57.2	70.0	62.9	55.5	59.4	63.3
	11 JUL 79/12:30 PM	86.3	75.5	69.1	60.6	59.4	63.3
	7 AUG 79/8:45 AM	73.1	80.8	73.6	63.9	59.5	63.4
	1 SEP 79/4:00 PM	84.0	73.4	71.1	65.5	59.4	63.3
	5 OCT 79/8:40 AM	65.2	68.8	69.1	66.6	59.7	63.6
	10 NOV 79/10:20 AM	42.4	52.3	58.9	63.9	59.4	63.3
BS-B-2	11 APR 79/5:40 PM	NDA	51.3	49.6	50.4	61.4	64.4
	22 APR 79/8:30 AM	NDA	52.9	51.1	50.8	61.7	64.7
DATE OF INSTALLATION	9 MAY 79/2:00 PM	57.9	57.2	55.3	52.3	61.6	64.6
7 APRIL 1979	6 JUN 79/5:00 PM	85.0	68.7	62.3	56.2	61.4	64.6
	12 JUL 79/12:00 N	87.6	75.6	69.5	62.0	61.5	64.6
	7 AUG 79/11:15 AM	78.9	81.4	75.0	65.9	61.7	64.6
	1 SEP 79/8:30 AM	68.3	74.6	72.5	67.6	61.8	64.7
	4 OCT 79/11:50 AM	77.9	69.7	70.3	68.4	61.7	64.7
	10 NOV 79/11:30 AM	50.5	55.1	60.8	65.3	61.9	64.8

* AVERAGE OF THREE THERMOCOUPLES AT EACH DEPTH

EXPLANATION

RR-B-3A:

RR - ABBREVIATION FOR CDP
RR - REVEILLE-RAILROAD
BS - BIG SMOKY

B - ABBREVIATION FOR BORING

3A - NUMBER OF BORING

NDA - NO DATA AVAILABLE

IN SITU SOIL TEMPERATURES
REVEILLE-RAILROAD AND BIG SMOKY CDPS
NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE
2-1

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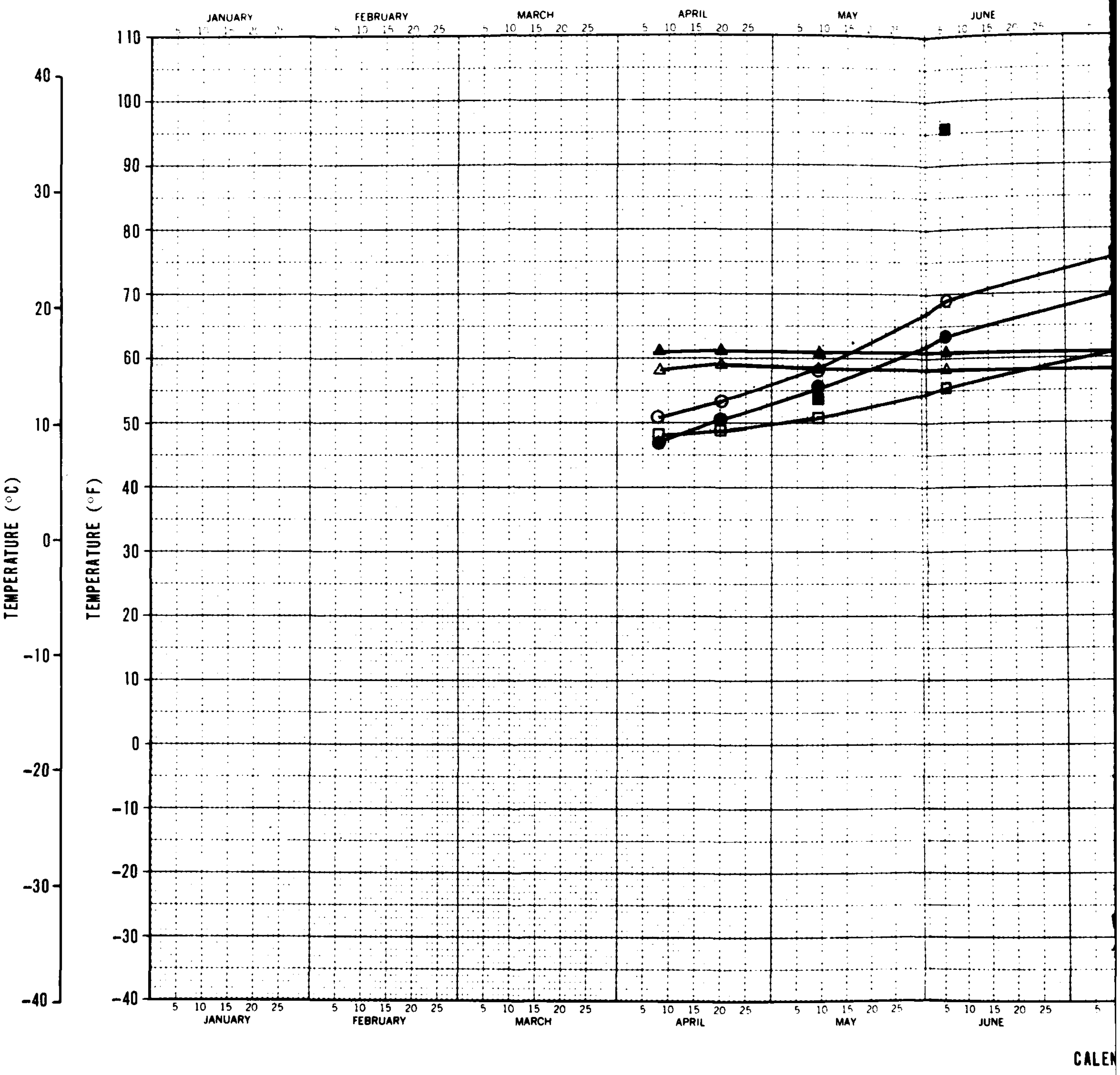
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
5 10 15 20 25
TEMPERATURE (°C)
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30
20
10
0
-10
-20
-30
-40
TEMPERATURE (°F)
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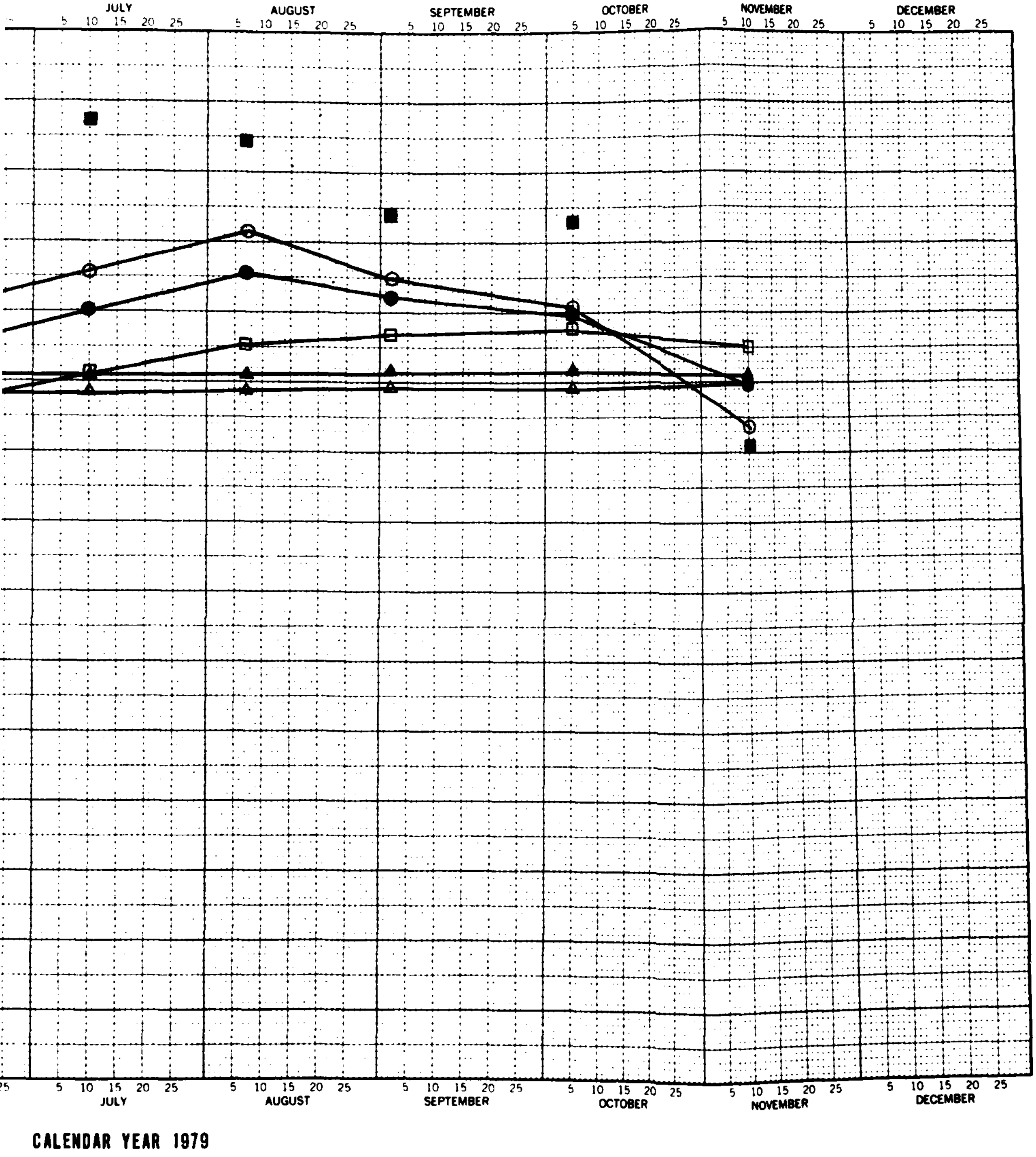

EXPLANATIO

■ AIR TEMPERATURE

○ 2 ft (0.6m)

● 4 ft (1.2m)

□ 8 ft (2.4m)

△ 50 ft (15.2m)

▲ 125 ft (38.1m)

NOTE:

SOIL TEMPERATURES SHOW
VALUES OF THREE THERMOC
EACH DEPTH

SOIL TEMPERATUR
THERMAL PROBE R
REVEILLE-RAILROAD C

MX SITING INVESTIGATI
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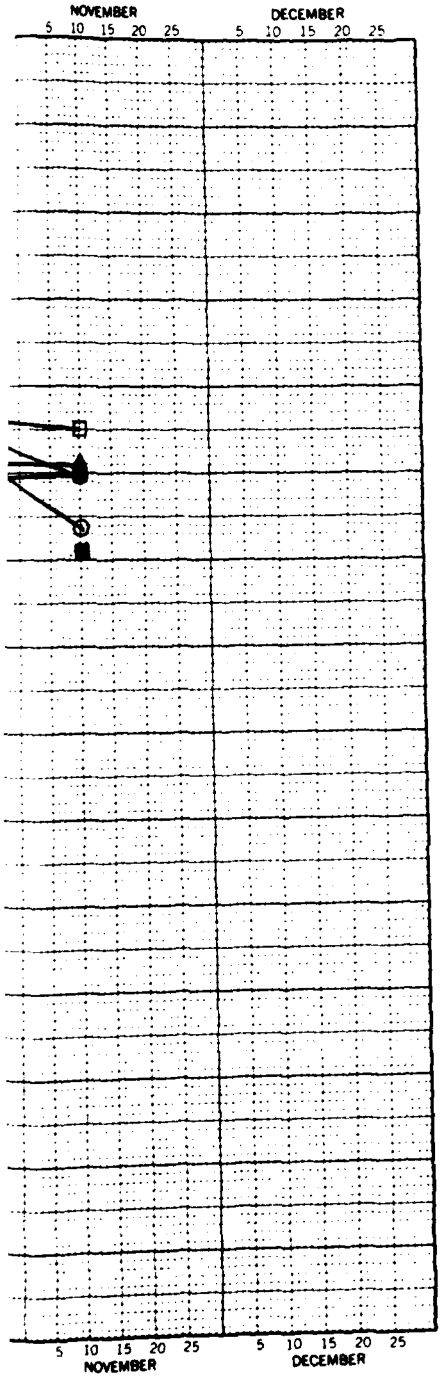
2



EXPLANATION

■ AIR TEMPERATURE

○ 2 ft (0.6m)

● 4 ft (1.2m)

□ 8 ft (2.4m)

△ 50 ft (15.2m)

▲ 125 ft (38.1m)

DEPTH BELOW GROUND SURFACE

NOTE.

SOIL TEMPERATURES SHOWN ARE AVERAGE VALUES OF THREE THERMOCOUPLES AT EACH DEPTH

SOIL TEMPERATURE PLOT
THERMAL PROBE RR-B-3A
REVEILLE-RAILROAD COP, NEVADA

MX SITING INVESTIGATION
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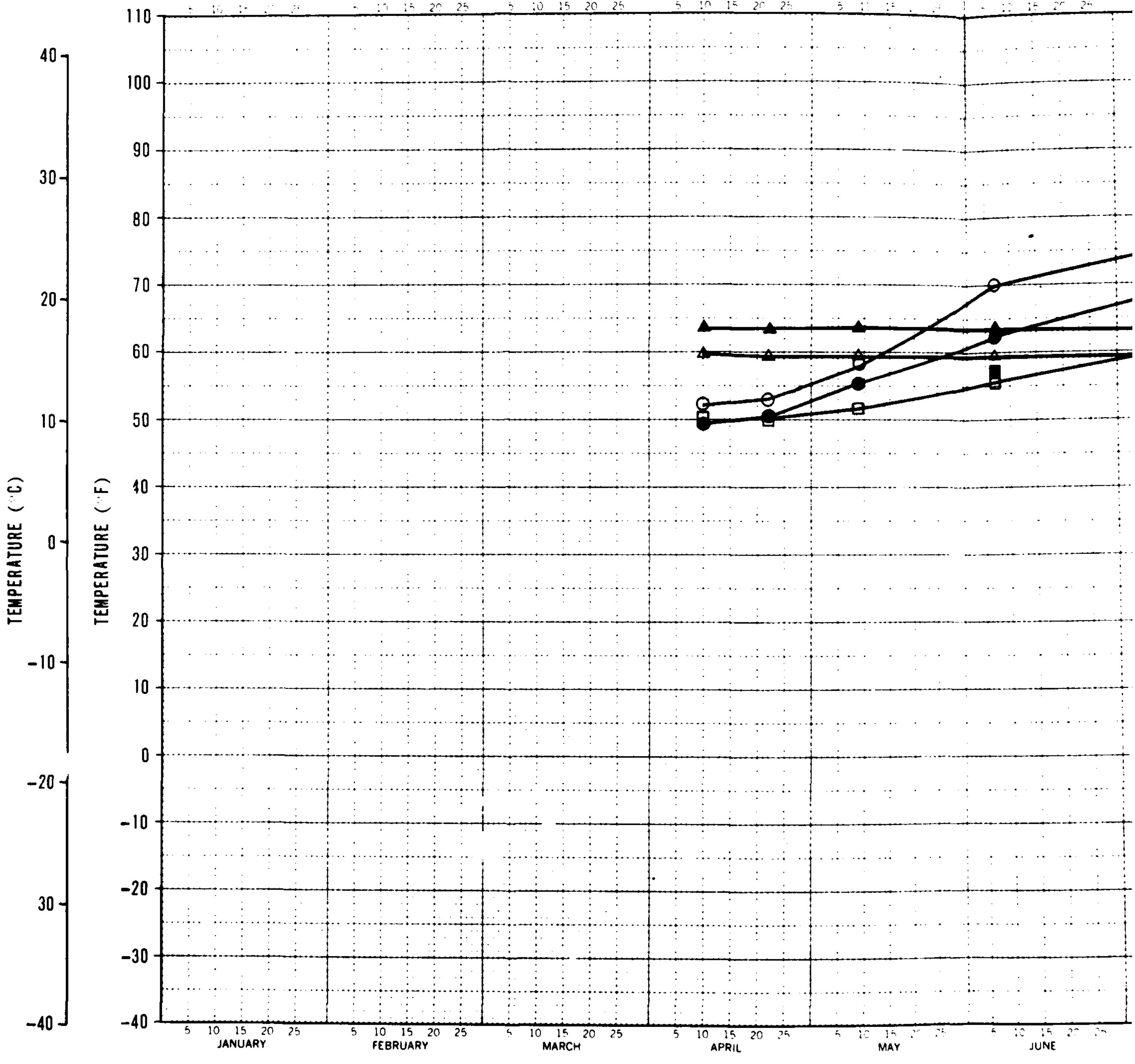
FIGURE
2-3

FUGRO NATIONAL, INC.

3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TEMPERATURE (°C)
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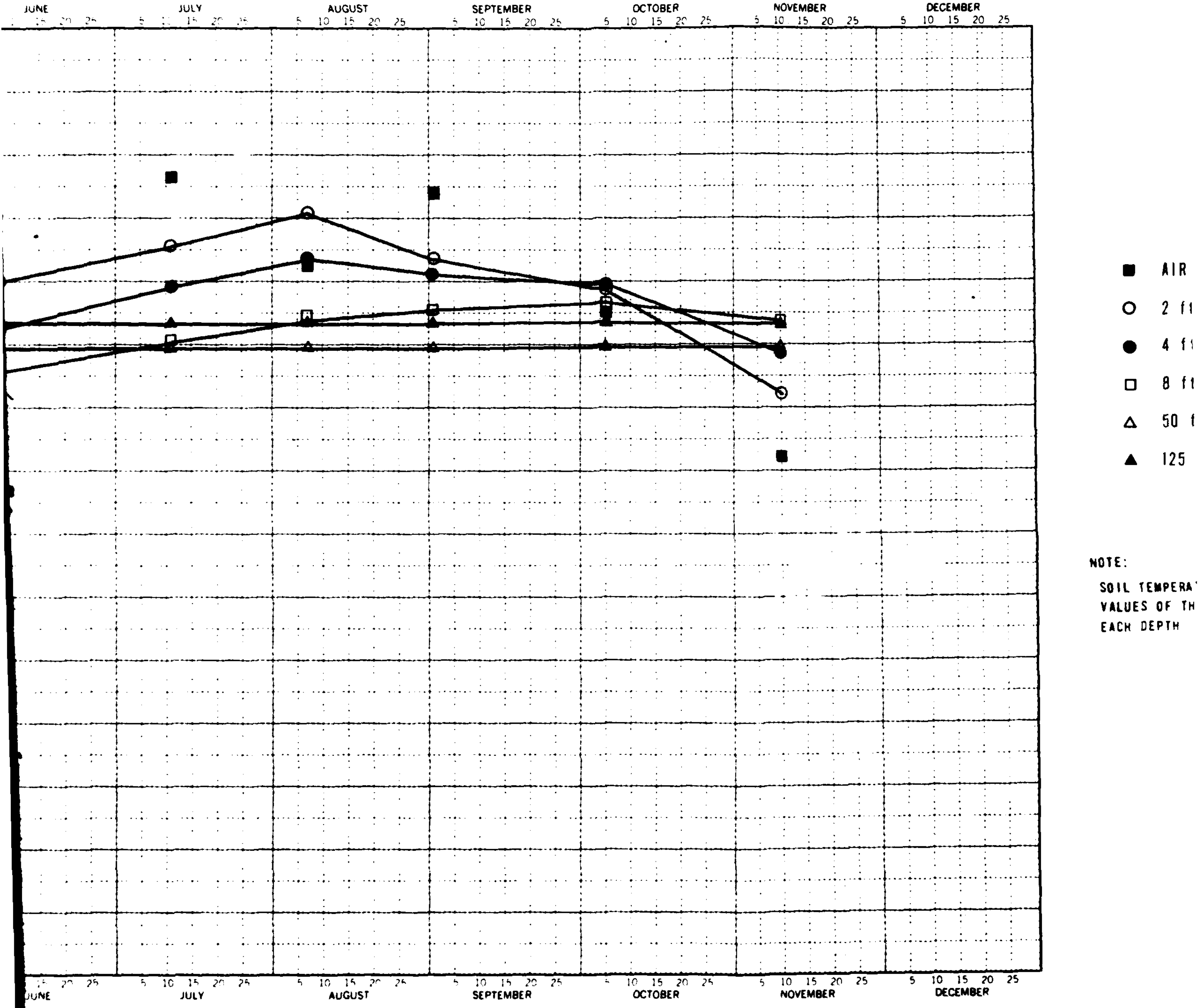

NOTE:

SOIL TEMPERA
VALUES OF TH
EACH DEPTH

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THER
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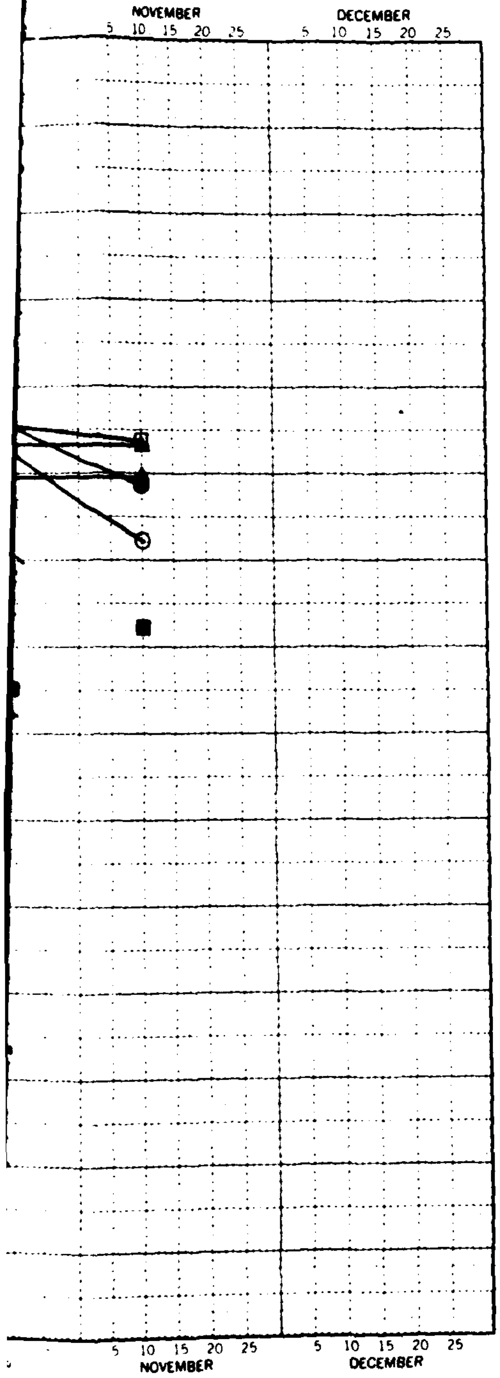


EXPLANATION

- ■ AIR TEMPERATURE
- ○ 2 ft (0.6m)
- ● 4 ft (1.2m)
- □ 8 ft (2.4m)
- △ 50 ft (15.2m)
- ▲ 125 ft (38.1m)

DEPTH BELOW GROUND SURFACE

NOTE:

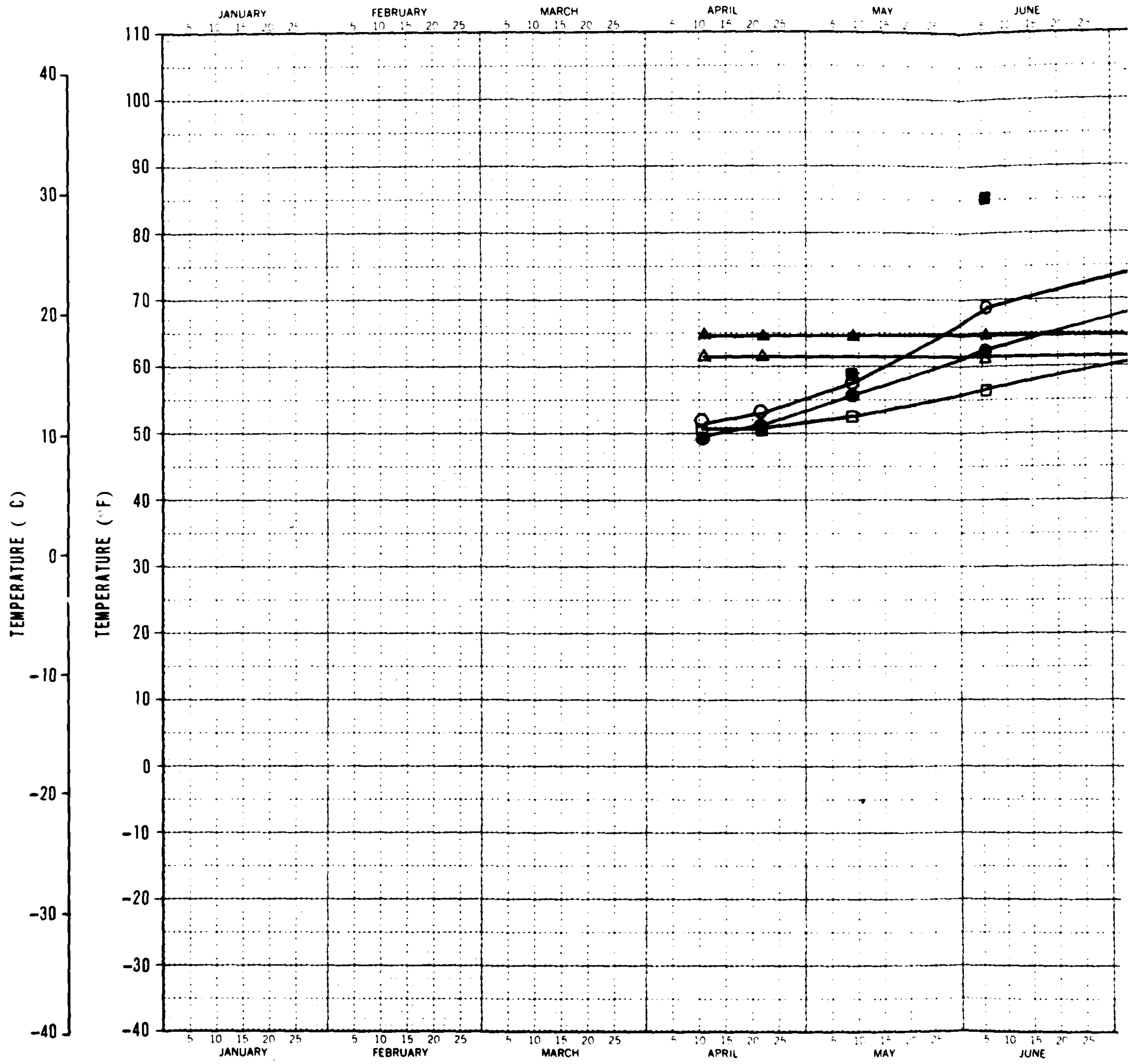
SOIL TEMPERATURES SHOWN ARE AVERAGE VALUES OF THREE THERMOCOUPLES AT EACH DEPTH

SOIL TEMPERATURE PLOT
THERMAL PROBE BS-B-1
BIG SMOKY CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
2-4

FUGRO NATIONAL, INC.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TEMPERATURE (°C)
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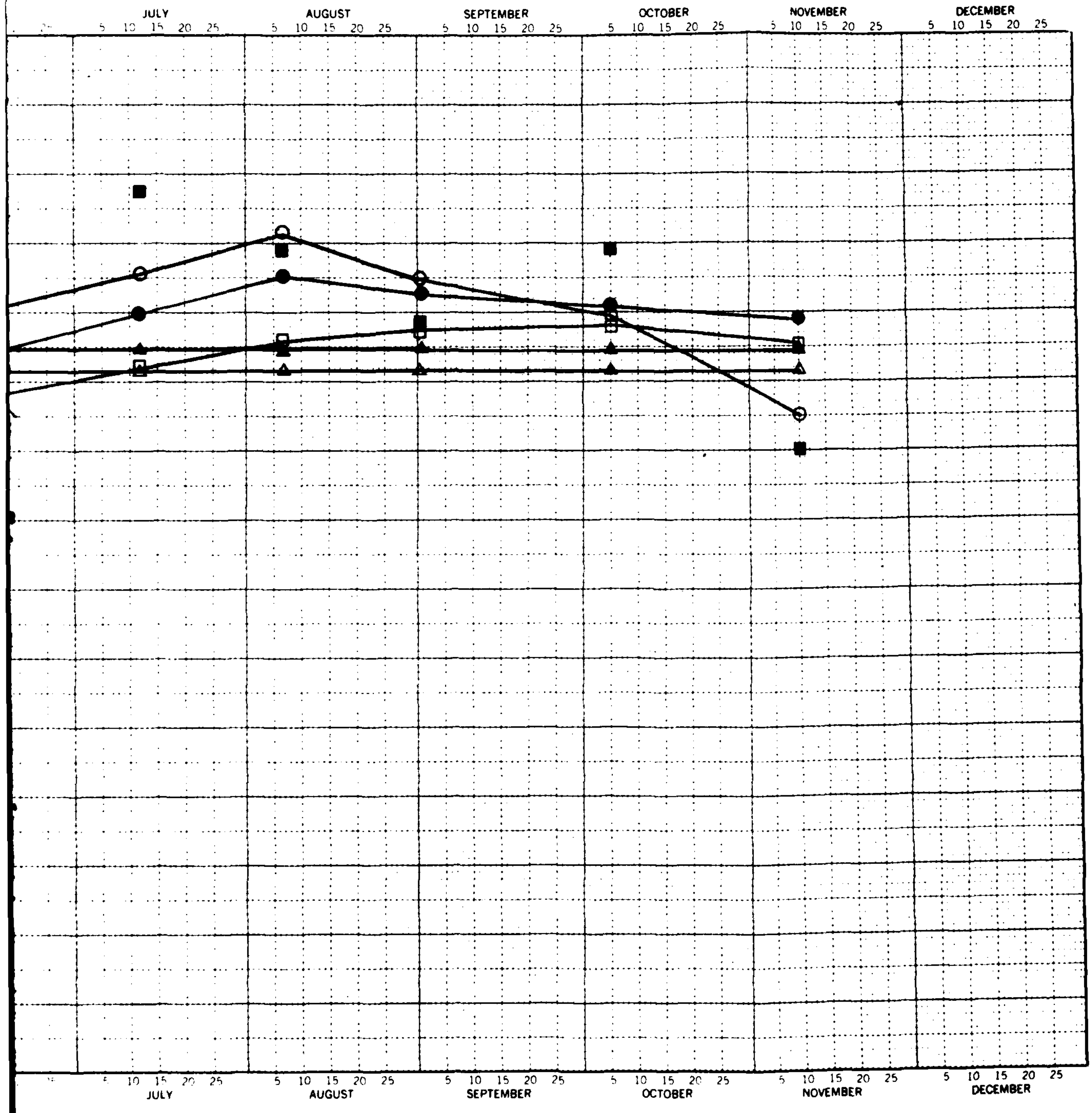


CALENDAR YEAR 1979

EXPL

■ AIR TEMPE

○ 2 ft (0.6

● 4 ft (1 2

□ 8 ft (2.4

△ 50 ft (15

▲ 125 ft (3

NOTE

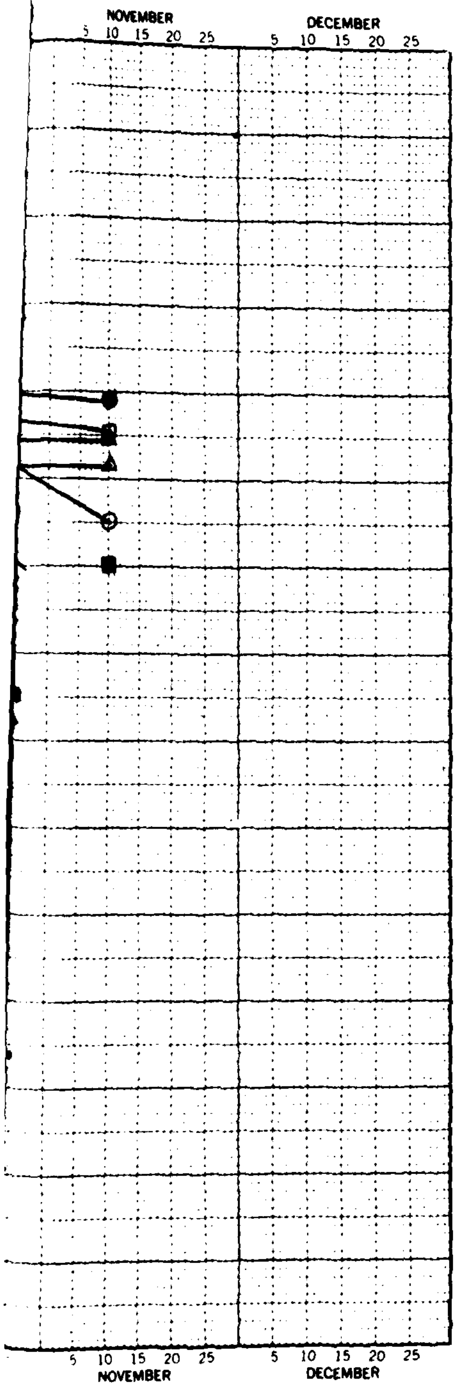
SOIL TEMPERATURE
VALUES OF THREE
EACH DEPTH

SOIL TEMP
THERMAL
BIG SMOKY

MX SITING INVES
DEPARTMENT OF THE AIR

FUGRO NA

2



EXPLANATION

■ AIR TEMPERATURE

DEPTH BELOW GROUND SURFACE:
- ○ 2 ft (0.6m)
- ● 4 ft (1.2m)
- □ 8 ft (2.4m)
- △ 50 ft (15.2m)
- ▲ 125 ft (38.1m)

NOTE

SOIL TEMPERATURES SHOWN ARE AVERAGE VALUES OF THREE THERMOCOUPLES AT EACH DEPTH

SOIL TEMPERATURE PLOT
THERMAL PROBE BS-B-2
BIG SMOKY CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
2-5

FUGRO NATIONAL, INC.

3. A temperature reversal between depths of 50 and 125 feet takes place, i.e., temperature at 125 feet is higher than the temperature at 50 feet by about 2.2 to 4.0°F.

In addition to the monthly readings, continuous monitoring of each thermal probe over a 24-hour period was performed. The thermocouples were read once every hour during the 24-hour period. The 24-hour soil temperature readings are presented in Tables 2-2 through 2-4. Plots of the 24-hour soil temperatures, as a function of time, are shown in Figures 2-6 through 2-8. A review of these data indicates that there is minimal variation of soil temperatures at any depth over a period of 24 hours. However, during spring freeze and thaw cycles, temperatures of the soil at shallow depth may vary considerably in a 24-hour period.

DATE	TIME	TEMPERATURE,* °F					
		AIR	DEPTH BELOW GROUND SURFACE				
			2 ft (0.6m)	4 ft (1.2m)	8 ft (2.4m)	50 ft (15.2m)	125 ft (38.1m)
10 JULY 1979	5:30 AM	53.3	76.0	70.2	61.3	59.1	61.3
	6:30	62.3	76.1	70.3	61.4	59.1	61.3
	7:30	73.6	76.1	70.4	61.5	59.2	61.4
	8:30	84.0	76.0	70.4	61.5	59.2	61.4
	9:30	84.0	76.0	70.2	61.3	59.1	61.3
	10:30	87.9	76.1	70.2	61.4	59.0	61.3
	11:30	91.4	75.9	70.1	61.3	58.9	61.3
	12:30	97.2	75.8	70.1	61.2	58.8	61.3
	13:30 PM	99.2	75.8	70.0	61.1	58.8	61.2
	14:30	98.3	75.8	70.0	61.1	58.6	61.2
	15:30	103.6	75.7	69.9	61.0	58.7	61.0
	16:30	97.2	75.7	69.9	61.0	58.5	60.9
	17:30	94.6	75.7	70.0	61.0	58.6	61.0
	18:30	93.5	75.8	70.0	61.1	58.6	61.0
	19:30	89.2	75.9	70.0	61.2	58.7	61.0
	20:30	78.8	76.0	70.1	61.3	58.8	61.1
	21:30	72.8	76.1	70.2	61.3	58.9	61.2
	22:30	68.0	76.2	70.3	61.4	59.0	61.3
	23:30	72.4	76.3	70.4	61.4	59.0	61.3
11 JULY 1979	00:30 AM	63.0	76.3	70.4	61.5	59.1	61.3
	1:30	62.0	76.4	70.4	61.6	59.1	61.4
	2:30	59.9	76.3	70.4	61.6	59.2	61.3
	3:30	64.7	76.3	70.4	61.5	59.1	61.3
	4:30	61.1	76.3	70.4	61.5	59.1	61.3
	5:30	58.2	76.3	70.4	61.5	59.0	61.3

* AVERAGE OF THREE THERMOCOUPLES AT EACH DEPTH

24-HOUR SOIL TEMPERATURES
THERMAL PROBE NO. RR-B-3A
REVEILLE-RAILROAD CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE
2-2

FUGRO NATIONAL, INC.

9 NOV 1979

DATE	TIME	TEMPERATURE,* °F					
		AIR	DEPTH BELOW GROUND SURFACE				
			2 ft (0.6m)	4 ft (1.2m)	8 ft (2.4m)	50 ft (15.2m)	125 ft (38.1m)
11 JULY 1979	9:30 AM	78.4	75.6	69.2	69.6	59.5	63.4
	10:30	81.1	75.5	69.1	60.6	59.5	63.4
	11:30	87.3	75.6	69.1	60.6	59.5	63.4
	12:30	86.3	75.5	69.1	60.6	59.4	63.3
	13:30 PM	88.2	75.5	69.1	60.5	59.4	63.3
	14:30	89.4	75.5	69.1	60.5	59.4	63.3
	15:30	89.4	75.5	69.1	60.5	59.3	63.3
	16:30	89.0	75.5	69.1	60.5	59.3	63.3
	17:30	89.1	75.6	69.1	60.5	59.3	63.3
	18:30	87.8	75.6	69.1	60.5	59.3	63.3
	19:30	83.5	75.7	69.1	60.6	59.3	63.3
	20:30	79.7	75.7	69.2	60.6	59.4	63.3
	21:30	76.5	75.7	69.2	60.6	59.4	63.3
	22:30	72.7	75.7	69.2	60.6	59.4	63.3
	23:30	68.5	75.7	69.3	60.7	59.5	63.3
12 JULY 1979	00:30 AM	66.9	75.7	69.3	60.6	59.4	63.3
	1:30	63.7	75.7	69.3	60.6	59.4	63.3
	2:30	58.5	75.7	69.2	60.6	59.4	63.3
	3:30	59.1	75.7	69.3	60.6	59.4	63.3
	4:30	57.0	75.7	69.2	60.6	59.4	63.3
	5:30	56.2	75.7	69.2	60.6	59.3	63.3
	6:30	66.2	75.7	69.3	60.7	59.4	63.3
	7:30	72.0	75.7	69.4	60.8	59.5	63.4
	8:30	78.4	75.7	69.4	60.9	59.6	63.5
	9:30	82.8	75.7	69.5	60.8	59.5	63.4

* AVERAGE OF THREE THERMOCOUPLES AT EACH DEPTH

24-HOUR SOIL TEMPERATURES
THERMAL PROBE NO. BS-B-1
BIG SMOKY CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE
2-3

FUGRO NATIONAL, INC.

DATE	TIME	TEMPERATURE,* °F					
			DEPTH BELOW GROUND SURFACE				
		AIR	2 ft (0.6m)	4 ft (1.2m)	8 ft (2.4m)	50 ft (15.2m)	125 ft (38.1m)
12 JULY 1979	11:00 AM	85.4	75.6	69.5	62.0	61.5	64.6
	12:00	87.6	75.6	69.5	62.0	61.5	64.6
	13:00 PM	91.2	75.6	69.6	62.0	61.5	64.6
	14:00	89.1	75.6	69.5	62.0	61.4	64.6
	15:00	87.7	75.6	69.5	61.9	61.4	64.5
	16:00	92.7	75.5	69.4	61.9	61.4	64.5
	17:00	91.7	75.5	69.4	61.9	61.3	64.5
	18:00	89.5	75.5	69.5	61.9	61.4	64.6
	19:00	86.9	75.6	69.5	62.0	61.4	64.5
	20:00	82.7	75.6	69.6	62.0	61.4	64.5
	21:30	77.7	75.7	69.7	62.1	61.6	64.6
	22:30	74.1	75.7	69.7	62.1	61.6	64.6
	23:30	71.1	75.7	69.8	62.0	61.6	64.6
13 JULY 1979	00:30 AM	68.7	75.7	69.8	62.0	61.6	64.6
	1:30	66.3	75.7	69.8	62.0	61.6	64.6
	2:30	63.7	75.7	69.8	62.1	61.6	64.6
	3:30	61.1	75.7	69.8	62.1	61.6	64.6
	4:30	59.9	75.7	69.8	62.2	61.5	64.6
	5:30	58.2	75.7	69.8	62.1	61.6	64.6
	6:30	61.7	75.8	69.9	62.1	61.6	64.6
	7:30	73.2	76.0	70.1	62.3	61.8	64.8
	8:30	79.4	75.8	70.0	62.3	62.0	64.7
	9:30	85.2	75.7	69.8	62.2	61.6	64.6
	10:30	85.1	75.7	69.8	62.1	61.6	64.6
	11:00	86.9	75.7	69.8	62.1	61.6	64.6

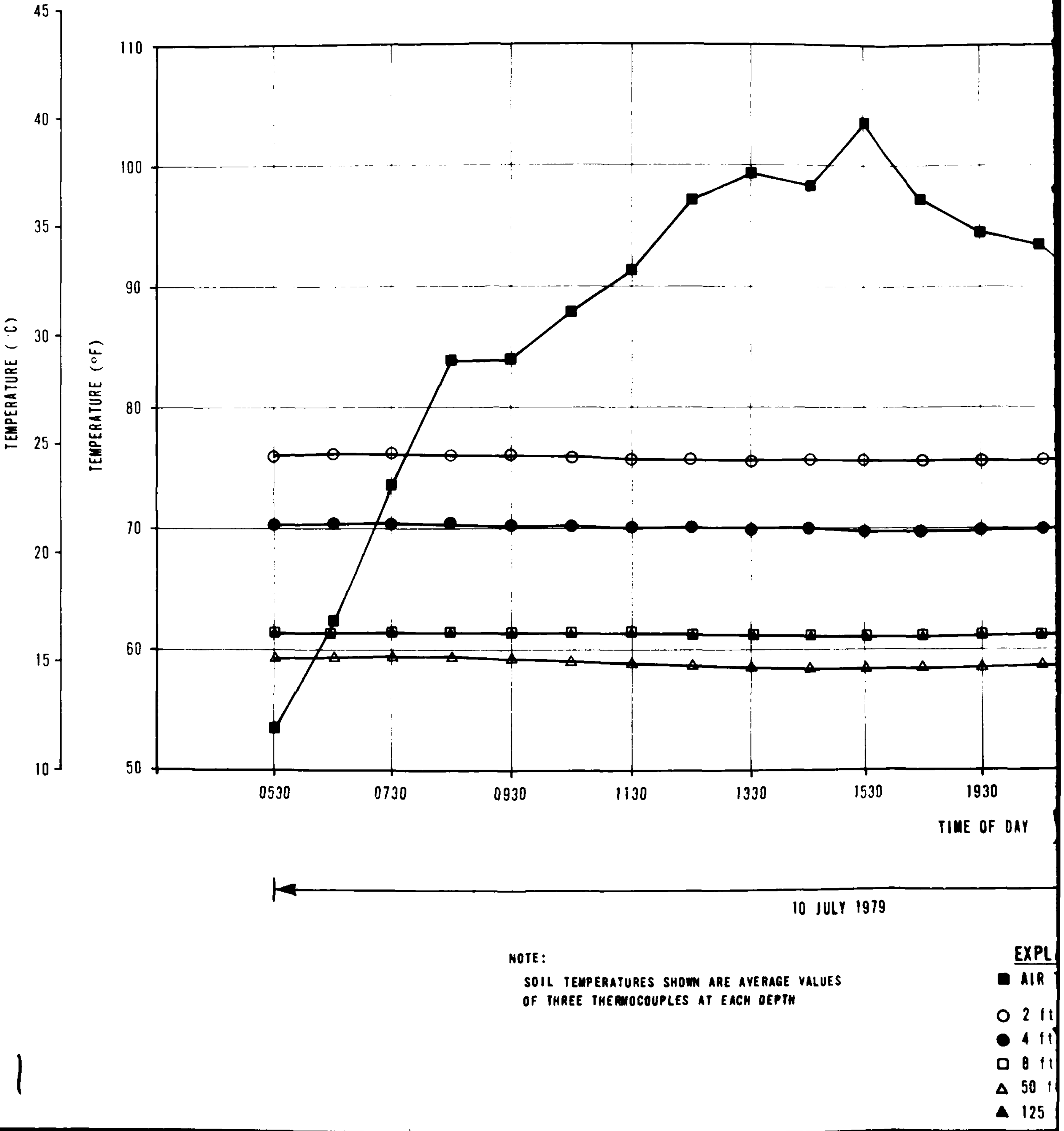
* AVERAGE OF THREE THERMOCOUPLES AT EACH DEPTH

24-HOUR SOIL TEMPERATURES
THERMAL PROBE NO. BS-B-2
BIG SMOKY CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

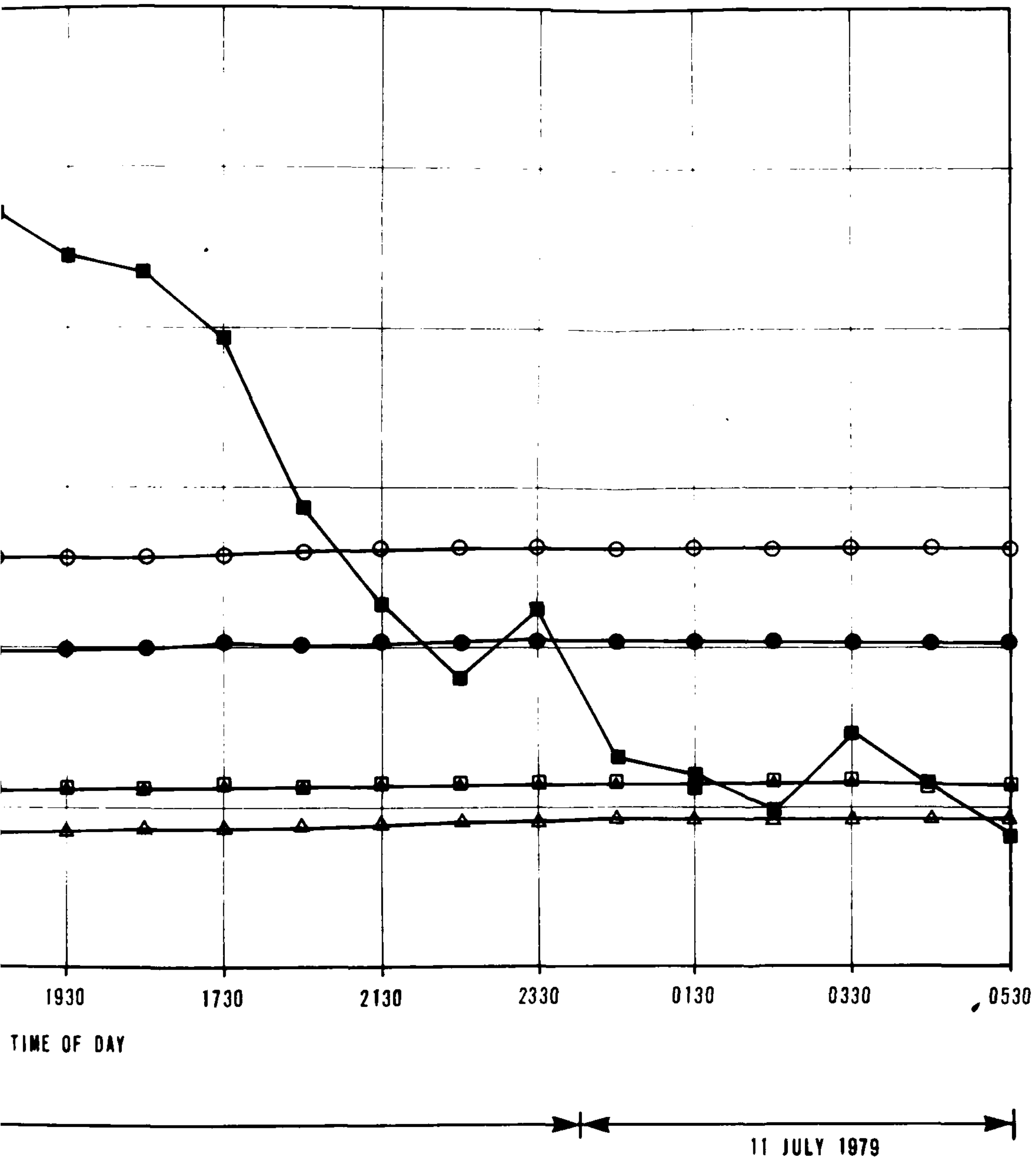
TABLE
2-4

FUGRO NATIONAL, INC.



NOTE:

SOIL TEMPERATURES SHOWN ARE AVERAGE VALUES OF THREE THERMOCOUPLES AT EACH DEPTH



EXPLANATION

■ AIR TEMPERATURE

○ 2 ft (0.6m)
● 4 ft (1.2m)
□ 8 ft (2.4m)
△ 50 ft (15.2m)
▲ 125 ft (38.1m)

DEPTH
BELOW
GROUND
SURFACE

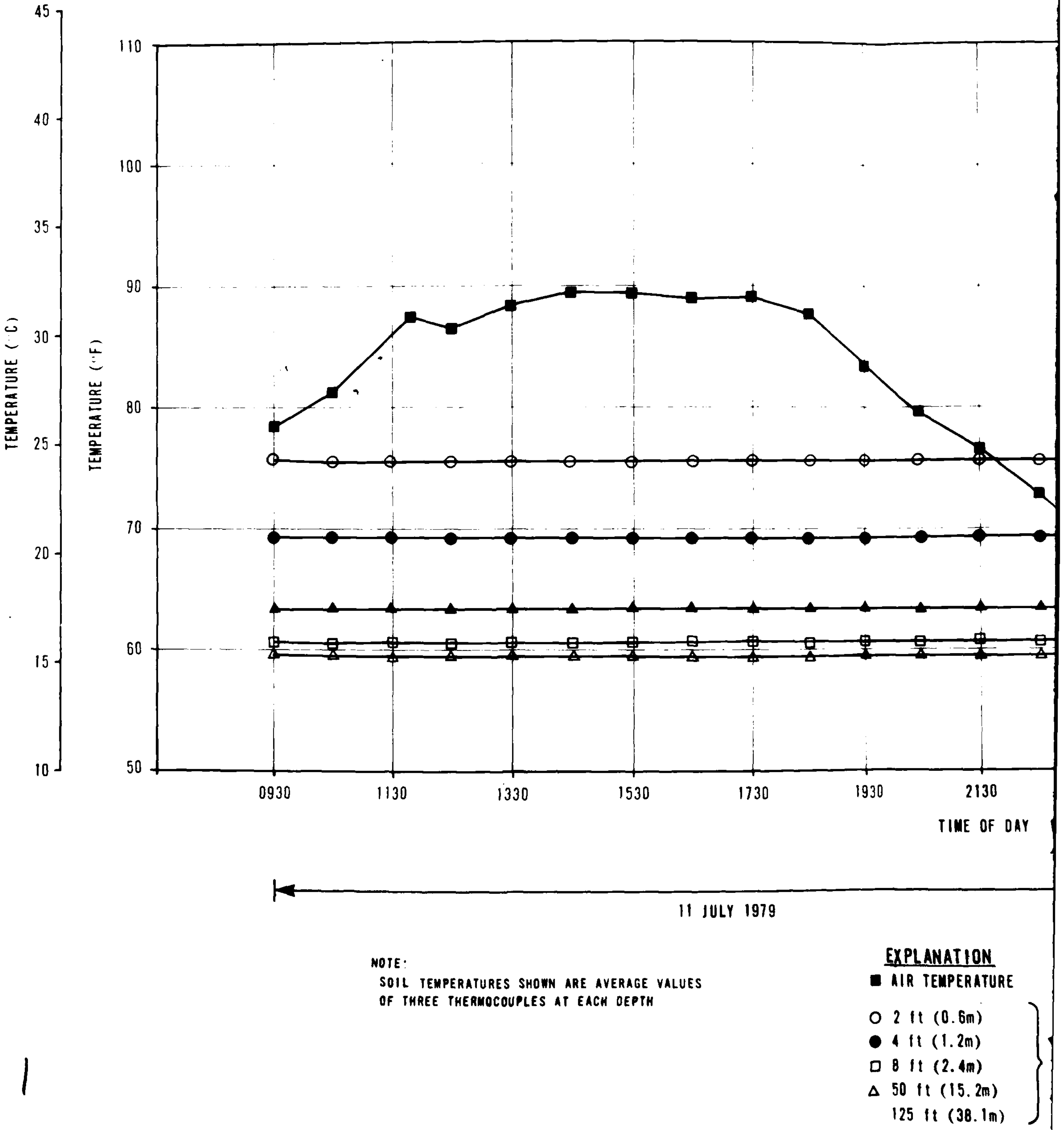
24-HOUR SOIL TEMPERATURE PLOTS
THERMAL PROBE NO. RR-B-3A
REVEILLE-RAILROAD CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

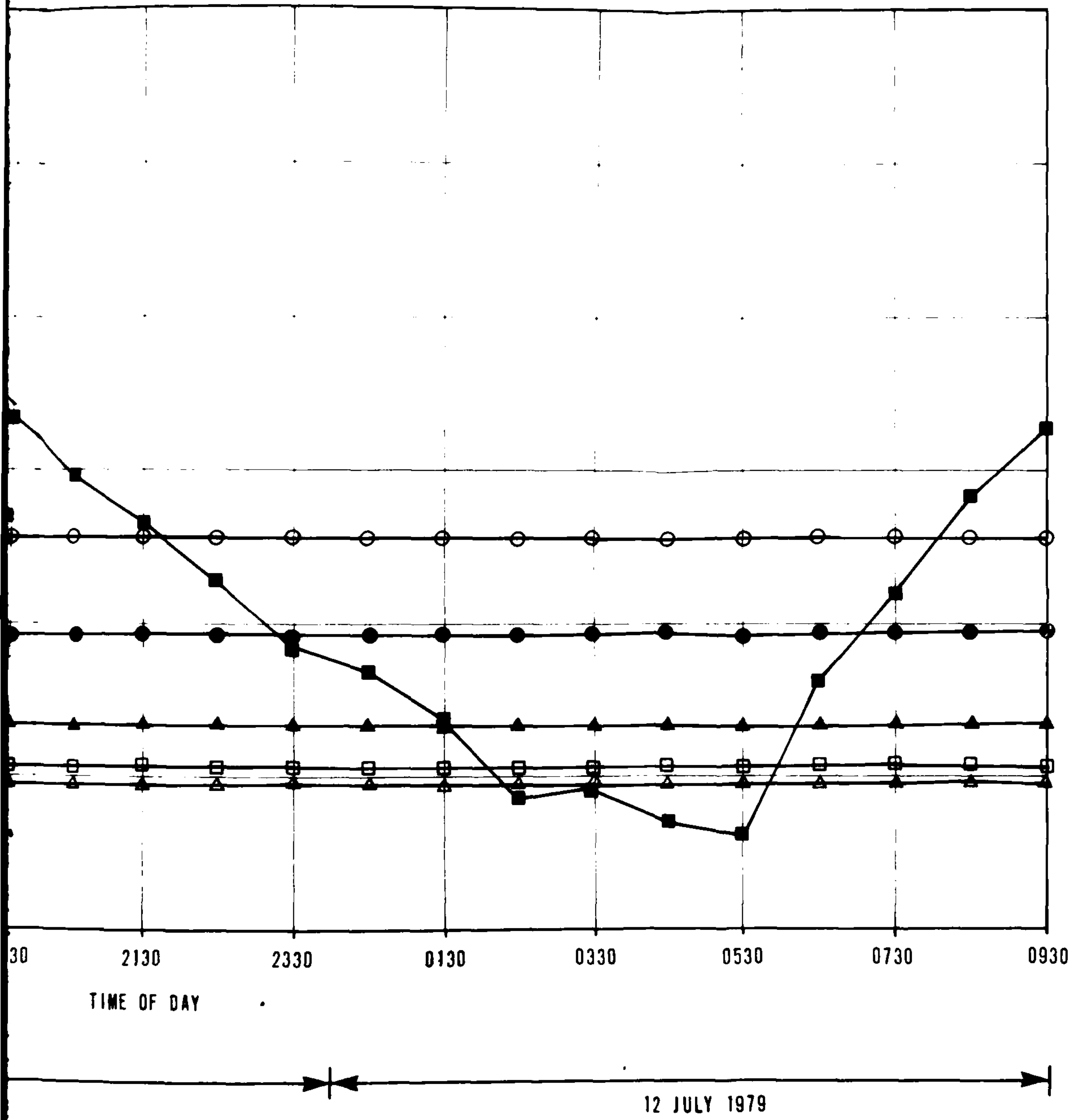
FIGURE
2-6

FUGRO NATIONAL, INC.

2



NOTE:
SOIL TEMPERATURES SHOWN ARE AVERAGE VALUES OF THREE THERMOCOUPLES AT EACH DEPTH



EXPLANATION

■ AIR TEMPERATURE

○ 2 ft (0.6m)
● 4 ft (1.2m)
□ 8 ft (2.4m)
▲ 50 ft (15.2m)
△ 125 ft (38.1m)

DEPTH
BELOW
GROUND
SURFACE

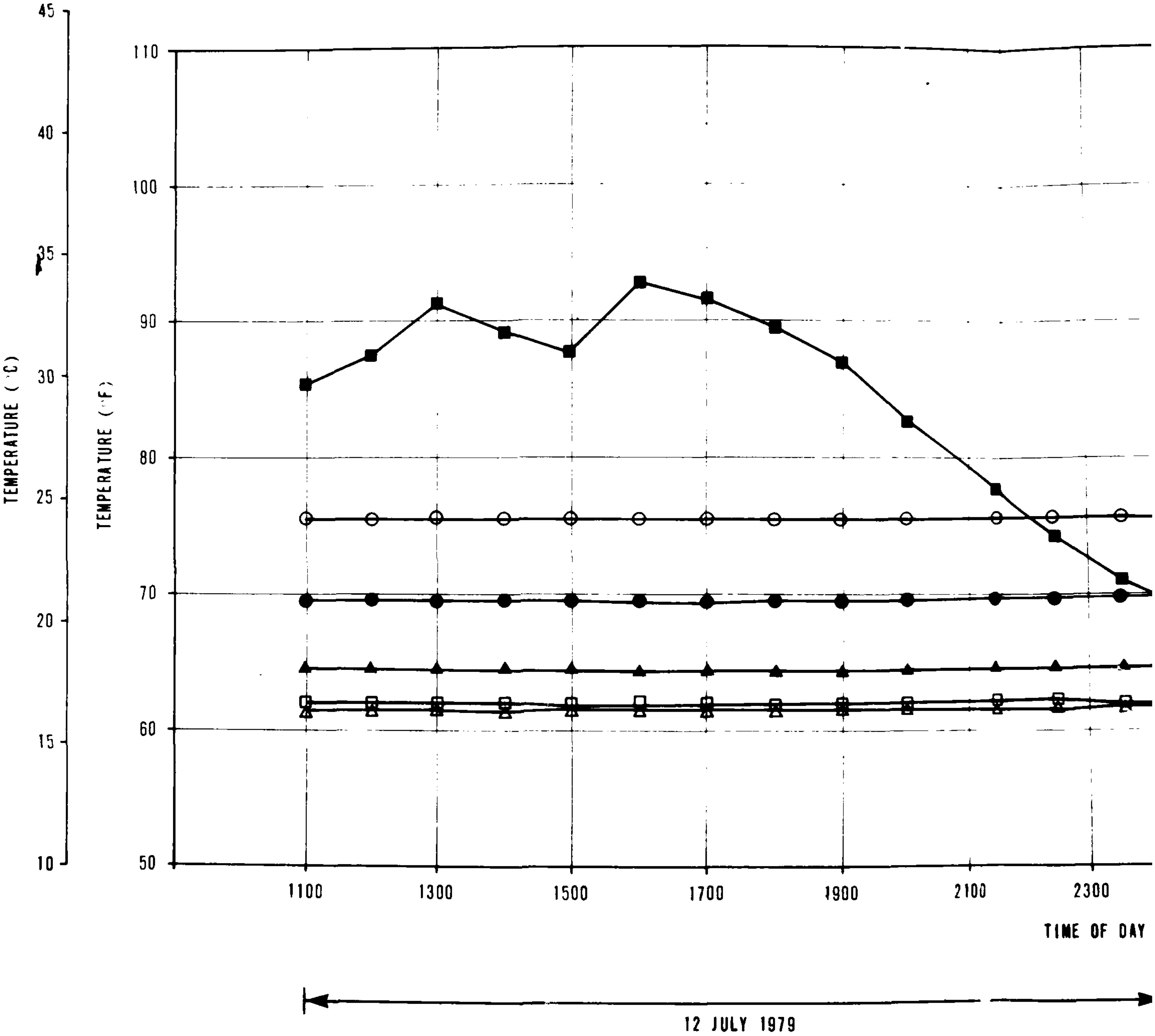
∂

24-HOUR SOIL TEMPERATURE PLOTS
THERMAL PROBE NO. BS-B-1
BIG SMOKY CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE
2-7

FUGRO NATIONAL, INC.



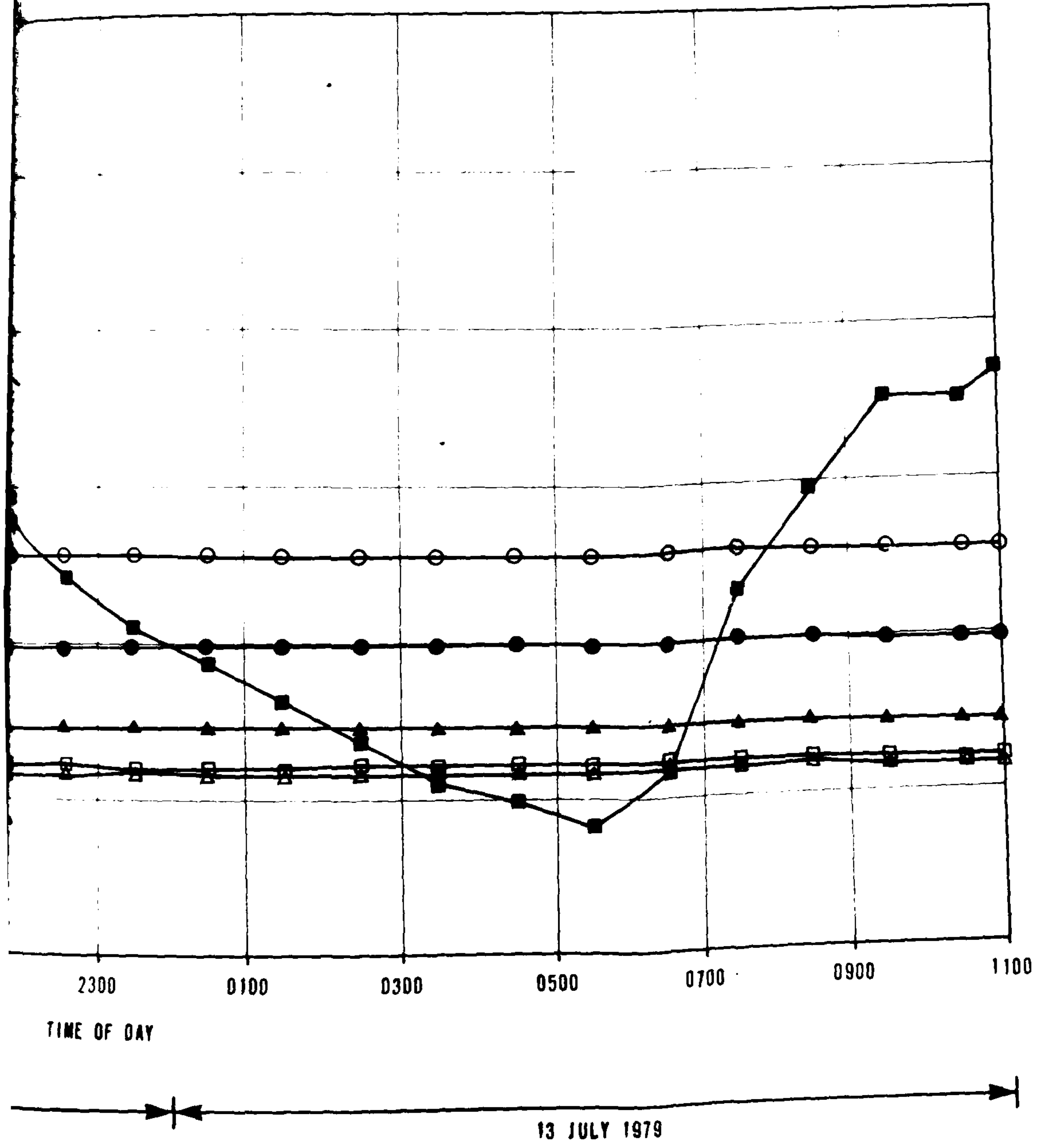
NOTE:

SOIL TEMPERATURES SHOWN ARE AVERAGE VALUES OF THREE THERMOCOUPLES AT EACH DEPTH

EXPLANATION

■ AIR TEMPERATURE

○ 2 ft (0.6m)
● 4 ft (1.2m)
□ 8 ft (2.4m)
△ 50 ft (15.2m)
▲ 125 ft (38.1m)



LANATION

TEMPERATURE

t (0.6m)
t (1.2m)
t (2.4m)
ft (15.2m)
ft (38.1m)

DEPTH
BELOW
GROUND
SURFACE

2

24-HOUR SOIL TEMPERATURE PLOTS
THERMAL PROBE NO. BS-B-2
BIG SMOKY CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE
2-8

UGRO NATIONAL, INC.

3.0 THERMAL RESISTIVITY

A knowledge of the thermal resistivity of soils is needed for several applications including analysis of heat dissipation from buried electrical cables, insulation and heat transfer analysis related to underground silos, and moisture migration under thermal gradients. Thermal resistivity of soils depends on soil composition, density, moisture content, particle shape and size, and particle-size distribution. Thermal resistivity is the inverse of thermal conductivity. Thermal conductivity is defined as the quantity of heat which flows normally across a surface of unit area per unit of time and per unit of temperature gradient normal to the surface.

3.1 THERMAL NEEDLE

In order to determine the thermal resistivity of the soil samples, the thermal needle method (also referred to as probe method or line source method) was used. This method is based on the measurement of the rate of temperature rise along a line heat source within an infinite, homogeneous medium. In practice, the line heat source is approximated by a small diameter needle which is heated at a constant rate by using electrical energy. The theory involved in computing the thermal resistivity using the thermal needle method is presented in Appendix C.

The thermal needle method involves simple apparatus and instrumentation. A thermal needle was constructed and calibrated in Fugro's laboratory. The design of the thermal needle, consisting of a stainless steel hypodermic tubing which contains a heater element and a thermocouple, was based on the work by Mitchell, Kao, and Abdel-Hadi (1977). Details of assembly and calibration of a thermal needle are also included in Appendix C.

3.2 TEST PROCEDURE

The following test procedure was used in determining thermal resistivity of a soil sample: an undisturbed soil sample (Fugro Drive or Pitcher) was prepared before testing. Preparation included trimming, weighing, and drilling a small hole in the center of the sample. The sample was contained in brass rings (Fugro Drive) or a steel tube (Pitcher) during preparation and testing. The thermal needle was then inserted into the hole and a known current source applied to the heater element in the needle. The thermocouple readings, as a function of time, were recorded, and the data were plotted as temperature-versus-log time. Testing continued until the straight line plot changed slope. Using the straight line relationship between temperature and time, the thermal resistivity was calculated. Details of sample preparation, test procedure, calculations, and typical test data sheets are also presented in Appendix C.

A total of 41 thermal resistivity tests (36 on sands and five on silts) were performed in the laboratory. The soil samples used in these tests were from six borings in Reveille-Railroad CDP and five borings in Big Smoky CDP. The soils were predominantly coarse-grained. In addition to the thermal resistivity tests, supplementary laboratory tests for determining physical properties of the soil samples were also performed. These supplementary tests were in general accordance with the procedures of American Society for Testing and Materials (ASTM); they consisted of: dry density, moisture content, and particle-size distribution. Details of the test procedures used for the supplementary tests are presented in Appendix D. Results of the supplementary tests were used in computing degree of saturation of the soil samples.

3.3 RESULTS

The results of thermal resistivity tests are presented in Table 3-1. Included in this table are the results of the supplementary tests and calculated percent saturation of the soil samples used in testing. Table 3-1 indicates that the range of density, moisture content, and particle-size distribution of the soil samples tested is wide. This may account for the considerable variation in the values of thermal resistivity presented in Table 3-1.

A plot of thermal resistivity versus percent saturation is shown in Figure 3-1. Because of the variation in the physical properties of the soils (as explained in the preceding paragraph), there is a considerable scatter of the data points. However, an average relationship between resistivity and saturation for coarse-grained soils (sands) is shown in Figure 3-1. This relationship indicates that the thermal resistivity of site soils gradually decreases with increasing saturation.

BORING NUMBER	SAMPLE[1] NUMBER	SAMPLE INTERVAL		DRY DENSITY		MOISTURE CONTENT	SATURATION	PARTICLE SIZE ANALYSIS	
		feet	meters	pcf	Kg m^3	%	%	GR	SA
RR-B-2	P-2	3.0-3.9	0.9-1.2	98.5	1593.6	7.0	26.6	5	75
	D-8	30.4-30.9	9.3-9.4	98.7	1596.8	6.2	23.7	0	93
	D-9	35.3-35.8	10.8-10.9	105.6	1708.4	6.9	31.2	2	53
	P-13	59.0-59.9	18.0-18.3	95.2	1540.2	15.1	53.0	0	24
	P-18	109.0-110.7	33.2-33.8	107.1	1732.7	17.2	81.1	0	58
RR-B-3	D-4	7.2-7.9	2.2-2.4	107.1	1732.7	4.0	19.1	7	87
	P-13	60.0-60.7	18.3-18.5	107.3	1736.0	6.8	32.3	18	72
	P-18	110.0-111.6	33.5-34.2	104.4	1689.0	4.6	20.2	0	98
RR-B-3A	P-3	7.5-9.1	2.3-2.8	98.0	1585.5	6.5	24.4	0	64
	P-4	10.0-11.8	3.1-3.6	88.3	1428.6	13.1	38.9	0	32
	P-8	50.0-50.9	15.3-15.5	76.6	1239.3	20.4	46.0	4	36
	P-9	76.9-77.7	23.5-23.7	106.9	1729.5	19.4	90.9	1	90
	P-12	126.5-127.2	38.6-38.8	109.0	1763.5	10.9	54.4	7	84
RR-B-4	P-4	7.0-8.9	2.1-2.7	100.3	1622.7	11.5	45.6	0	68
	P-13	50.0-51.7	15.3-15.8	93.9	1519.2	12.4	42.3	0	81
	P-18	101.5-102.4	31.0-31.2	97.1	1570.9	25.1	92.3	11	32
RR-B-5	D-12	50.2-50.9	15.3-15.5	110.2	1782.9	12.9	65.9	18	56
RR-B-6	P-1	0.0-0.7	0.0-0.2	90.5	1464.2	9.7	30.5	5	60
	D-14	65.7-66.4	20.0-20.2	115.9	1875.1	12.2	72.8	15	59
	D-17	92.0-92.6	28.1-28.2	117.2	1896.1	14.4	88.8	25	64
BS-B-1	D-3	3.9-4.6	1.2-1.4	106.2	1718.2	4.6	21.3	8	83
	D-4	7.1-7.8	2.2-2.4	106.2	1718.2	7.1	32.6	12	69
	P-13	50.4-51.3	15.4-15.6	73.1	1182.7	41.3	85.5	0	44
	P-14	60.0-61.0	18.3-18.6	91.2	1480.3	15.9	50.9	0	54
BS-B-2	D-6	7.0-7.5	2.1-2.3	117.9	1907.5	10.9	68.6	13	81
	D-7	10.0-10.7	3.1-3.3	113.4	1834.7	5.9	32.8	1	87
	P-14	50.0-52.7	15.3-16.1	97.2	1572.6	13.6	50.0	3	84
	P-15	60.0-61.4	18.3-18.7	96.4	1559.6	16.9	61.0	12	82
	D-24	160.0-160.5	48.8-49.0	115.4	1867.0	13.7	80.1	24	67

SIZE ANALYSIS , (2)		USCS (3) CLASSIFICATION	THERMAL RESISTIVITY	
SA	FI		°F-ft-hr/B	°C-cm watt
75	20	SM	2.56	148.2
93	7	SP-SM	2.98	172.3
53	45	SM	2.21	128.0
24	76	ML	1.60	92.4
58	42	SM	1.14	65.8
87	6	SP-SM	3.89	224.9
72	10	SP-SM	1.45	83.6
98	2	SP	2.34	135.1
64	36	SM	1.54	88.9
32	68	ML	1.49	86.3
36	60	ML	2.29	132.2
90	9	SP-SM	1.17	67.6
84	9	SP-SM	1.13	65.3
68	32	SM	1.60	92.4
81	19	SM	2.02	116.7
32	57	ML	1.25	72.3
56	26	SM	2.05	118.5
60	35	SM	2.89	167.2
59	26	SM	1.03	59.3
64	11	SP-SM	1.26	72.8
83	9	SP-SM	5.05	292.0
69	19	SM	2.10	121.3
44	56	ML	1.95	112.6
54	46	SM	1.99	115.0
81	6	SP-SM	1.82	105.0
87	12	SM	1.84	106.6
84	13	SM	1.78	103.0
82	6	SP-SM	1.41	81.4
67	9	SP-SM	1.06	61.4

EXPLANATION

(1) P - PITCHER SAMPLE
    D - FUGRO DRIVE SAMPLE

(2) GR - GRAVEL (RETAINED ON NO.4 SIEVE)
    SA - SAND (PASSING NO.4 SIEVE BUT RETAINED ON NO.200 SIEVE)
    FI - FINES (PASSING NO.200 SIEVE)

(3) USCS - UNIFIED SOIL CLASSIFICATION SYSTEM (SEE APPENDIX B FOR DETAILS)

THERMAL RESISTIVITY TEST RESULTS
REVEILLE-RAILROAD AND
BIG SMOKY CDPS, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE
3-1
1 OF 2

FUGRO NATIONAL, INC.

2

BORING NUMBER	SAMPLE NUMBER(1)	SAMPLE INTERVAL		DRY DENSITY		MOISTURE CONTENT	SATURATION	PARTICLE SIZE ANALYSIS		
		feet	meters	pcf	Kg m^3	%	%	GR	SA	
BS-B-3	D-3	4.2-4 9	1.3-1.5	119.8	1938.2	6.4	42.8	45	48	
	P-9	30 0-31 2	9 1-9.5	108.9	1761.8	9.4	46.5	3	69	
	D-14	70 2-70 9	21.4-21.6	118.8	1922.0	13 5	87.3	23	46	
	D-16	90.0-90 7	27.5-27 7	116.4	1883.2	12.3	74.5	1	80	
BS-B-5	P-1	0.6-1 3	0 2-0 4	99.1	1603.3	9 7	37.5	5	66	
	D-10	35.0-35.6	10.7-10 9	107.7	1742.4	13.7	65.4	13	80	
	P-15	80.0-81 1	24.4-24.7	93 9	1519.2	18.2	62 0	2	88	
	D-21	160.2-160 9	48.9-49.1	111 7	1807.1	15.2	80 7	40	55	
BS-B-6	P-1	0 7-1.4	0.2-0.4	90 5	1464.2	9 7	63.8	12	68	
	D-8	25 7-26.4	7.8-8 1	115 0	1860.5	6.8	39.1	7	81	
	D-9	30 2-30.9	9 2-9 4	123.8	2002.9	8.3	62.0	41	51	
	D-19	120.4-120.9	36.7-36 9	120.7	1952.8	6.4	43.6	26	63	

ICLE SIZE ANALYSIS % (2)		USCS (3) CLASSIFICATION	THERMAL RESISTIVITY	
SA	FI		°F-ft-hr/B	°C-cm watt
48	7	SP-SM	1.71	99.0
69	28	SM	1 75	101.0
46	31	SM	1.43	82.9
80	19	SM	1.54	88.9
66	29	SM	2.91	168.3
80	7	SP-SM	1 94	112.0
88	10	SP-SM	1.62	93.9
55	5	SP	1.17	67.6
68	20	SM	1.94	112 0
81	12	SP-SM	1.98	114.6
51	8	SP-SM	0.91	52 6
63	11	SP-SM	2.79	161.2

EXPLANATION

(1) P - PITCHER SAMPLE
D - FUGRO DRIVE SAMPLE

(2) GR - GRAVEL (RETAINED ON NO.4 SIEVE)
SA - SAND (PASSING NO.4 SIEVE BUT RETAINED ON NO.200 SIEVE)
FI - FINES (PASSING NO 200 SIEVE)

(3) USCS - UNIFIED SOIL CLASSIFICATION SYSTEM (SEE APPENDIX B FOR DETAILS)

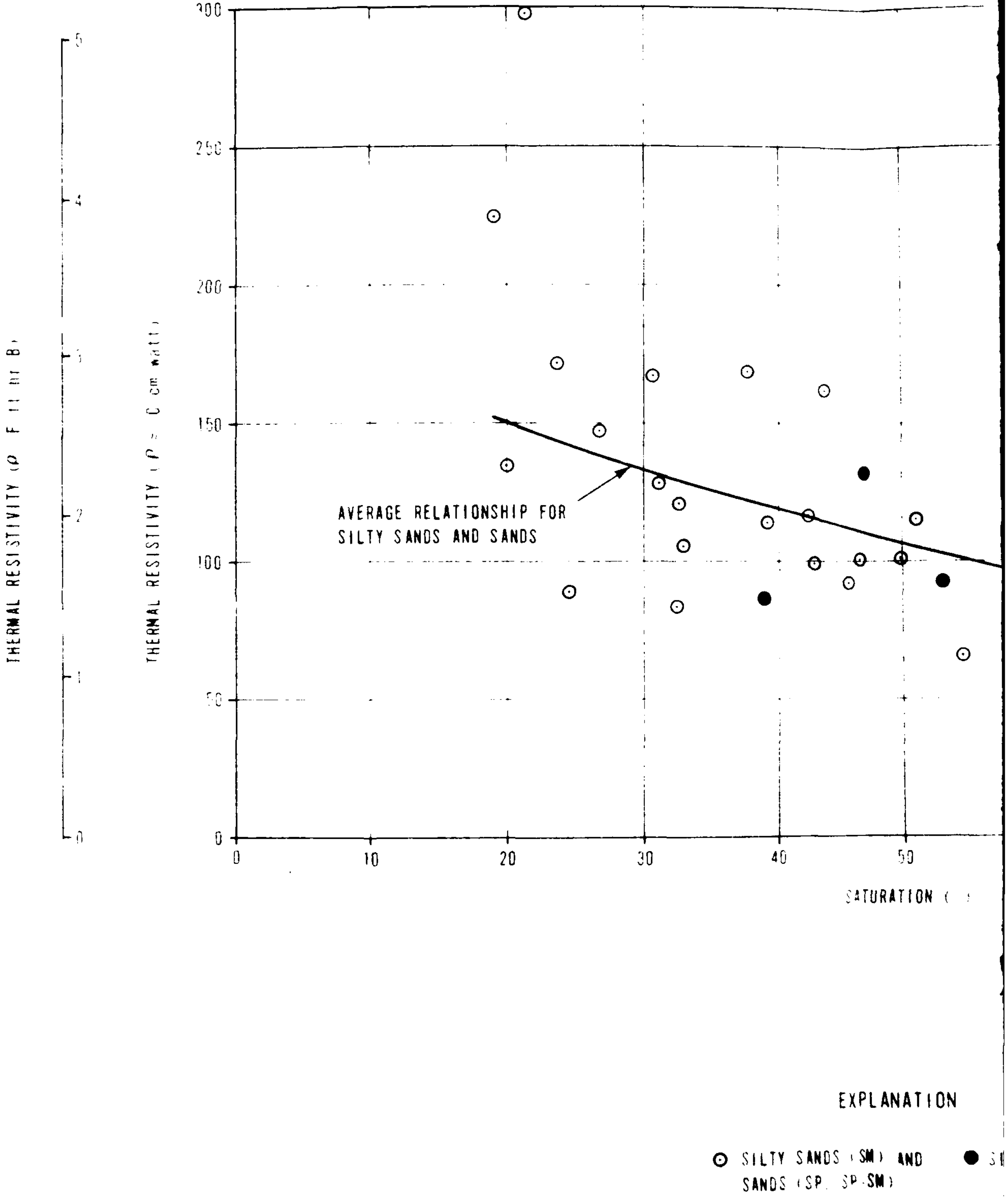
2

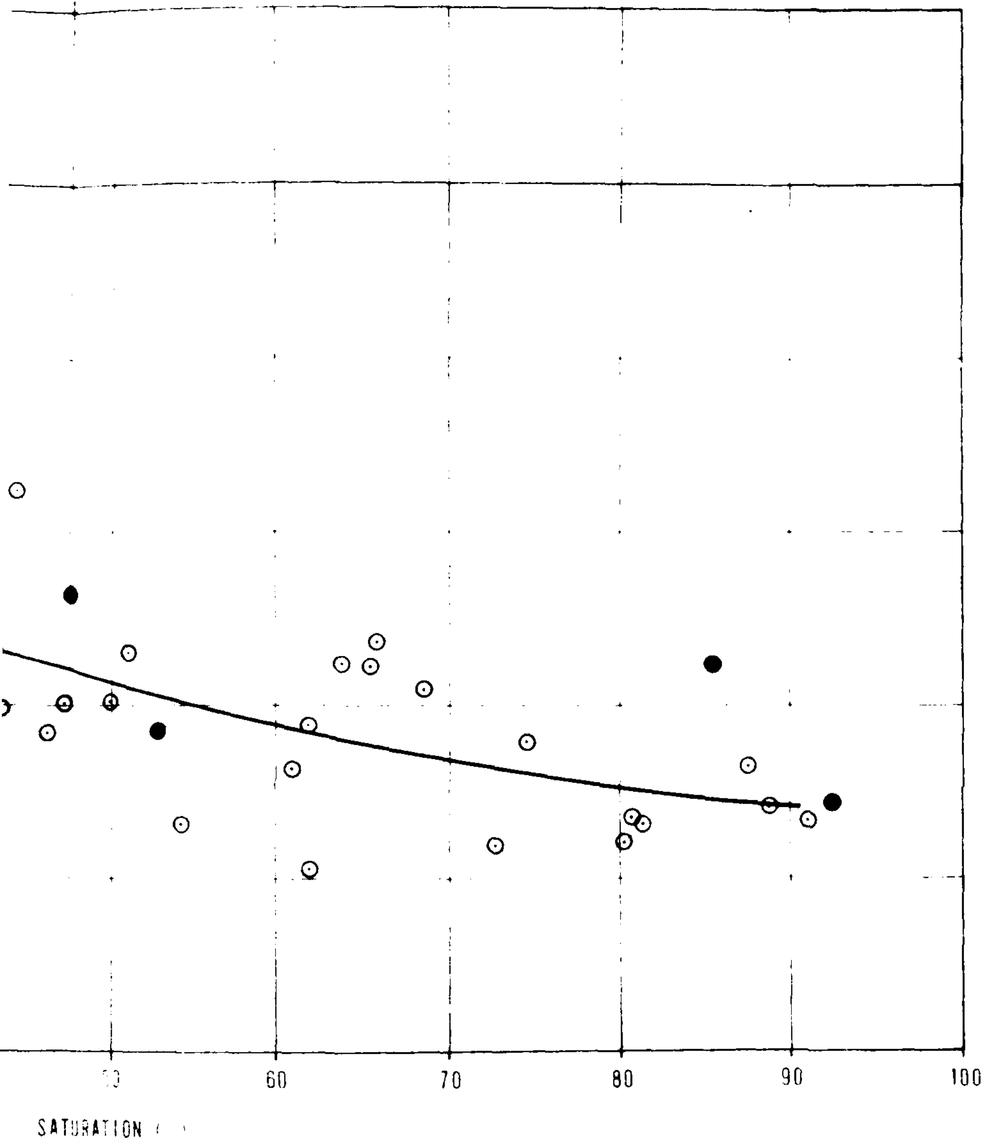
THERMAL RESISTIVITY TEST RESULTS
REVEILLE-RAILROAD AND
BIG SMOKY COPS, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE
3-1
2 OF 2

FUGRO NATIONAL, INC.


THERMAL RESISTIVITY (ρ F ft hr B)
5
4
3
2
1
0
THERMAL RESISTIVITY (ρ = C cm watt)
300
250
200
150
100
50
0
0
10
20
30
40
50
SATURATION (
AVERAGE RELATIONSHIP FOR
SILTY SANDS AND SANDS
EXPLANATION
○ SILTY SANDS (SM) AND
SANDS (SP, SP-SM)
● S



EXPLANATION

DS (SM AND
, SP-SM.

● SILTS (ML)

THERMAL RESISTIVITY VERSUS SATURATION
REVEILLE-RAILROAD AND
BIG SMOKY CDPS, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE
3-1

FUGRO NATIONAL, INC.

2

Based on the results of the thermal needle calibration tests performed before and after the test series, the repeatability of the reported thermal resistivity values of the soil samples is within ±2 percent.

4.0 VOLUMETRIC HEAT CAPACITY

Volumetric heat capacity of a soil is defined as the amount of heat necessary to change the temperature of a unit volume of the soil by one degree. The amount of temperature change in response to the absorption or release of heat is governed by the heat capacity. The heat capacity of natural soils is strongly dependent on the soil porosity and water content, both of which may be subject to fluctuations. If the specific heat and amounts of each soil constituent and water content are known, the heat capacity of the soil-water system can be calculated. Specific heat is defined as follows: The ratio of the amount of heat necessary to change the temperature of a unit mass of a substance by one degree to the amount of heat necessary to raise a unit mass of water through the same change in temperature.

4.1 TEST PROCEDURE

The methodology utilized to determine the specific heat of soil constituents is similar to that presented by Taylor and Jackson (1965). A calorimeter, an accessory vessel, and thermometers were used in the test. Both the calorimeter and accessory vessels were one-pint thermos jars (with insulated caps) placed inside foam insulated boxes.

The test procedure used in determining specific heat of soils consisted of adding a known quantity of dry representative soil to the calorimeter along with a measured amount of water, sufficient to form a dilute suspension. The temperature of the suspension was measured. Then, a measured quantity of water at a higher known temperature was added to the calorimeter so that the final temperature of the soil-water suspension was 1° to 5°C higher than the initial temperature. The final temperature of the suspension in the calorimeter was measured. Using these results, the specific heat of the soil was calculated.

Details of the test apparatus, test procedure, test data sheets, and calculations used to compute the specific heat and volumetric heat capacity of the soil are presented in Appendix E.

Volumetric heat capacity of a soil sample was calculated using specific heat of the soil constituent and dry density and the moisture content of the soil sample. Specific heat of water was assumed to be 1.0 B/lb-°F (1.0 cal/g-°C).

4.2 RESULTS

A total of 33 specific heat tests were performed in the laboratory on soil samples from both Reveille-Railroad and Big Smoky CDPs. The test results are presented in Table 4-1. In addition, physical properties and volumetric heat capacity of soil samples are also included in the table. A review of Table 4-1 indicates that the specific heat of the sands from the two sites ranges between 0.154 to 0.197 cal/g-°C. However, there is considerable variation in the volumetric heat capacity of the in situ soil samples; this is attributed to the variation in density and moisture content of the soils.

BORING NUMBER	SAMPLE NUMBER	SAMPLE INTERVAL		DRY DENSITY		MOISTURE CONTENT	SATURATION	PARTICLE SIZE ANALYSIS	
		feet	meters	pcf	Kg/m^3			GR	S
RR 5	P 1	[illegible]	[illegible]	98	[illegible]	[illegible]	26.6	[illegible]	
	D 6	[illegible]	[illegible]	95	[illegible]	[illegible]	23	0	[illegible]
	P 12	[illegible]	[illegible]	95.0	1540.2	[illegible]	55.0	[illegible]	[illegible]
RR B	P 13	60.0	18	107	1736.0	6.8	32	5	[illegible]
	P	[illegible]	33.6-34.2	104.4	1689.0	4.6	[illegible]	[illegible]	[illegible]
RR B A	P	7 9.1	2.3 2.8	98	158	6	24.4	[illegible]	[illegible]
	P 4	10.0 11.6	3.1 3.6	88.3	1428.5	[illegible]	[illegible]	[illegible]	[illegible]
	P 8	50.0 50.9	15.3 15.5	76.6	1239	20.4	46.0	4	[illegible]
	P 9	76.9 77.7	23.5 23.7	106.9	1725	9.4	90.9	[illegible]	
	P 12	126 127.2	38.6-38.8	109.0	1765	10.9	4.4	[illegible]	84
RR 5 4	P 4	7.0 8.9	2.1 2.7	100.3	1622.7	[illegible]	45	[illegible]	[illegible]
	P 13	50.0 51.7	15.2 15.8	93.9	1519.2	12.4	42.3	0	-
	P 16	101 102.4	31.0 31.2	97.1	1570.8	2	[illegible]		[illegible]
RR 6	D-12	50.2-50.9	15.3-15.5	110	1782.9	12.9	[illegible]	16	[illegible]
RR 8	P 1	0.0 0.7	0.0-0.2	90.5	1464.2	9.7	[illegible]		[illegible]
	D 14	6 7 66.4	20.0 20.2	115.9	1875.1	12.2	[illegible]	[illegible]	9
	D 17	92.0 92.6	28.1 28.2	117.2	1896	4.4	66	[illegible]	[illegible]
BS B 1	D	4.6	1.4	106	1719.2	4.6	[illegible]	[illegible]	[illegible]
	D 4	7.1 7.6	2.2 2.4	106.2	1718.2	7.1	32.6	[illegible]	9
	P 13	50.4 51.3	15.4-15.6	73.1	1182.7	41	8		44
	P 14	60.0-61.0	18.3 18.6	91.2	1480.3	15.9	50.9	0	4
BS B 2	D	7.0 7.5	2.1 2.3	117.9	1907.5	10.9	69.6	[illegible]	[illegible]
	P 14	50.0-52	15.3-16.1	97.2	1572.6	13.6	50	[illegible]	4
	P 15	60.0 61.4	18.3-18.7	96.4	1559.6	16.9	61.0	12	[illegible]
	D 24	160.0-160.5	48.8 49.0	115.4	1867.0	13.7	80	24	[illegible]
BS B 3	P 9	30.0 31.2	9.1 9.5	108.9	1761.8	9.4	46.5	[illegible]	9
BS-B 5	P 15	80.0 81.1	24.4 24.7	93.9	1519.2	16.2	62.0	[illegible]	[illegible]
	D 21	160 160.9	48.9 49.1	111.7	1807.1	15.2	80.7	40	[illegible]
BS B 6	P 1	0.7-1.4	0.2 0.4	90.5	1464.2	9.7	63.8	12	8
	D 8	25.7-26.4	7.8 8.1	115.0	1860.5	6.8	39.1	7	81
	D 9	30.2-30.9	9.2-9.4	123.8	2002.9	8.3	62.0	41	[illegible]
	D 19	120.4 120.9	36.7-36.9	120.7	1952.8	6.4	42.6	26	63

[illegible]	USCS[3] CLASSIFICATION	SPECIFIC HEAT c_s		VOLUMETRIC HEAT CAPACITY, c_v	
FI		$\frac{B}{lb-F}$	$\frac{cal}{g-C}$	$\frac{B}{ft^3-F}$	$\frac{cal}{cm^3-C}$
[illegible]	SM	0.154	0.154	22.06	0.35
[illegible]	SP SM	0.167	0.167	[illegible]	0.36
[illegible]	ML	0.178	0.176	31.[illegible]	0.50
[illegible]	SP SM	0.179	0.179	[illegible]	0.42
[illegible]	SP	0.187	0.187	24.[illegible]	0.39
[illegible]	SM	0.189	[illegible]	24.[illegible]	0.40
[illegible]	ML	0.18[illegible]	[illegible]	[illegible]	0.44
[illegible]	ML	0.180	0.190	[illegible]	[illegible]
[illegible]	SP SM	0.194	0.194	41.48	0.66
[illegible]	SP SM	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	SM	[illegible]	[illegible]	[illegible]	0.49
[illegible]	SM	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	ML	0.198	0.198	4[illegible]	[illegible]
[illegible]	SM	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	SM	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	SM	0.18[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	SP SM	0.188	0.188	[illegible]	[illegible]
[illegible]	SP SM	[illegible]	[illegible]	[illegible]	0.37
[illegible]	SM	0.186	0.186	[illegible]	0.41
[illegible]	ML	0.17[illegible]	0.17[illegible]	42.96	0.69
[illegible]	SM	0.186	0.186	31.46	0.50
[illegible]	SP SM	0.196	0.196	[illegible]	[illegible]
[illegible]	SM	0.181	0.181	30.61	0.49
[illegible]	SP SM	0.193	[illegible]	34.[illegible]	0.55
[illegible]	SP SM	0.197	0.197	38.54	0.62
6	SM	0.178	0.178	[illegible]	0.41
	SP SM	0.165	0.165	32.58	0.52
[illegible]	SP	0.161	0.161	34.96	0.56
[illegible]	SM	0.167	0.167	23.89	0.38
[illegible]	SP SM	0.167	0.167	27.02	0.43
[illegible]	SP SM	0.166	0.166	30.83	0.49
[illegible]	SP SM	0.196	0.196	[illegible]	[illegible]

2

EXPLANATION

(1) P - PITCHER SAMPLE
D - FUGRO DRIVE SAMPLE

(2) GR - GRAVEL (RETAINED ON NO 4 SIEVE)
SA - SAND (PASSING NO 4 SIEVE BUT
RETAINED ON NO 200 SIEVE)
FI - FINES (PASSING NO 200 SIEVE)

(3) USCS - UNIFIED SOIL CLASSIFICATION
SYSTEM (SEE APPENDIX B FOR DETAILS)

VOLUMETRIC HEAT CAPACITY TEST RESULTS
REVEILLE RAILROAD AND
BIG SMOKY CUPS NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE
4-1

FUGRO NATIONAL, INC.

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APPENDIX A

THERMAL PROBE

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APPENDIX A - THERMAL PROBE

PLATES

A1.0 COMPONENTS

Components used in the assembly of a thermal probe are as follows:

1. Thermocouples - Type T special (copper-constantan)

   PVC/PE ±3/4°F

   Manufacturer: Omega Engineering, Inc.

   The thermocouple covering consisted of two layers. The inner layer was polyvinyl chloride (PVC) and the outer layer was polyethylene (PE). Some thermocouples were calibrated by an outside agency. They were found to be accurate within ±0.2°F.

2. Polyethylene rope - 0.25-inch diameter (6 mm)
3. PVC pipe and fittings -

   Manufacturer: Ryan Herco

   Pipe: Schedule 80, nominal size 3/4 inch (19 mm)

   O.D. 1.050 inch (26.7 mm), I.D. 0.722 inch (18.3 mm)

   Fittings: compression couplings, brass plug, compression adapter, coupling and flange

4. Jack panel - suitable for 18 circuits

   Manufacturer: Omega Engineering, Inc.

5. Male plugs - suitable for copper-constantan thermocouples
6. Hoffman box (junction box) - to house the jack panel
7. Manhole - frame with cover, made of plastic and watertight
8. Digital readout unit - Fluke 2100A-06 digital thermometer with battery pack

A2.0 ASSEMBLY

Procedures used in the assembly of a thermal probe are as follows:

1. The thermocouples were covered with a SILASTIC compound (silicone) encapsuled by heat shrinkable polyolefin tubing. The process consisted of:
   - A. Place SILASTIC on thermocouple bead;
   - B. Load shrink tube sleeve with SILASTIC;
   - C. Slide shrink tube over thermocouple bead; and
   - D. Apply light amount of heat to shrink the tube.
2. The thermocouples were attached to the polyethylene rope as follows:
   - A. Tie thermocouple with nylon lacing cord to the polyethylene rope at the desired place; and
   - B. Wrap the thermocouple and the rope with rubber tape.
3. Each thermocouple was identified by a number as shown in Figure 2-1 (Section 2.0 of main text). The thermocouple wires were attached to the polyethylene rope with self-vulcanizing rubber tape at intervals of 1 to 2 feet (30 to 60 cm).
4. The polyethylene rope was laid on the floor and the thermocouples were attached to the rope at various intervals as described in Step 2.
5. The bottom end of the rope was connected to a coupling and a brass plug. The rope was threaded through sections of PVC pipe with compression couplings attached to one end. The

pipe sections were laid side by side so that the rope could form a loop while transversing from one section to the next.

6. The PVC sections were secured in a wooden crate and loaded on an overhead rack of a pickup truck ready for shipment to the field.

Photographs of the thermocouples and assembly of thermal probes are presented in Plate A-1.

A3.0 FIELD INSTALLATION

A schematic drawing of a typical installation of a thermal probe is shown in Figure 2-2. The procedures followed during installation of the thermal probe are as follows:

1. Following drilling of a boring, it was flushed with water until the return water was clear.
2. A borehole rabbit, consisting of a weighted 3-inch-diameter (75-mm) and 12-inch-long (300-mm) PVC pipe, was lowered into the boring to check for possible caving of the sides.
3. A wooden pipe clamp was placed over the top of the boring.
4. The pickup truck carrying the thermal probe was moved adjacent to the boring.
5. The bottom section of the probe was lowered into the boring and the top of the PVC pipe was secured in place using the pipe clamp. The second section of the PVC pipe was connected to the bottom section using the compression coupling, and it was lowered into the boring. The top of the second section was secured using the pipe clamp.

6. Approximately 20 pounds of lead shot were added to the bottom two sections of the PVC pipe to overcome buoyancy.
7. The next PVC section was brought in line with the sections in the borings and was connected to them using a compression coupling. The coupling was filled with a latex caulking compound to prevent convection air currents in the PVC pipes following installation.
8. By repeating the procedure in Step 7, all the PVC sections were lowered into the boring until the bottom of the probe was at 125 feet (38.1 m) below the ground surface. During lowering of each PVC section, the top end of the polyvinyl rope inside was pulled to ensure that there were no kinks in the string.
9. After the installation, a continuity check of the thermocouples was made using an ohmmeter.
10. The boring was backfilled with Monterey No. 1 sand up to a depth of approximately 10 feet (3 m) below the ground surface. The top 10 feet was backfilled with in situ soil at the surface.
11. The thermocouple wires were connected to a jack panel which was placed and fastened inside a junction box. The junction box was connected to the top of the thermal probe at the ground level. A continuity check of the thermocouples was performed again.
12. A shallow hole (6 inches deep; 150 mm) was excavated around the junction box and ready-mix concrete was placed in it.

13. A manhole with cover was placed around the junction box with anchor bolts embedded in the fresh concrete.
14. A minimum of 12 hours was allowed for the concrete to harden. The anchor bolts were tightened and more concrete was placed around the manhole.
15. An initial set of readings of the thermocouples was taken. After placing and locking the manhole cover, a cattle guard was built around the manhole.

Photographs showing various stages of field installation are presented in Plate A-2.

A4.0 READINGS

The Fluke digital readout unit was used to read the thermocouples. The procedure used for taking temperature readings was as follows:

1. The manhole cover was opened and a minimum of ten minutes was allowed for the junction box to come to thermal equilibrium with the surrounding temperature.
2. The male jack from the readout unit was plugged into the female jack of a thermocouple.
3. Temperature readings were taken immediately and then again two minutes after plugging in the male jack.
4. The procedure outlined in Step 3 was repeated for all 15 thermocouples.

Normally, there was no difference between the zero- and two-minute readings. The temperature difference between the three thermocouples at any level was generally not more than 0.2°F.

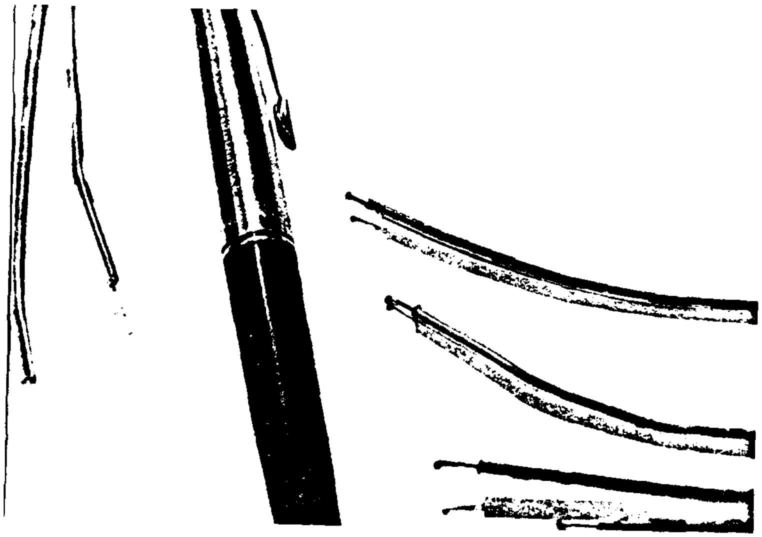


PHOTO 1 - SINGLE BEAD THERMOCOUPLE

PHOTO 2 - SINGLE BEAD THERMOCOUPLE WITH INSULATION

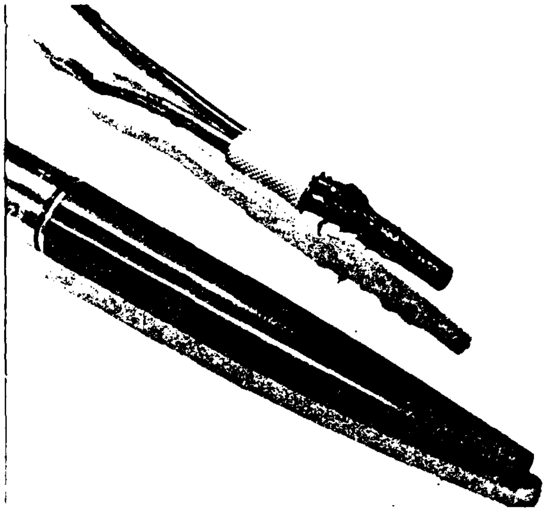


PHOTO 3 - BRANCHED BEAD THERMOCOUPLE WITH INSULATION

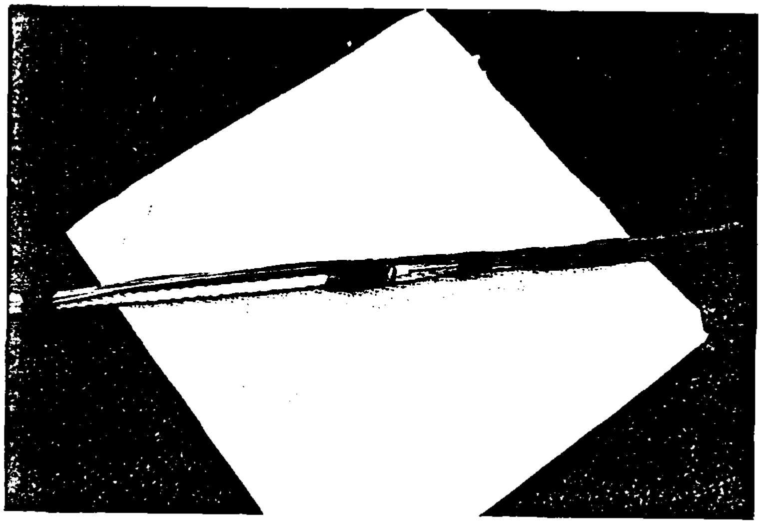
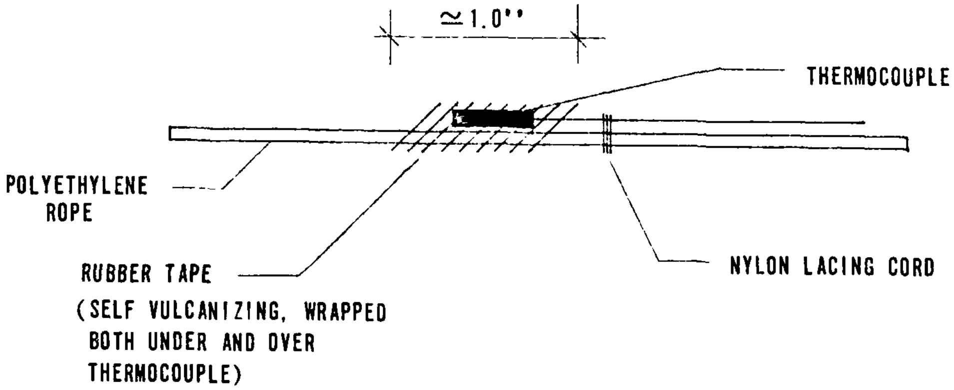


PHOTO 4 - ATTACHMENT OF THERMOCOUPLES TO POLYETHYLENE ROPE



THERMAL PROBE ASSEMBLY

PHOTO 5 - THERMAL PROBE BEING ASSEMBLED

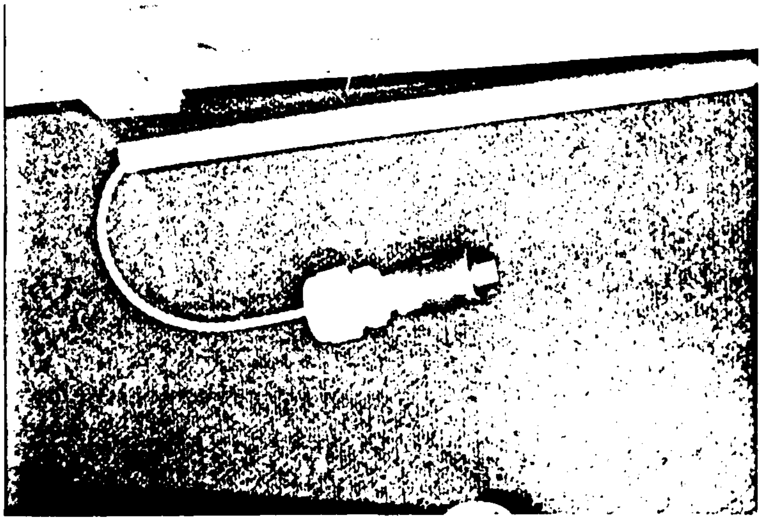


PHOTO 6 - DETAIL OF THERMAL PROBE END

THERMAL PROBE ASSEMBLY

PHOTO 7 - THERMAL PROBE SECURED IN A WOODEN CRATE READY FOR SHIPMENT

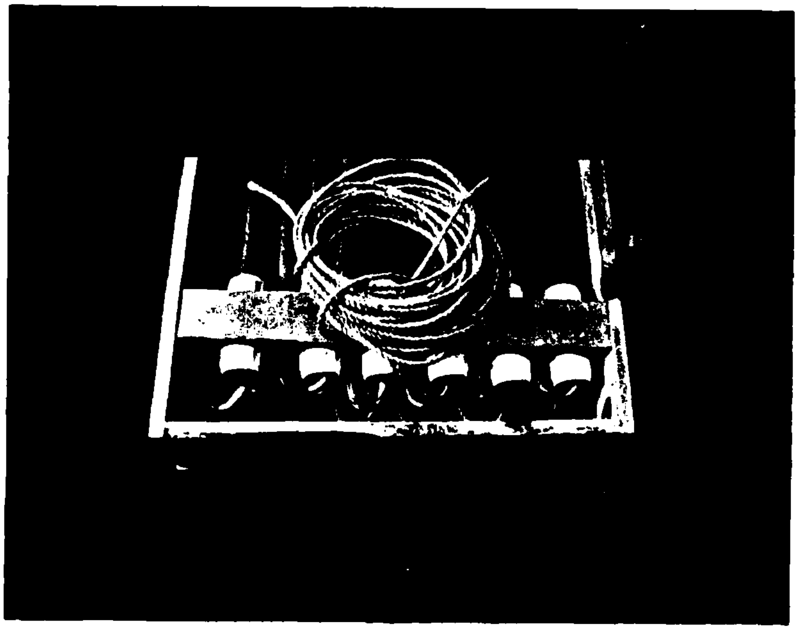


PHOTO 8 - DETAIL OF THERMAL PROBE IN SHIPPING CRATE

PHOTO 1 - BOREHOLE RABBIT USED TO CHECK COLLAPSE
OF SIDEWALLS BEFORE PROBE INSTALLATION

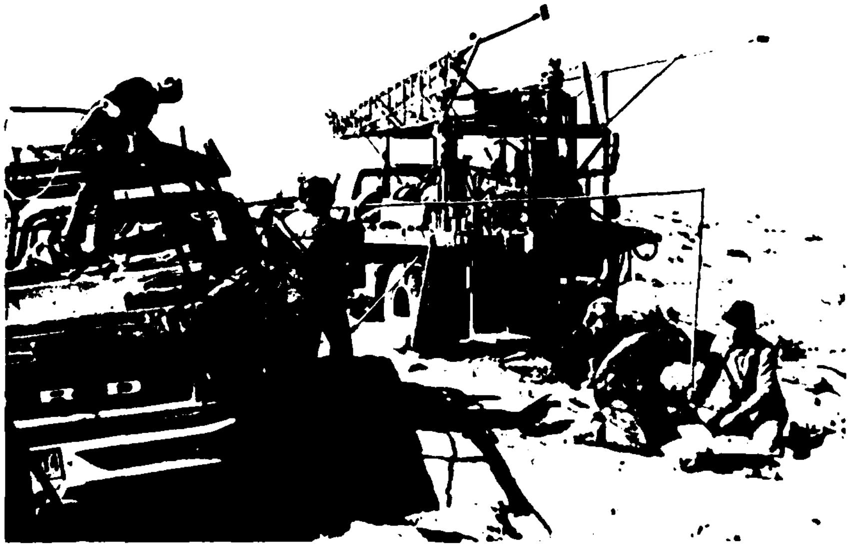


PHOTO 2 - LOWERING FIRST SECTION OF THERMAL PROBE INTO BORING

THERMAL PROBE INSTALLATION

PLATE A-2
1 OF 6

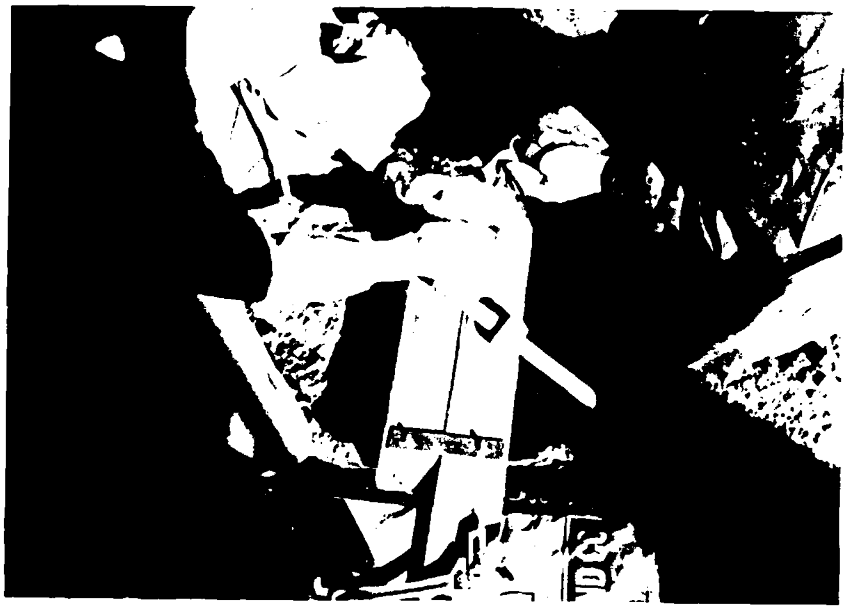


PHOTO 3 – ADDING LEADSHOT TO BOTTOM TWO SECTIONS OF PVC PIPE

PHOTO 4 – COMPRESSION COUPLING HELD BY WOODEN PIPE CLAMP

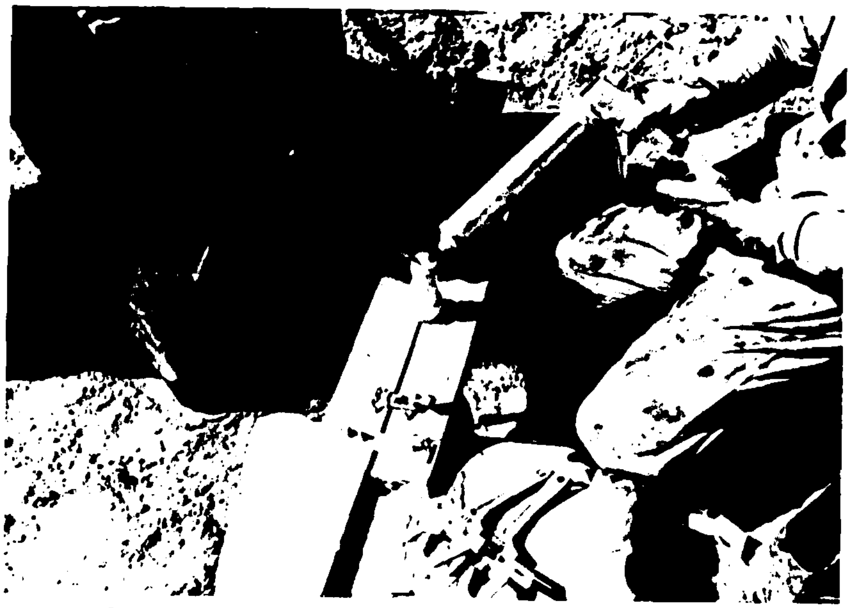


PHOTO 5 - INJECTING CAULKING COMPOUND INTO COUPLING

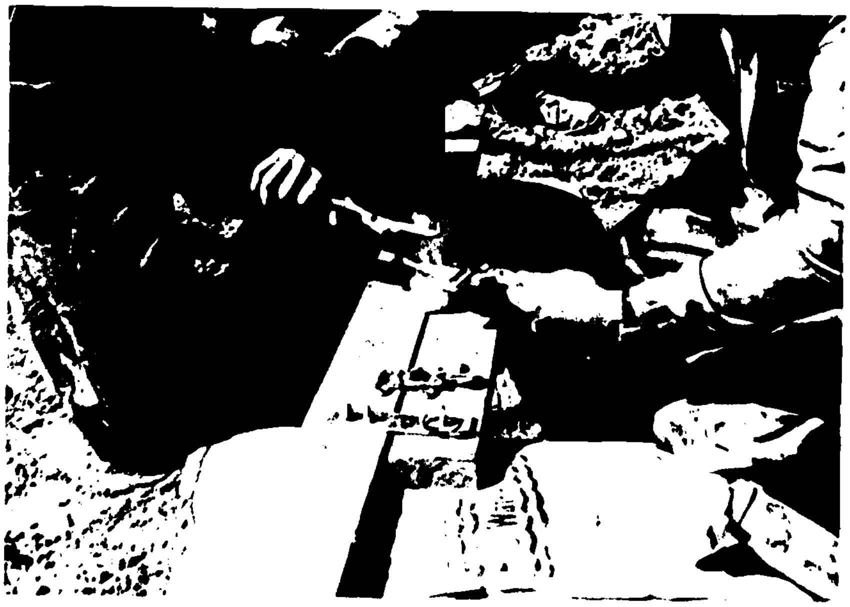


PHOTO 6 - TIGHTENING COMPRESSION COUPLING

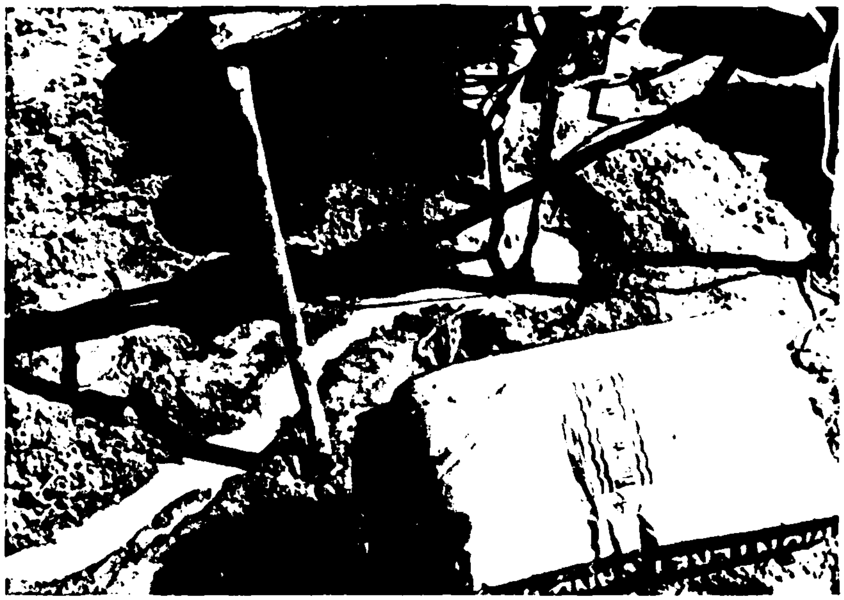


PHOTO 7 - BACKFILLING THE BORING WITH MONTEREY NO. 1 SAND AFTER PROBE INSTALLATION

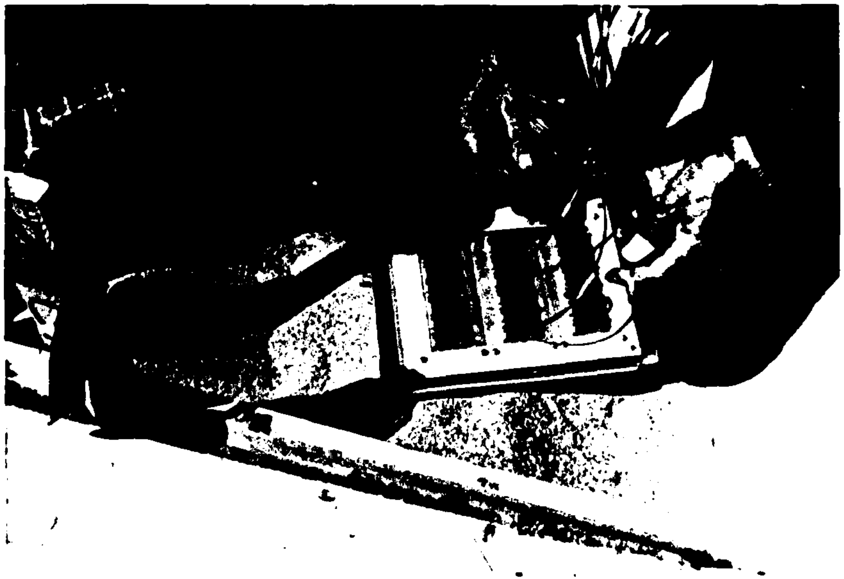


PHOTO 8 - HOFFMAN BOX AND JACK PANEL IN PLACE-THERMOCOUPLE WIRES BEING ATTACHED TO JACKS

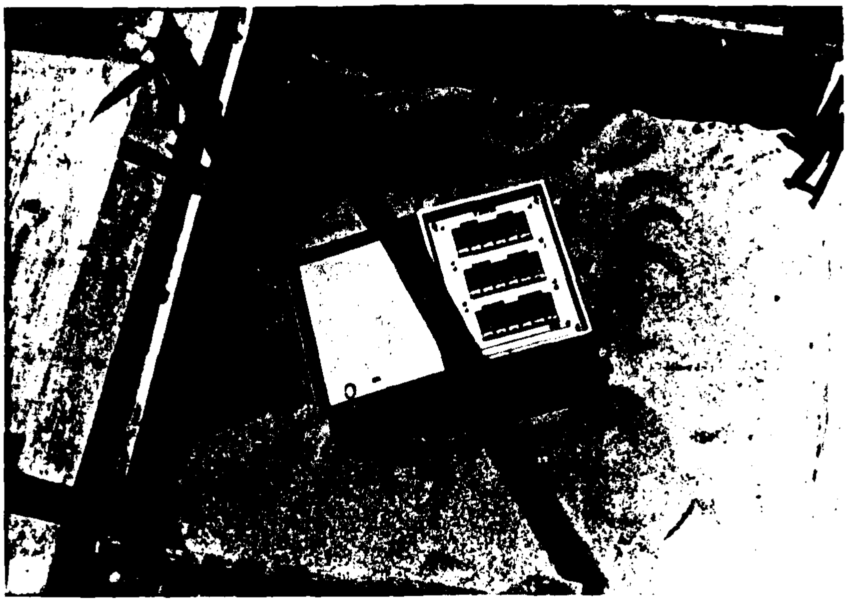


PHOTO 9 - CONCRETE FORMS AROUND JUNCTION BOX

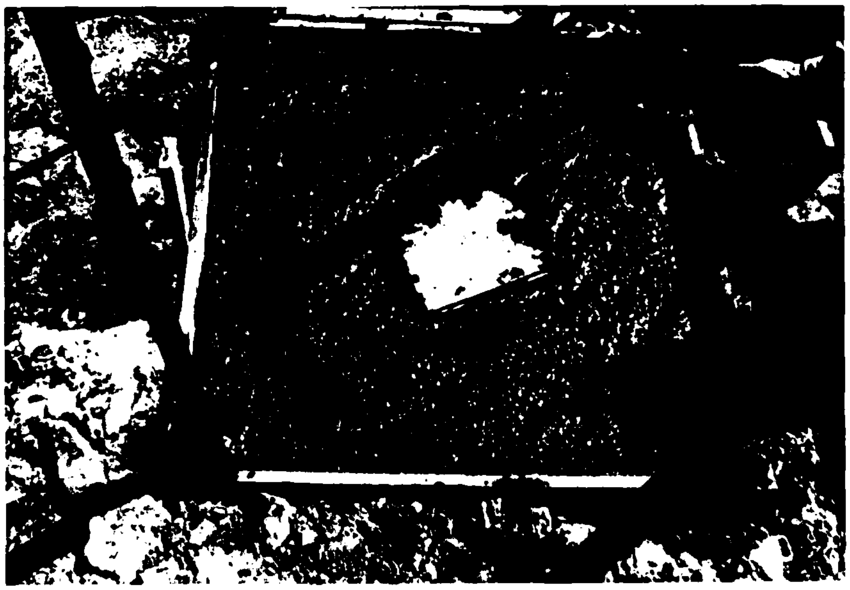


PHOTO 10 - CONCRETE PLACED AROUND JUNCTION BOX

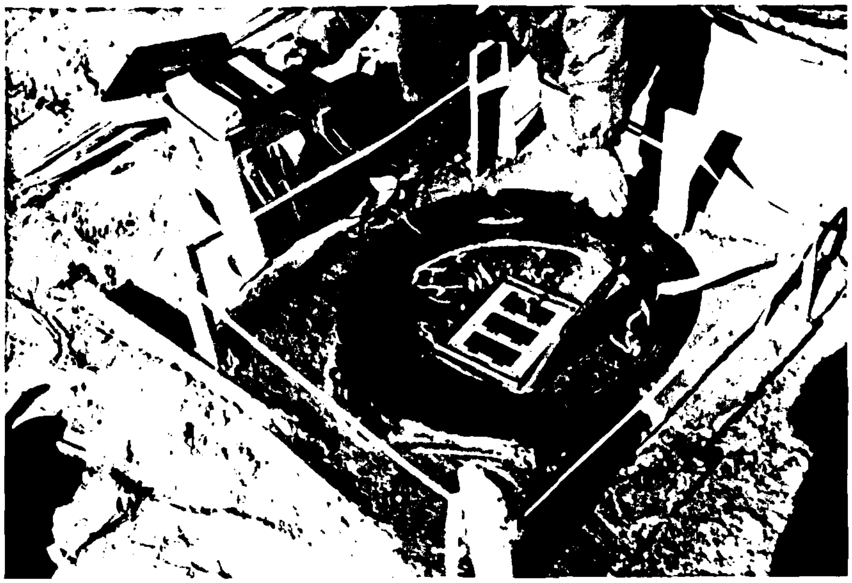


PHOTO 11 - MANHOLE RING IN PLACE AND READING THERMOCOUPLES USING DIGITAL READOUT UNIT

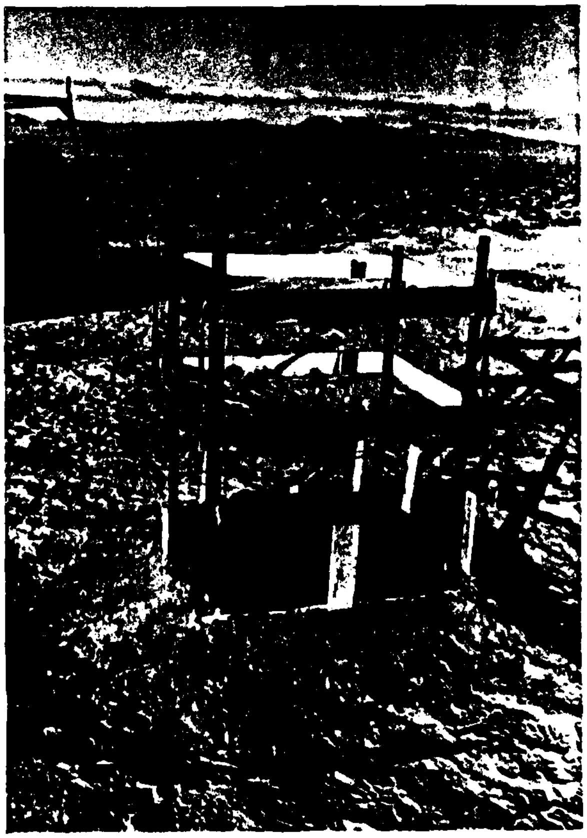


PHOTO 12 - COMPLETED THERMAL PROBE INSTALLATION WITH CATTLE GUARD

APPENDIX B

DRILLING PROCEDURES AND BORING LOGS

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LIST OF FIGURES (Cont.)

B1.0 DRILLING PROCEDURES

B1.1 DRILLING EQUIPMENT

The borings were drilled at designated locations using a truck-mounted Failing 1500 drilling rig with hydraulic pulldown and rotary wash techniques. Borings were nominally 4-7/8 inches (124 mm) in diameter, and drilling fluid (typically a bentonite-water slurry) was used to stabilize the hole. A tricone drill bit was used for coarse-grained soils and a drag bit for drilling in fine-grained soils. Nominal maximum depth drilled was 160 feet (49 m).

B1.2 SOIL SAMPLING

B1.2.1 Sampling Intervals

Soil samples were obtained at the following nominal depths as well as depths of change in soil type.

0' - 2'	(0-0.6 m)	- drive sample
2.5' - 5'	(0.8-1.5 m)	- Pitcher or drive
6' - 8'	(1.8-2.4 m)	- Pitcher or drive
10' - 30'	(3.0-9.1 m)	- Pitcher or drive - samples at 5' intervals, starting at a depth of 10'
30' - 130'	(9.1-39.0 m)	- Pitcher or drive - samples at 10' intervals
130' - 160'	(39.0-48.0 m)	- Pitcher or drive - samples at 15' intervals

B1.2.2 Sampling Techniques

B1.2.2.1 Fugro Drive Samples

Fugro Drive samplers were used to obtain relatively undisturbed soil samples. The Fugro Drive sampler is a ring-lined barrel sampler with an outside diameter of 3.0 inches (76.2 mm) and inside diameter of 2.50 inches (63.5 mm). It contains 12 individual 1-inch-long (25.4-mm) rings and is attached to a 12-inch-long (30-cm) waste barrel. The sampler was advanced using a downhole hammer weighing 335 pounds (76 kg) with a drop of 18 inches (46 cm).

The number of blows required to advance the sampler for a 6-inch (15-cm) interval was recorded. Samples obtained were retained in the rings, placed in plastic bags with manually twisted top ends, and sealed in plastic sample containers. Each sample was identified with a label indicating job number, boring number, sample number, depth range, Unified Soil Classification (USCS), and date. Ring samples were placed in foam-lined steel boxes.

B1.2.2.2 Pitcher Tube Samples

The Pitcher sampler was used to obtain undisturbed soil samples. The primary components of this sampler are an outer rotating core barrel with a bit and an inner, stationary, spring-loaded, thin-walled sampling tube which leads or trails the outer barrel drilling bit, depending on the hardness of the material penetrated. The average inside diameter of the sampling tubes used was 2.87 inches (73 mm). Before placing the Pitcher tube in the outer barrel, the tube was inspected for sharpness or protrusions.

The Pitcher sampler was then lowered to the bottom of the boring and the thin-walled sampling tube advanced into the soil ahead of the rotating cutting bit by the weight of the drill rods and hydraulic pulldown. The thin-walled sampling tube was retracted into the core barrel and the sampler was brought to the surface. After removal of the sampling tube from the core barrel, the length of the recovered soil sample was measured and recorded. Before preparing and sealing the tube, the drilling fluid in the Pitcher tube was removed. Cap plugs were taped in place on the top and bottom of the Pitcher tube and sealed with wax. When Pitcher samples could not be retrieved without disturbance, they were clearly marked as "disturbed." Each sealed Pitcher tube was labeled as explained under "Fugro Drive Samples" and then placed vertically in foam-lined wooden boxes.

B1.2.2.3 Wash Samples (Bulk Samples)

Wash samples (cuttings) were obtained by screening the returning drilling fluid during the drilling operations to obtain lithologic information between samples. Recovered wash samples were placed in plastic bags and labeled as explained previously.

B1.2.2.4 Standard Penetration Test Samples

These samples were obtained using split-spoon samplers. They are disturbed but representative soil samples. The split-spoon sampler consists of a barrel shoe, a split barrel or tube, a solid sleeve, and a sampler head. The inside diameter of the sampler shoe is 1.375 inches (35 mm) and the length is about 18 inches (45.7 cm). Sampling with the split-spoon sampler is accomplished by driving the sampler into the ground with a 140-pound (63.6-kg) hammer dropped 30 inches (76 cm). The number of blows required to drive the sampler a distance of 12 inches

(30.4 cm) was recorded as the Standard Penetration Resistance (N value; ASTM D 1586-67). The disturbed samples obtained from the split-spoon sampler were placed in plastic bags and labeled as explained previously.

B1.3 LOGGING

All soils were classified in the field as explained in Section B2.0. The following general information was entered on the boring logs at the time of drilling: boring number; project name, number, and location; name of drilling company and driller; name of logger and date logged; and method of drilling and sampling, drill bit type and size, driving weight and average drop as applicable.

B1.4 SAMPLE STORAGE AND TRANSPORTATION

Samples were handled with care, drive sample containers being placed in foam-lined steel boxes, while Pitcher samples were transported in foam-lined wooden boxes. Core samples were placed in specially constructed wooden or cardboard boxes. Particular care was exercised by drivers while traversing rough terrain so as not to cause any disturbance to the undisturbed samples. Whenever ambient air temperatures fell below 32°F, all samples were stored in heated rooms during the field work and transported to Fugro National's Long Beach laboratory in heated cabins in back of pickup trucks.

B2.0 EXPLANATIONS OF BORING LOGS

Logs of borings drilled in Reveille-Railroad and Big Smoky CDPs are presented on standard Fugro National logs in Figures B-1 through B-13. The following explanations are provided as a key to the logs.

A. Designations - Borings are identified as follows:

RR-B-1

RR - abbreviation for the site (e.g., RR-Reveille-Railroad)
B - abbreviation for activity (e.g., B-boring)
1 - number of activity

B. Sample Type - Different sampling techniques were used and the symbols are explained at the bottom of the boring logs. Horizontal lines, to scale, indicate the depth where sampling was attempted.

C. Percent Recovery - The numbers shown represent the ratio (in percent) of the soil sample recovered in the sampler to the full penetration of the sampler.

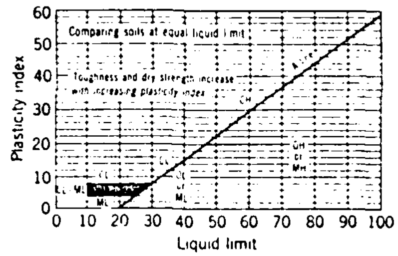
D. N Value - Corresponds to standard penetration resistance, which is number of blows required to drive a standard split-spoon sampler for the second and third of three 6-inch (15-cm) increments with a 140-pound (63.5-kg) hammer falling 30 inches (76 cm) (ASTM D 1586-67).

E. Depth - Corresponds to depth below ground surface in meters and feet.

F. Lithology - Graphic representation of the soil types.

G. USCS - Unified Soil Classification System (see Table B-1 for complete details) symbols.

Field Identification Procedures (Excluding particles larger than 3 in. and basing fractions on estimated weights)						Group Symbols [a]	Typical Names	Information Required for Describing Soils	Laboratory Classification Criteria
Coarse grained soils More than half of material is *larger* than No. 200 sieve size[b] (The No. 200 sieve size is about the smallest particle visible to naked eye)	Gravels More than half of coarse fraction is larger than No. 4 sieve size (For visual classification, the $\frac{1}{4}$ in. size may be used as equivalent to the No. 4 sieve size)	Clean gravels (little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes			*GW*	Well graded gravels, gravel-sand mixtures, little or no fines	Give typical name. indicate approximate percentages of sand and gravel, maximum size, angularity, surface condition, and hardness of the coarse grains, local or geologic name and other pertinent descriptive information, and symbols in *parentheses* For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics Example *Silty sand*, gravelly, about 20%, hard, angular gravel particles $\frac{1}{2}$-in maximum size, rounded and subangular sand grains coarse to fine, about 15% non-plastic fines with low dry *strength*, *well compacted and* moist in place, alluvial sand, (*SM*)	Use grain size curve in identifying the *fractions* as given under field identification Determine percentages of gravel and sand from grain size curve Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse grained soils are classified as follows Less than 5% *GW, GP, SW, SP* More than 12% *GM, GC, SM, SC* 5% to 12% *Borderline* cases requiring use of dual symbols $C_U = \frac{D_{60}}{D_{10}}$ Greater than 4 $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3
			Predominantly one size or a range of sizes with some intermediate sizes missing			*GP*	Poorly graded gravels, gravel-sand mixtures, little or no fines		Not meeting all gradation requirements for *GW*
		Gravels with fines (appreciable amount of fines)	Nonplastic fines (for identification procedures see *ML* below)			*GM*	Silty gravels, poorly graded gravel-sand-silt mixtures		Atterberg limits below "A" line, or *PI* less than 4 Above "A" line with *PI* between 4 and 7 are *borderline* cases requiring use of dual symbols
			Plastic fines (for identification procedures, see *CL* below)			*GC*	Clayey gravels, poorly graded gravel-sand-clay mixtures		Atterberg limits above "A" line with *PI* greater than 7
	Sands More than half of coarse fraction is smaller than No. 4 sieve size	Clean sands (little or no fines)	Wide range in grain sizes and substantial amounts of all intermediate particle sizes			*SW*	Well graded sands, gravelly sands, little or no fines		$C_U = \frac{D_{60}}{D_{10}}$ Greater than 6 $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3
			Predominantly one size or a range of sizes with some intermediate sizes missing			*SP*	Poorly graded sands, gravelly sands, little or no fines		Not meeting all gradation requirements for *SW*
		Sands with fines (appreciable amount of fines)	Nonplastic fines (for identification procedures, see *ML* below)			*SM*	Silty sands, poorly graded sand-silt mixtures		Atterberg limits below "A" line or *PI* less than 5 Above "A" line with *PI* between 4 and 7 are *borderline* cases requiring use of dual symbols
			Plastic fines (for identification procedures, see *CL* below)			*SC*	Clayey sands, poorly graded sand-clay mixtures		Atterberg limits below "A" line with *PI* greater than 7
Fine grained soils More than half of material is *smaller* than No. 200 sieve size			Identification Procedures on Fraction Smaller than No 40 Sieve Size						
			Dry Strength (crushing characteristics)	Dilatancy (reaction to shaking)	Toughness (consistency near plastic limit)				
	Silts and clays liquid limit less than 50		None to *slight*	Quick to *slow*	None	*ML*	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	Give typical name; indicate degree and character of plasticity, *amount and maximum size of* coarse grains, colour in wet condition, odour if any, local or geologic name, and other pertinent descriptive information, and symbol in parentheses For undisturbed soils add information on structure, stratification, consistency in undisturbed and remoulded states, moisture and drainage conditions Example. *Clayey silt*, brown; slightly *plastic*, *small percentage of* fine sand, numerous vertical root holes, firm and dry in place; loess, (*ML*)	
			Medium to high	None to very slow	Medium	*CL*	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays		
			Slight to medium	Slow	Slight	*OL*	Organic silts and organic silt-clays of low plasticity		
	Silts and clays liquid limit greater than 50		Slight to medium	Slow to none	Slight to medium	*MH*	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts		
			High to very high	None	High	*CH*	Inorganic clays of high plasticity, fat clays		
			Medium to high	None to very slow	Slight to medium	*OH*	Organic clays of medium to high plasticity		
Highly Organic Soils			Readily identified by colour, odour, spongy feel and frequently by fibrous texture			*Pt*	Peat and other highly organic soils		



Plasticity chart
for laboratory classification of fine grained soils

From Wagner, 1957.

[a] *Boundary classifications*. Soils possessing characteristics of two groups are designated by combinations of group symbols For example *GW-GC*, well graded gravel-sand mixture with clay binder.

[b] All sieve sizes on this chart are U S. standard.

Field Identification Procedure for Fine Grained Soils or Fractions

These procedures are to be performed on the minus No. 40 sieve size particles, approximately $\frac{1}{64}$ in. For field classification purposes, screening is not intended, simply remove by hand the coarse particles that interfere with the tests

Dilatancy (Reaction to shaking)

After removing particles larger than No 40 sieve size, prepare a pat of moist soil with a volume of about one-half cubic inch. Add enough water if necessary to make the soil soft but not sticky

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens and finally it cracks or crumbles The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction Inorganic silts, such as a typical rock flour, show a moderately quick reaction

Dry Strength (Crushing characteristics)

After removing particles larger than No. 40 sieve size, mould a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun or air drying, and then test its strength by breaking and crumbling between the fingers This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the CH group. A typical inorganic silt possesses only very slight dry strength Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

Toughness (Consistency near plastic limit).

After removing particles larger than the No 40 sieve size, a specimen of soil about one-half inch cube in size, is moulded to the consistency of putty If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about one-eight inch in diameter The thread is then folded and re-rolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays which occur below the A-line.

Highly organic clays have a very weak and spongy feel at the plastic limit.

UNIFIED SOIL CLASSIFICATION SYSTEM

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TABLE
B-1

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H. Soil Description - Except in cases where samples were classified based on laboratory test data, the descriptions are based on visual classification. The procedures outlined in ASTM D 2487-69, Classification of Soils for Engineering Purposes, and D 2488-69, Description of Soils (Visual-Manual Procedure), were followed. Solid lines across the column indicate known change in strata at the depth shown.

Definitions of some of the terms and criteria to describe soils and conditions encountered during the investigation follow.

Gradation : A coarse-grained soil is well graded if it has a wide range in grain size and substantial amounts of most intermediate particle sizes.

Poorly graded indicates that the soil consists predominantly of one size (uniformly graded) or has a wide range of sizes with some intermediate sizes obviously missing (gap-graded).

Moisture :
Dry - no feel of moisture
Slightly Moist - much less than normal moisture
Moist - normal moisture for soil
Very Moist - much greater than normal moisture
Wet - for soils below the water table (if known)

Consistency: Consistency descriptions of coarse-grained soils (GW, GP, GM, GC, SW, SP, SM, SC) are as follows.

Consistency	N Value (ASTM D 1586-67)
Very Loose	0 - 4
Loose	4 - 10
Medium Dense	10 - 30
Dense	30 - 50
Very Dense	>50

Consistency descriptions of fine-grained soils (ML, CL, MH, CH) are as follows:

Consistency	Shear Strength (ksf)	(kn/m^2)	Field Guide
Very Soft	0.25	12	Sample with height equal to twice the diameter, sags under own weight
Soft	0.25- 0.50	12 - 24	Can be squeezed between thumb and forefinger
Firm	0.50- 1.00	24- 48	Can be molded easily with fingers
Stiff	1.00- 2.00	48- 96	Can be imprinted with slight pressure from fingers
Very Stiff	2.00- 4.00	96- 192	Can be imprinted with considerable pressure from fingers
Hard	over 4.00	over 192	Cannot be imprinted by fingers

Grain Shape: Angular - particles have sharp edges and relatively plane sides with unpolished surfaces.

Subangular - particles are similar to angular but have somewhat rounded edges.

Subrounded - particles exhibit nearly plane sides but have well-rounded corners and edges.

Rounded - particles have smoothly curved sides and no edges.

Calcareous : Containing calcium carbonate; presence of calcium carbonate is commonly identified on the basis of reaction with dilute hydrochloric acid.

Caliche : Soils cemented by porous calcium carbonate and/or other soluble minerals by upward-moving solutions.

Secondary Material : Example - Sand with trace silt

Trace - 5-12% (by dry weight)
Little - 13-20% (by dry weight)
Some - >21% (by dry weight)

Plasticity : Plasticity index is the range of water content, expressed as a percentage of the weight of the oven-dried soil, through which the soil is plastic. It is defined as the liquid limit minus the plastic limit. Descriptive ranges used on the logs include:

Nonplastic (PI, 0 - 4)
Slightly Plastic (PI, 4 - 15)
Medium Plastic (PI, 15 - 30)
Highly Plastic (PI, >31)

Cobbles and Boulders : A cobble is a rock fragment, usually rounded by weathering or abrasion, with an average diameter ranging between 3 and 12 inches (8 and 30 cm).

A boulder is a rock fragment, usually rounded by weathering or abrasion, with an average diameter of 12 inches (30 cm) or more.

I. Remarks - This column was provided on boring logs for comments regarding drilling difficulty, number and size of cobbles or boulders encountered, loss of drilling fluid in the boring, and other conditions encountered during drilling.

J. Dry Density and Moisture Content - The boring logs include a graphical display of laboratory test results for dry density in pounds per cubic foot and kilograms per cubic meter and moisture content (ASTM D 2216-71) in percent from representative samples taken during drilling. The symbols are explained at the bottom of the boring logs.

K. Sieve Analysis - The numbers represent the percentage by dry weight (ASTM D 422-63) of each of the following soil components:

GR - Gravel; rock particles that will pass a 3-inch (76-mm) sieve and are retained on No. 4 (4.75 mm) sieve.

SA - Sand; soil particles passing No. 4 sieve and retained on No. 200 (0.075 mm) sieve.

FI - Fines (silt or clay); soil particles passing No. 200 sieve.

L. Atterberg Limits (LL and PI) -

LL - Liquid Limit, the water content corresponding to the arbitrary limit between the liquid and plastic states of consistency of a soil (ASTM D 423-66).

PL - Plastic Limit, the water content corresponding to an arbitrary limit between the plastic and the semisolid state of consistency of a soil (ASTM D 424-59).

PI - Plasticity Index, numerical difference between the liquid limit (LL) and the plastic limit (PL) indicating the range of moisture content within which a soil-water mixture is plastic.

NP - Nonplastic.

M. Miscellaneous Information -

Elevations - indicated elevations on the logs are estimated from topographic maps of the study area, within an accuracy of half the contour interval.

Surficial Geologic Unit - indicates the surficial geologic unit in which the activity is located.

Date Drilled - indicates the period from beginning to completion of the activity.

Drilling Method - signifies the type of drilling procedure used such as rotary wash.

Hole Diameter - nominal size of boring drilled.

Water Level - indicates depth from ground surface to water table where encountered.

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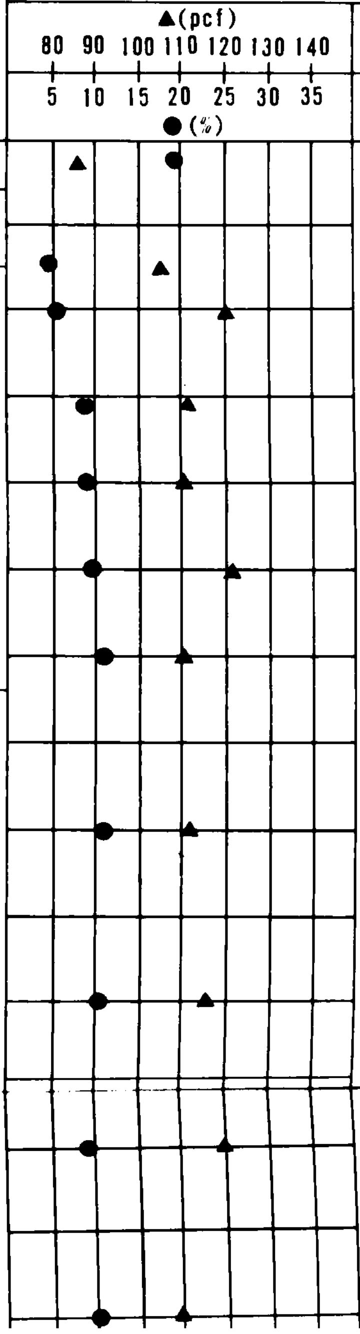
SAMPLE TYPE	% RECOVERY	N VALUE	DEPTH METERS	DEPTH FEET	LITHOLOGY	USCS	SOIL DESCRIPTION	REMARKS	SIEVE ANALYSIS GR	SIEVE ANALYSIS SA	SIEVE ANALYSIS FI	LL	PI
	100		0	0		SM	**SILTY SAND**, light brown, fine to coarse, poorly graded, loose to dense, angular to subangular, calcareous; little to some silt; trace to little fine angular to subangular gravel; lense of sandy clay (0.5'-1.2')						
	47							drill chatter					
	80					SP			13	85	2		
	100		3	10		SM			37	43	20		
	100					SP	**GRAVELLY SAND**, brown, fine to coarse, poorly to well graded, very dense, angular to subangular calcareous; some fine to coarse angular to subangular gravel; layer of silty sand (9.0'-10.5').		26	71	3		
	100		6	20									
	100					SW			33	64	3		
	100		9	30									
	100					SM	**SILTY SAND** light brown fine to coarse poorly graded, very dense, angular to subangular, calcareous; little silt; little fine subangular gravel.						
	100		12	40		SW-SM	**SAND**, light brown, fine to coarse, well graded, very dense, angular to subangular; trace fine angular to subrounded gravel; trace silt.		11	81	8		
	100		15	50									
	100		18	60			**GRAVELLY SAND**, brown, fine to coarse, poorly graded, very dense, angular to subangular; trace to some fine angular to subangular gravel; little silt; layer of silty sand (59.0'-62.5').		1	85	14		
			21										



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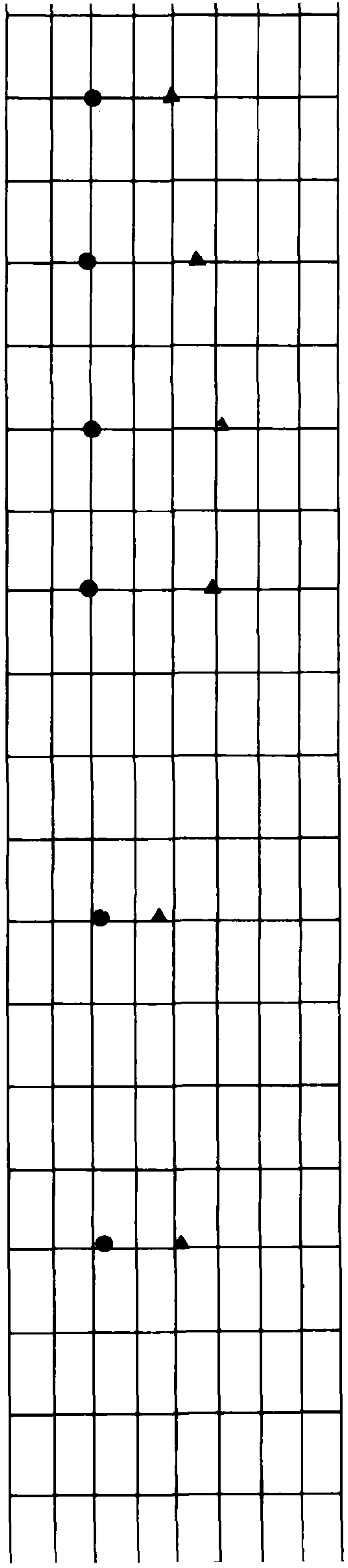
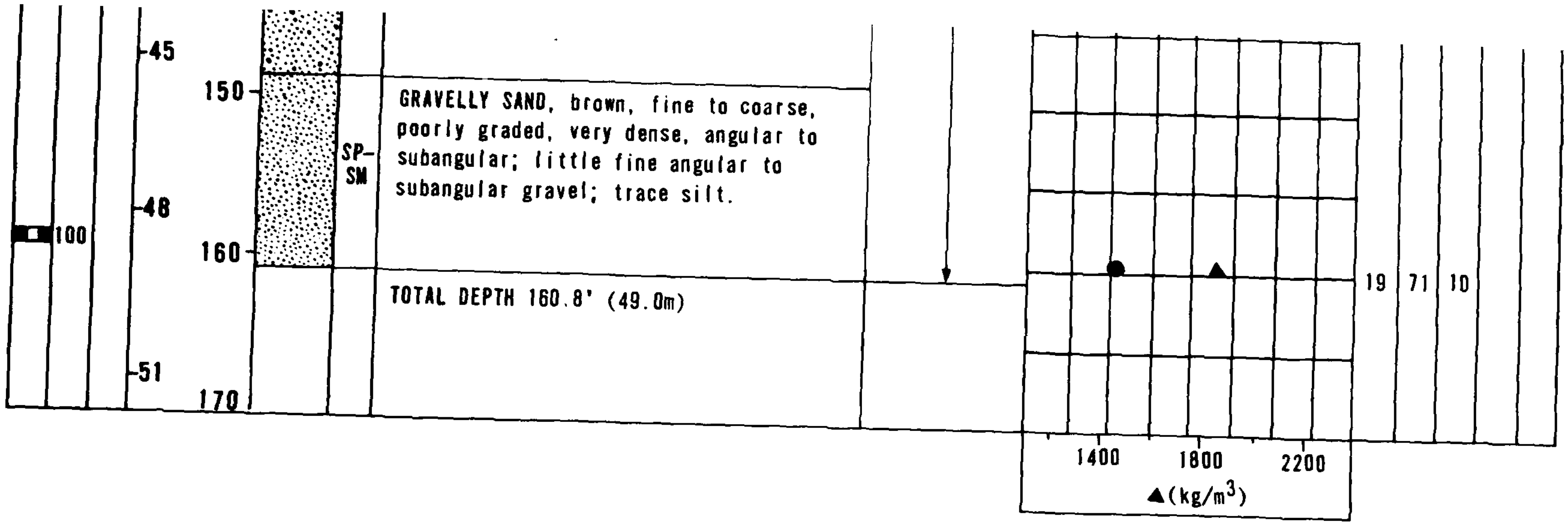
100	-21	70	SM	to subangular gravel; little silt; layer of silty sand (59.0'-62.5').				
100	-24	80						
100	-27	90				42	43	15
100	-30	100			drill chatter			
100	-33	110						
100	-36	120						
	-39	130	SW	**SAND**, brown, fine to coarse, well graded, very dense, angular to subangular; trace fine angular to subangular gravel.				
100	-42	140				10	86	4
	-45	150	SP-SM	**GRAVELLY SAND**, brown, fine to coarse, poorly graded, very dense, angular to subangular; little fine angular to subangular gravel; trace silt.				
	-48							





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EXPLANATION

- ◧ FUGRO DRIVE SAMPLE
- ▥ BULK SAMPLE
- ■ PITCHER TUBE SAMPLE
- ◨ STANDARD PENETRATION TEST SAMPLE
- ▨ CORE SAMPLE

N - STANDARD PENETRATION RESISTANCE

▲ - DRY UNIT WEIGHT

● - MOISTURE CONTENT (ASTM: D-2216-71)

NR - NO RECOVERY

BORING DETAILS

ELEVATION : 5600' (1707m)
SURFICIAL GEOLOGIC UNIT : A2
DATE DRILLED : 20- 21 MARCH 1979
DRILLING METHOD : Rotary Wash
HOLE DIAMETER : 4 7/8" (124mm)
WATER LEVEL : Not Encountered

LOG OF BORING RR-B-1
VERIFICATION SITE
REVEILLE-RAILROAD CDP, NEVADA

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FIGURE
B-1

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AFV-06

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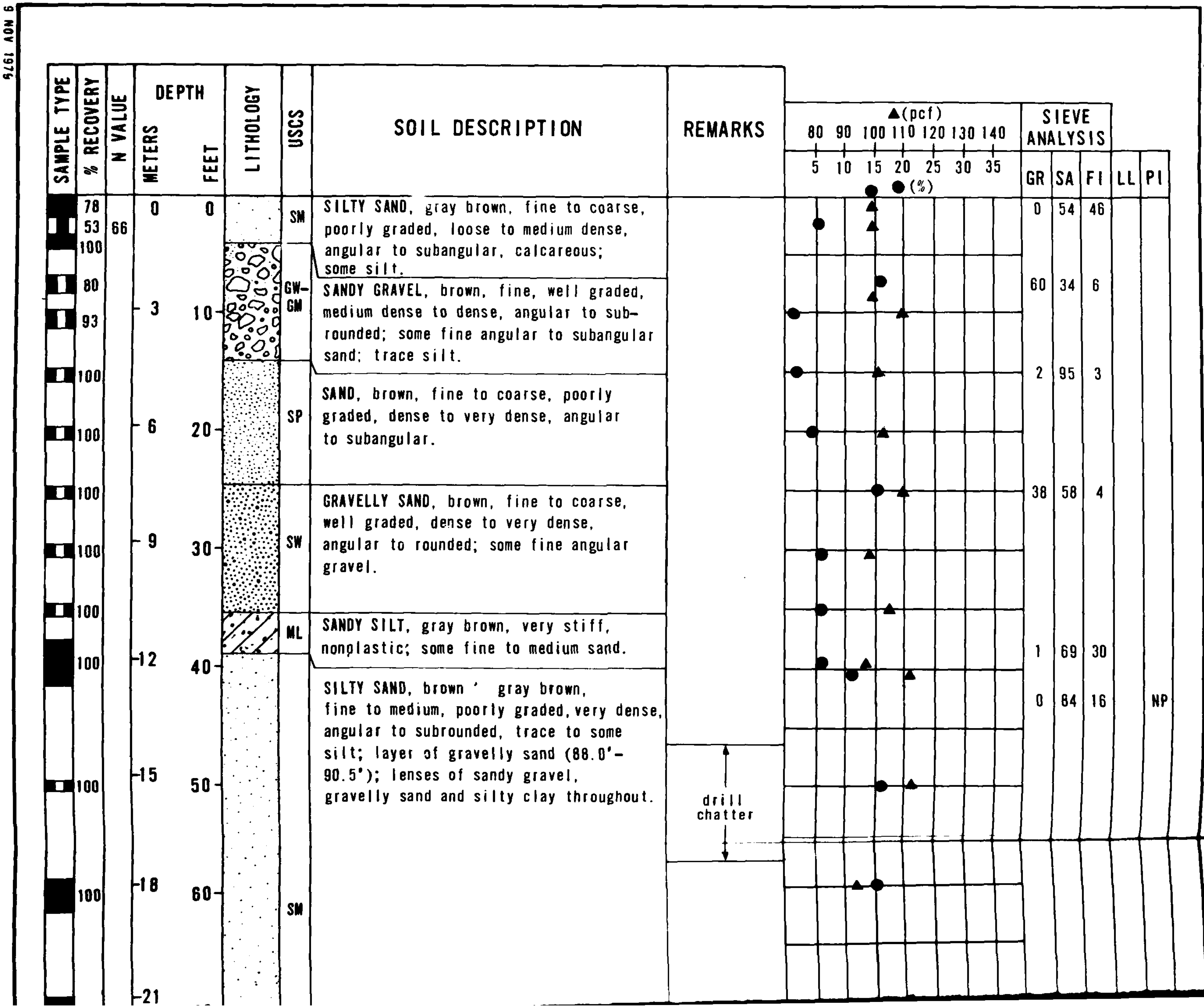

SOIL DESCRIPTION

SILTY SAND, gray brown, fine to coarse, poorly graded, loose to medium dense, angular to subangular, calcareous; some silt.

SANDY GRAVEL, brown, fine, well graded, medium dense to dense, angular to subrounded; some fine angular to subangular sand; trace silt.

SAND, brown, fine to coarse, poorly graded, dense to very dense, angular to subangular.

GRAVELLY SAND, brown, fine to coarse, well graded, dense to very dense, angular to rounded; some fine angular gravel.

SANDY SILT, gray brown, very stiff, nonplastic; some fine to medium sand.

SILTY SAND, brown ' gray brown, fine to medium, poorly graded, very dense, angular to subrounded, trace to some silt; layer of gravelly sand (88.0'-90.5'); lenses of sandy gravel, gravelly sand and silty clay throughout.

SIEVE ANALYSIS				
GR	SA	FI	LL	PI
0	54	46		
60	34	6		
2	95	3		
38	58	4		
1	69	30		
0	84	16		NP

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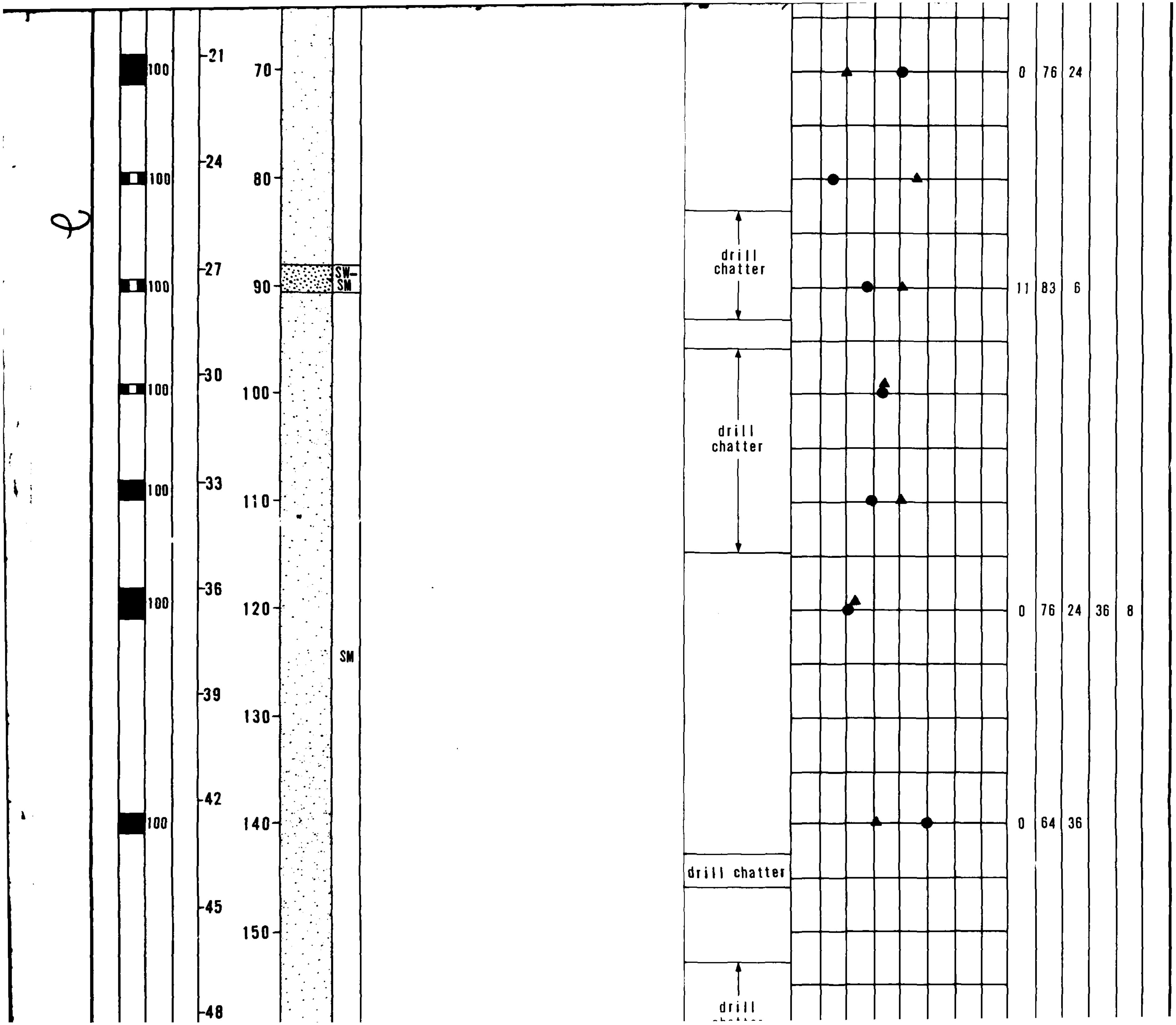
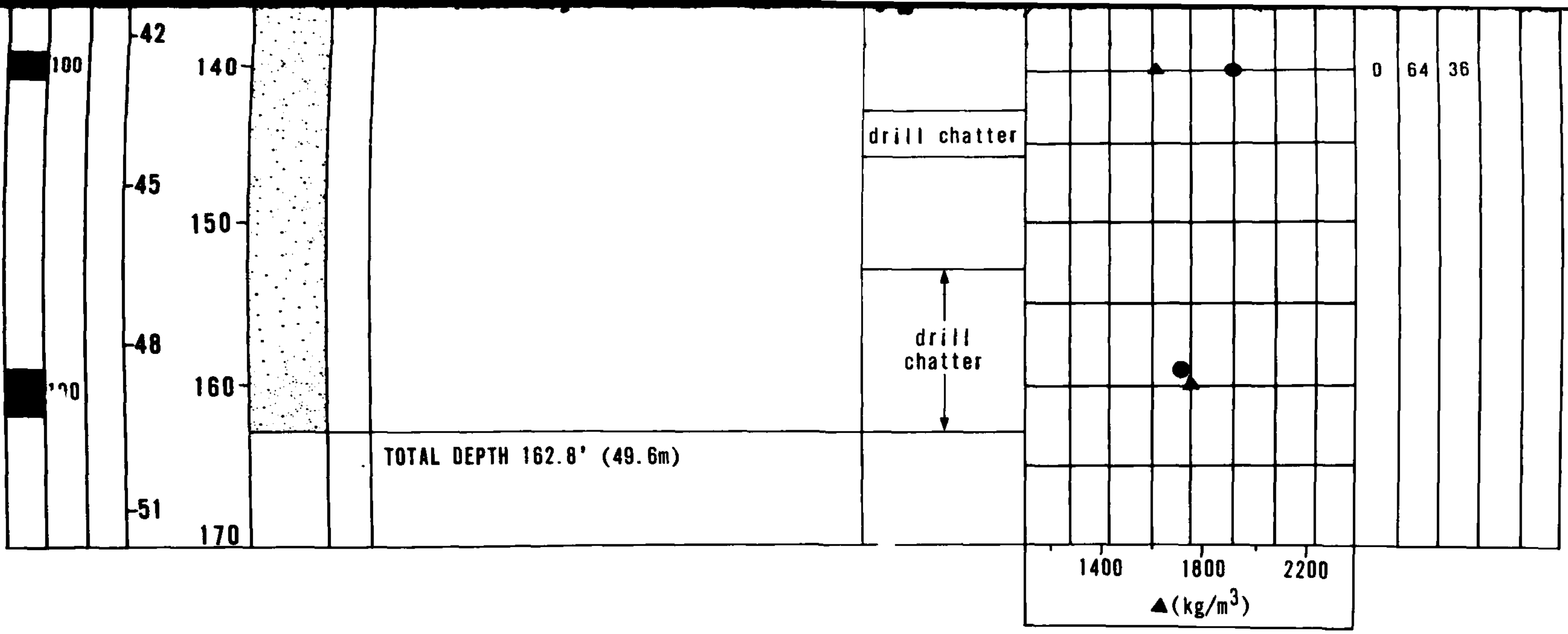

100
100
100
100
100
100
100
-21
-24
-27
-30
-33
-36
-39
-42
-45
-48
70
80
90
100
110
120
130
140
150
SW-SM
SM
drill chatter
drill chatter
drill chatter
drill
0 76 24
11 83 6
0 76 24 36 8
0 64 36

2



EXPLANATION

- ◧ FUGRO DRIVE SAMPLE
- ▥ BULK SAMPLE
- ■ PITCHER TUBE SAMPLE
- ◨ STANDARD PENETRATION TEST SAMPLE
- ▨ CORE SAMPLE
- N - STANDARD PENETRATION RESISTANCE
- ▲ - DRY UNIT WEIGHT
- ● - MOISTURE CONTENT (ASTM: D-2216-71)
- NR - NO RECOVERY

BORING DETAILS

ELEVATION : 4930' (1503m)
SURFICIAL GEOLOGIC UNIT : A4o
DATE DRILLED : 21-22 March 1979
DRILLING METHOD : Rotary Wash
HOLE DIAMETER : 4 7/8" (124mm)
WATER LEVEL : Not Encountered

LOG OF BORING RR-B-2
VERIFICATION SITE
REVEILLE-RAILROAD CDP, NEVADA

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DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE
B-2

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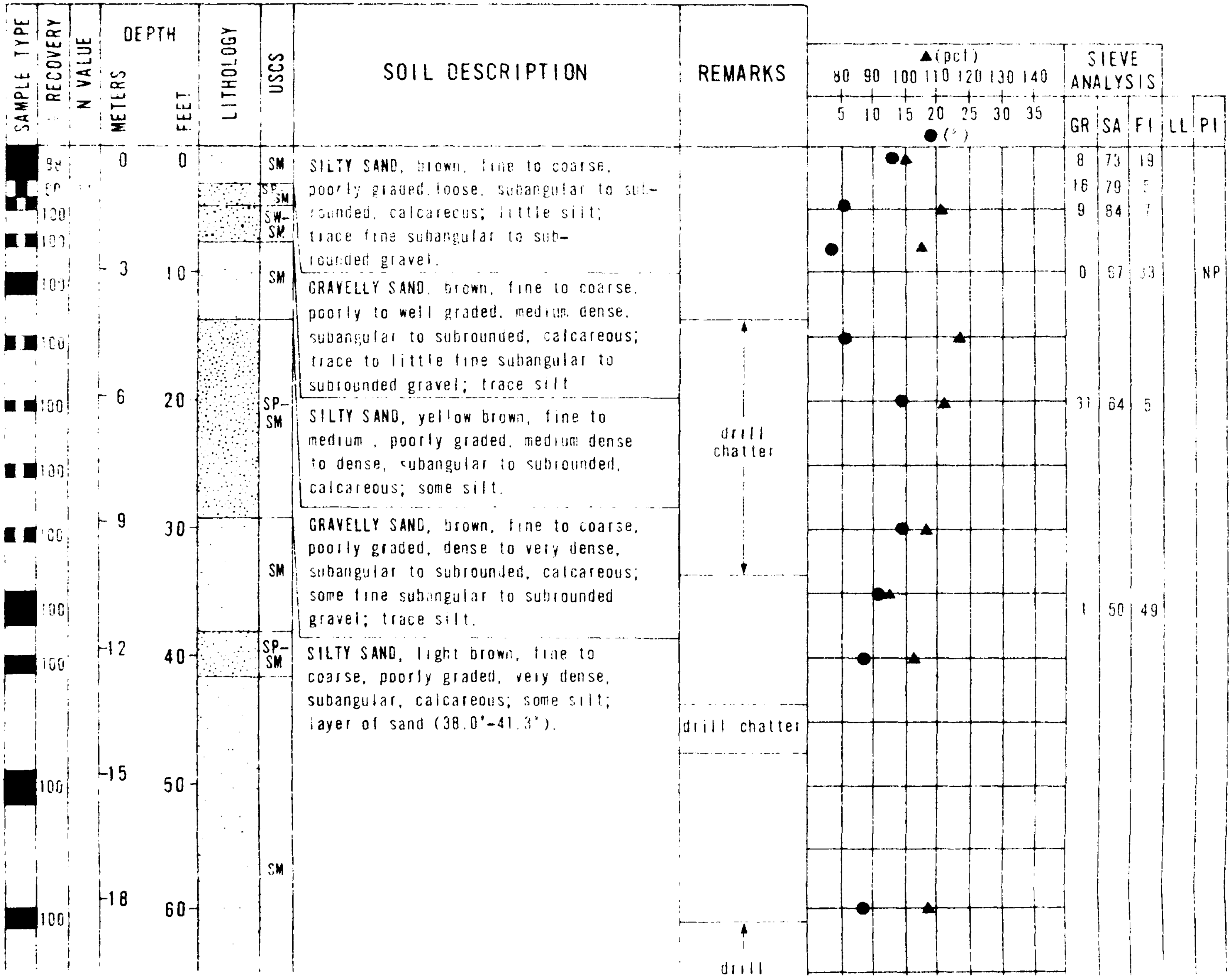
AFV-06



SILTY SAND, brown, fine to coarse, poorly graded, loose, subangular to subrounded, calcareous; little silt; trace fine subangular to subrounded gravel.

GRAVELLY SAND, brown, fine to coarse, poorly to well graded, medium dense, subangular to subrounded, calcareous; trace to little fine subangular to subrounded gravel; trace silt

SILTY SAND, yellow brown, fine to medium, poorly graded, medium dense to dense, subangular to subrounded, calcareous; some silt.

GRAVELLY SAND, brown, fine to coarse, poorly graded, dense to very dense, subangular to subrounded, calcareous; some fine subangular to subrounded gravel; trace silt.

SILTY SAND, light brown, fine to coarse, poorly graded, very dense, subangular, calcareous; some silt; layer of sand (38.0'-41.3').

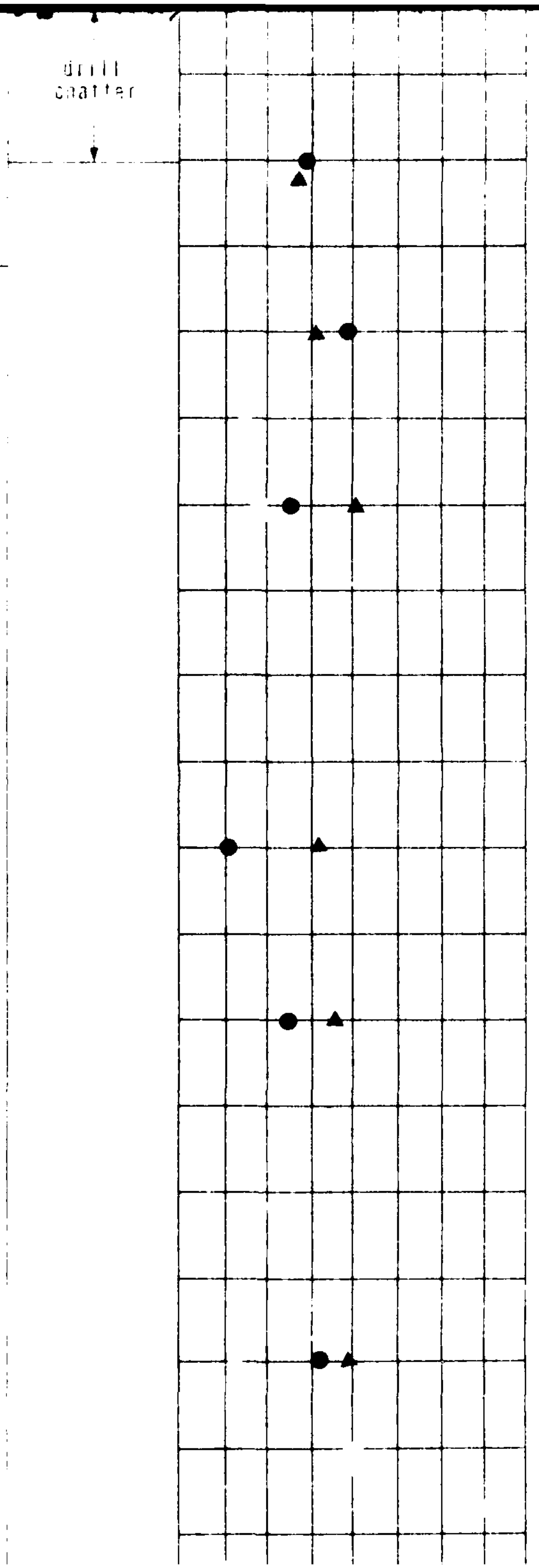
GR	SA	FI	LL	PI
8	73	19		
16	79	5		
9	84	7		
0	67	33		NP
31	64	5		
1	50	49		

2

-21	70	100	0	77	23
-24	80	100			
-27	90	100			
-30	100	100	0	98	2
-33	110	100			
-36	120	100			
-39	130				
-42	140	100	11	83	6
-45	150				

SP

SAND, brown, fine to coarse, poorly graded, very dense, subangular to subrounded; trace fine subangular gravel (141.2'-142 0'); lenses of silty sand and sand throughout



AD-A112 408 FUGRO NATIONAL INC LONG BEACH CA F/G 8/13
THERMAL PROPERTIES OF SOILS.(U)
NOV 79 F04704-80-C-0006
UNCLASSIFIED FN-TR-29 NL

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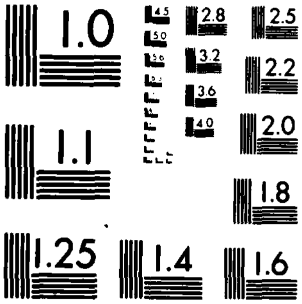
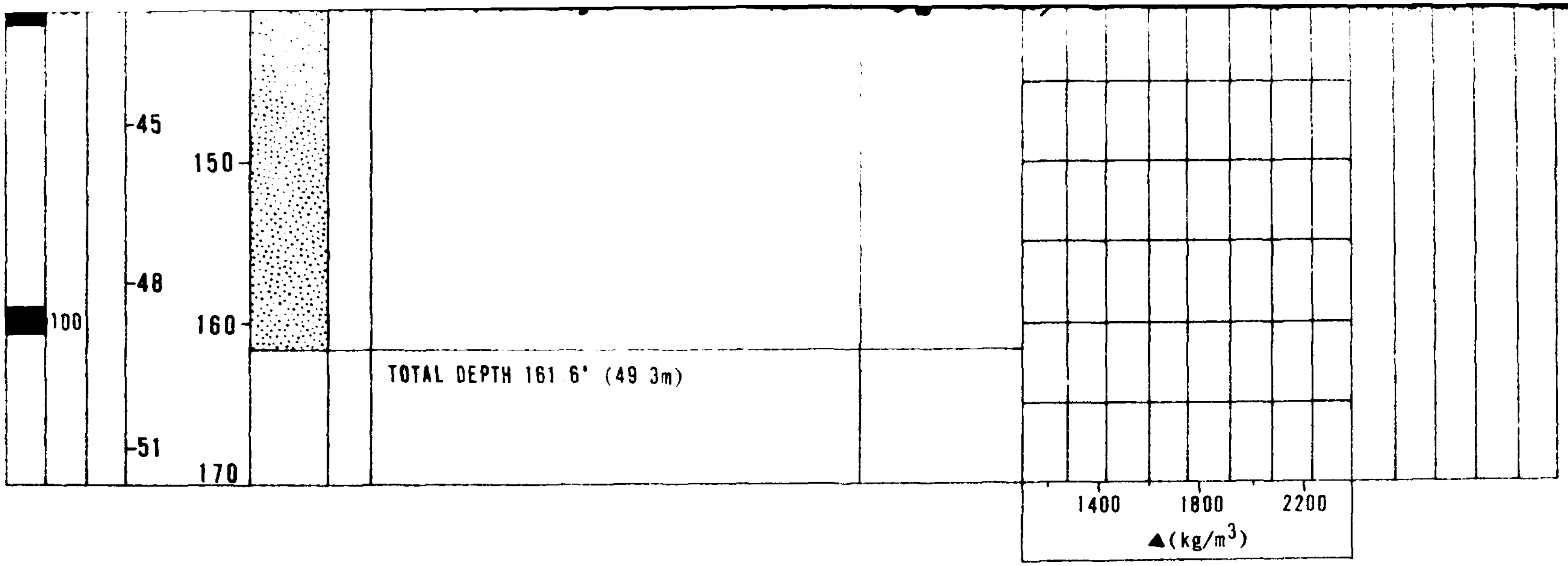


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



EXPLANATION

- ◨ FUGRO DRIVE SAMPLE
- ▥ BULK SAMPLE
- ■ PITCHER TUBE SAMPLE
- ◧ STANDARD PENETRATION TEST SAMPLE
- ▨ CORE SAMPLE
- N - STANDARD PENETRATION RESISTANCE
- ▲ - DRY UNIT WEIGHT
- ● - MOISTURE CONTENT (ASTM: D-2216-71)
- NR - NO RECOVERY

BORING DETAILS

ELEVATION : 4965' (1513m)
SURFICIAL GEOLOGIC UNIT : 23 March 1979
DATE DRILLED : A5y
DRILLING METHOD : Rotary Wash
HOLE DIAMETER : 4 7/8" (124mm)
WATER LEVEL : Not Encountered

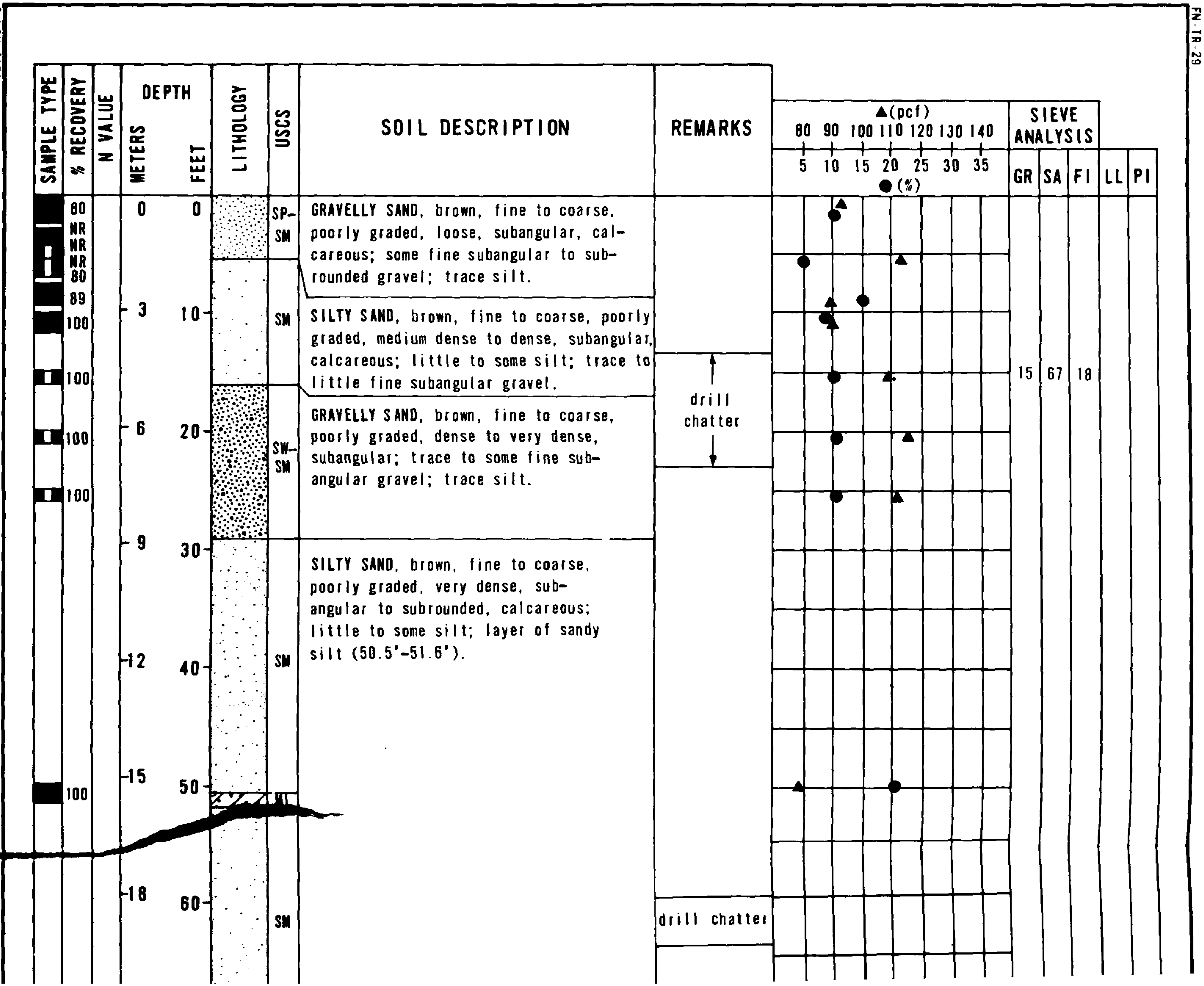
LOG OF BORING RR-B-3
VERIFICATION SITE
REVEILLE-RAILROAD CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSC

FIGURE
B-3

FUGRO NATIONAL, INC.

CHECKED BY________________ APPROVED BY________________



GRAVELLY SAND, brown, fine to coarse, poorly graded, loose, subangular, calcareous; some fine subangular to subrounded gravel; trace silt.

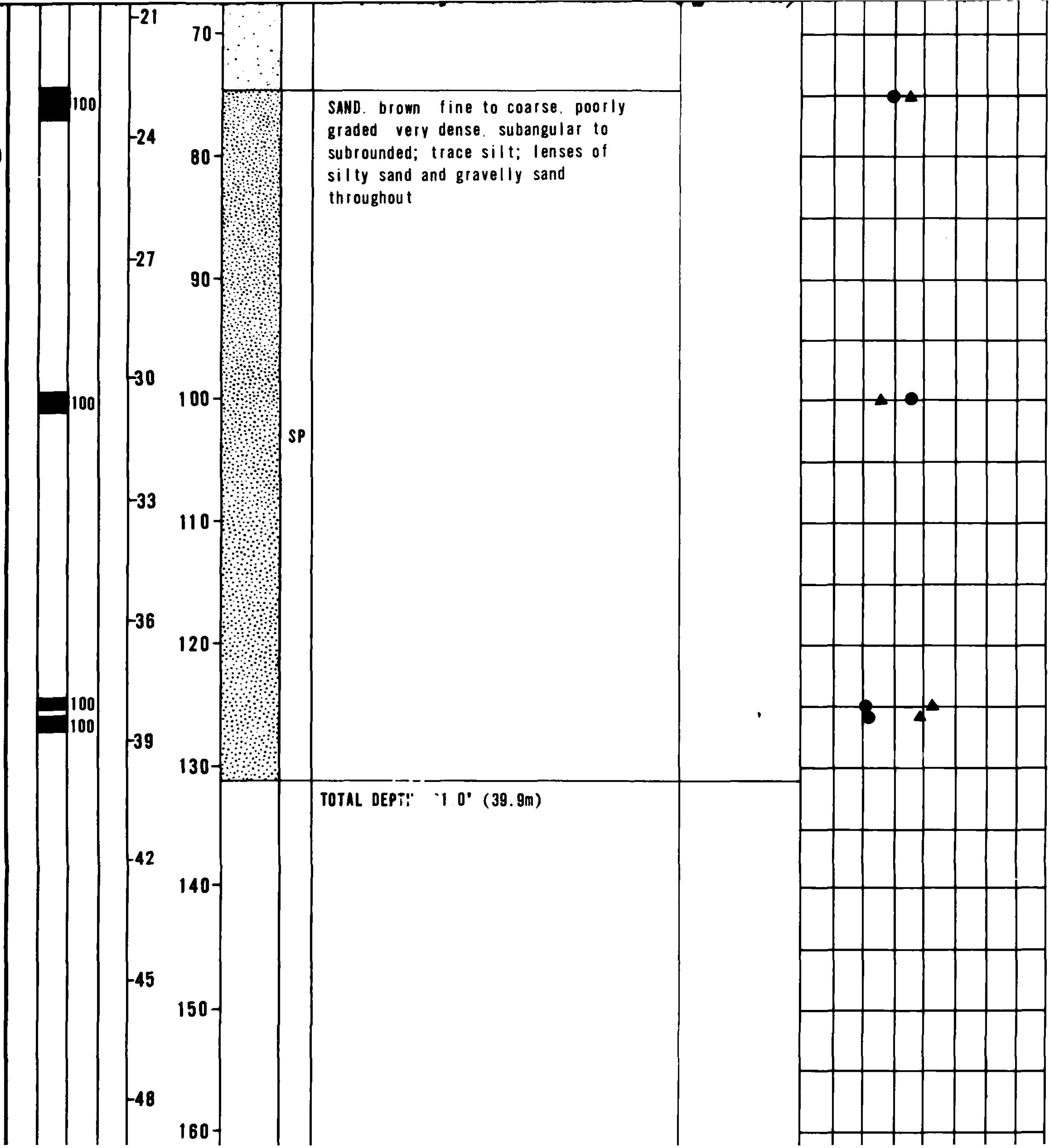
SILTY SAND, brown, fine to coarse, poorly graded, medium dense to dense, subangular, calcareous; little to some silt; trace to little fine subangular gravel.

GRAVELLY SAND, brown, fine to coarse, poorly graded, dense to very dense, subangular; trace to some fine subangular gravel; trace silt.

SILTY SAND, brown, fine to coarse, poorly graded, very dense, subangular to subrounded, calcareous; little to some silt; layer of sandy silt (50.5'-51.6').

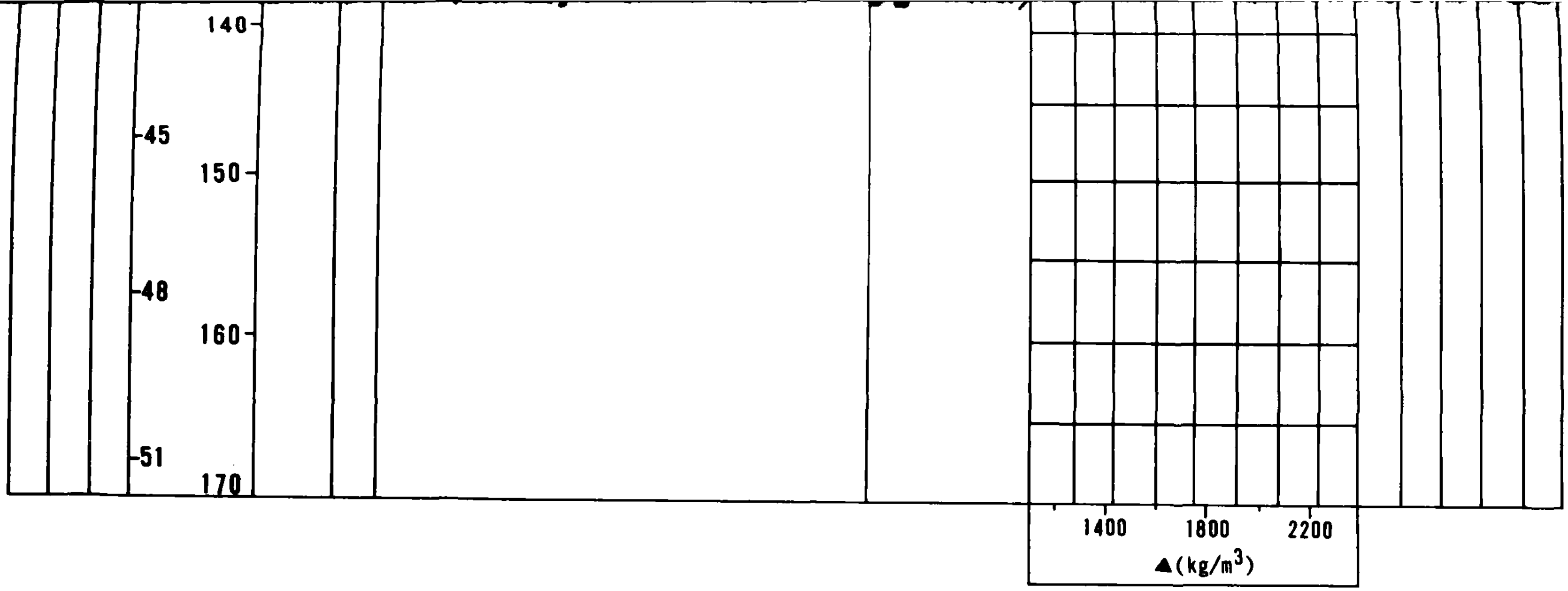
9 NOV 1979

2



SAND. brown fine to coarse. poorly graded very dense. subangular to subrounded; trace silt; lenses of silty sand and gravelly sand throughout

TOTAL DEPT:' `1 0' (39.9m)



3

EXPLANATION

- ◧ FUGRO DRIVE SAMPLE
- ▥ BULK SAMPLE
- ■ PITCHER TUBE SAMPLE
- ◨ STANDARD PENETRATION TEST SAMPLE
- ▨ CORE SAMPLE
- N - STANDARD PENETRATION RESISTANCE
- ▲ - DRY UNIT WEIGHT
- ● - MOISTURE CONTENT (ASTM: D-2216-71)
- NR - NO RECOVERY

BORING DETAILS

ELEVATION : 4965' (1513m)
SURFICIAL GEOLOGIC UNIT : A5y
DATE DRILLED : 2-3 April 1979
DRILLING METHOD : Rotary Wash
HOLE DIAMETER : 4 7/8" (124mm)
WATER LEVEL : Not Encountered

LOG OF BORING RR-B-3A
VERIFICATION SITE
REVEILLE-RAILROAD CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
B-4

FUGRO NATIONAL, INC.

AFV-06

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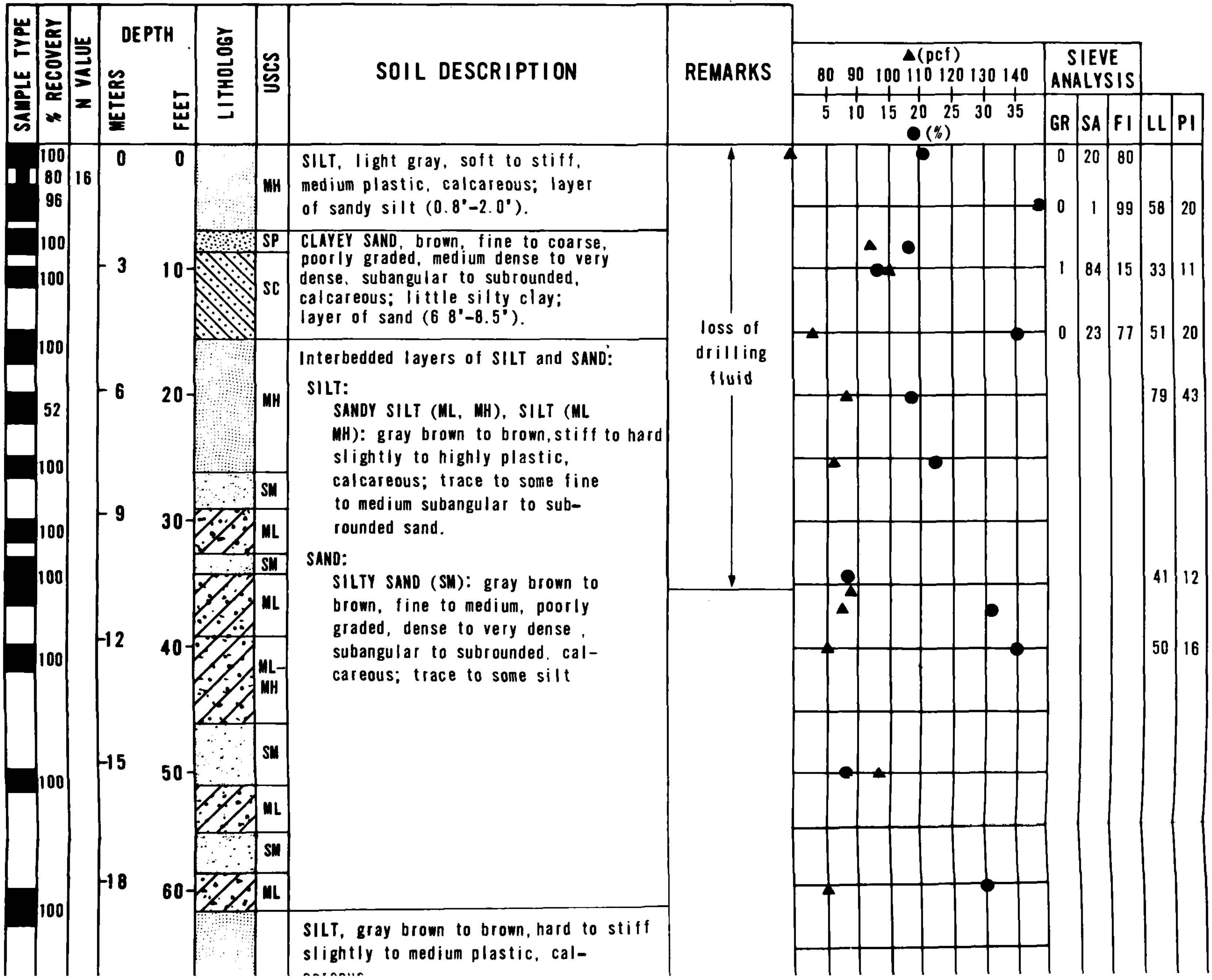
9 NOV 1978

FN-TR-29



SOIL DESCRIPTION

SILT, light gray, soft to stiff, medium plastic, calcareous; layer of sandy silt (0.8'-2.0').

CLAYEY SAND, brown, fine to coarse, poorly graded, medium dense to very dense, subangular to subrounded, calcareous; little silty clay; layer of sand (6.8'-8.5').

Interbedded layers of SILT and SAND:

SILT:

SANDY SILT (ML, MH), SILT (ML MH): gray brown to brown, stiff to hard slightly to highly plastic, calcareous; trace to some fine to medium subangular to subrounded sand.

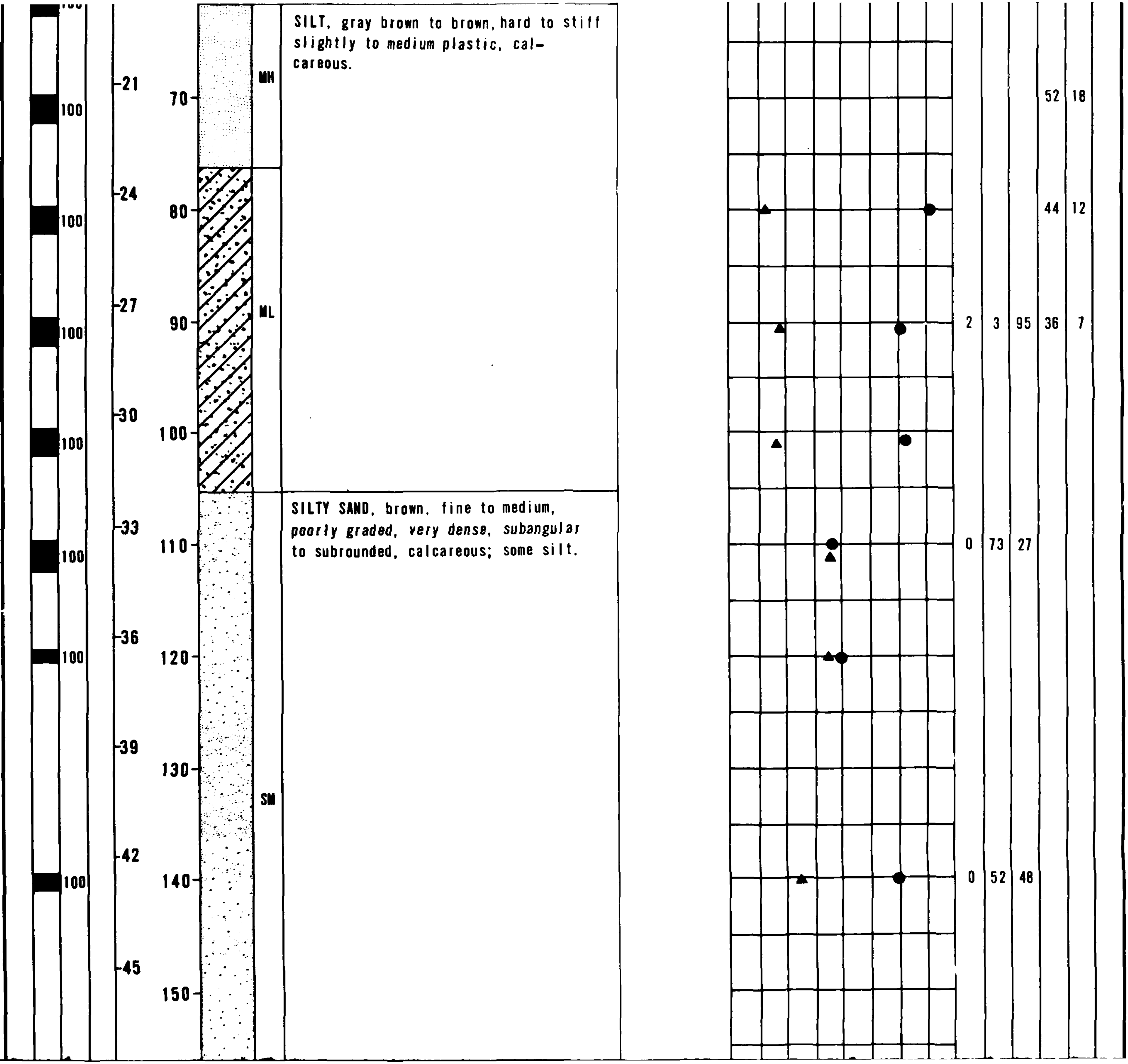
SAND:

SILTY SAND (SM): gray brown to brown, fine to medium, poorly graded, dense to very dense , subangular to subrounded, calcareous; trace to some silt

SILT, gray brown to brown, hard to stiff slightly to medium plastic, cal-

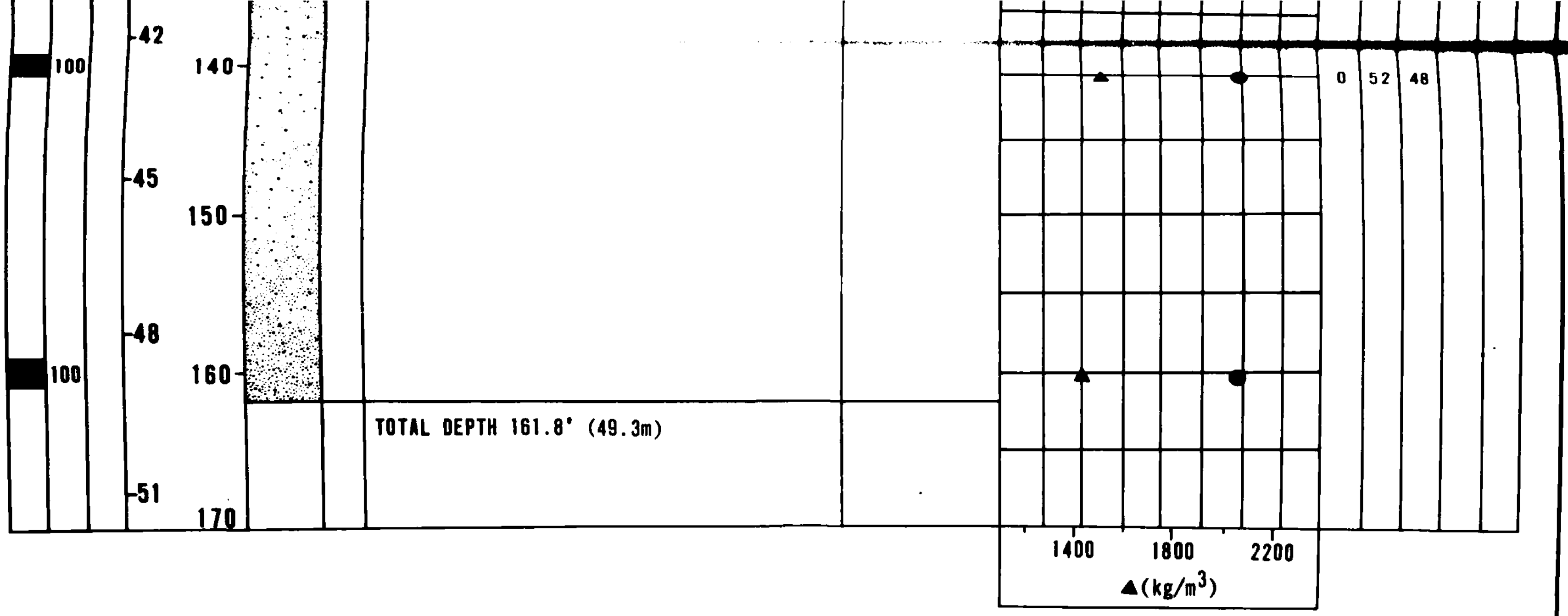
SIEVE ANALYSIS				
GR	SA	FI	LL	PI
0	20	80		
0	1	99	58	20
1	84	15	33	11
0	23	77	51	20
			79	43
			41	12
			50	16

2



SILT, gray brown to brown, hard to stiff slightly to *medium plastic*, calcareous.

SILTY SAND, brown, fine to medium, *poorly graded*, *very dense*, subangular to subrounded, calcareous; some silt.



EXPLANATION

- ◧ FUGRO DRIVE SAMPLE
- ▥ BULK SAMPLE
- ■ PITCHER TUBE SAMPLE
- ◫ STANDARD PENETRATION TEST SAMPLE
- ▨ CORE SAMPLE
- N - STANDARD PENETRATION RESISTANCE
- ▲ - DRY UNIT WEIGHT
- ● - MOISTURE CONTENT (ASTM: D-2216-71)
- NR - NO RECOVERY

BORING DETAILS

ELEVATION : 4855' (1480m)
SURFICIAL GEOLOGIC UNIT : A4o
DATE DRILLED : 24-25 March 1979
DRILLING METHOD : Rotary Wash
HOLE DIAMETER : 4 7/8" (124mm)
WATER LEVEL : 79' (24.1m)

LOG OF BORING RR-B-4
VERIFICATION SITE
REVEILLE-RAILROAD CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
B-5

FUGRO NATIONAL, INC.

AFV-08

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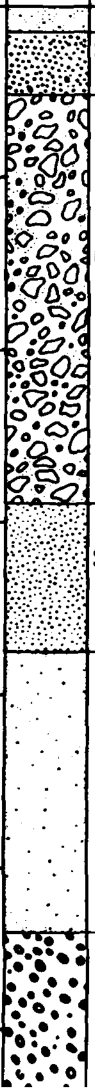
FN-TR-29

9 NOV 1978

SAMPLE TYPE	% RECOVERY	N VALUE	DEPTH METERS	DEPTH FEET	USCS
	80		0	0	SM
	33	13			SW-SM
	100				
	100				GW-GM
	100		3	10	
	100				
	100		6	20	
	100				
	100		9	30	SP-SM
	100				
	100		12	40	SM
	100		15	50	
	100		18	60	



SOIL DESCRIPTION

Interbedded layers of SAND and GRAVEL:

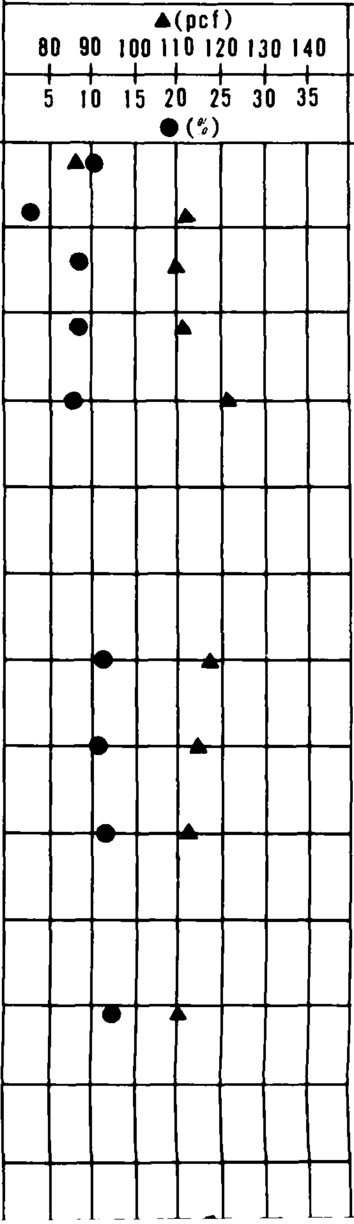
SAND:

GRAVELLY SAND (SP-SM, SW-SM, SM): brown, fine to coarse, poorly to well graded, dense to very dense, angular to subangular, calcareous; some fine to coarse angular to subangular gravel; trace to little silt; occasional cobbles to 7" size; layer of silty sand (0.0'-1.5').

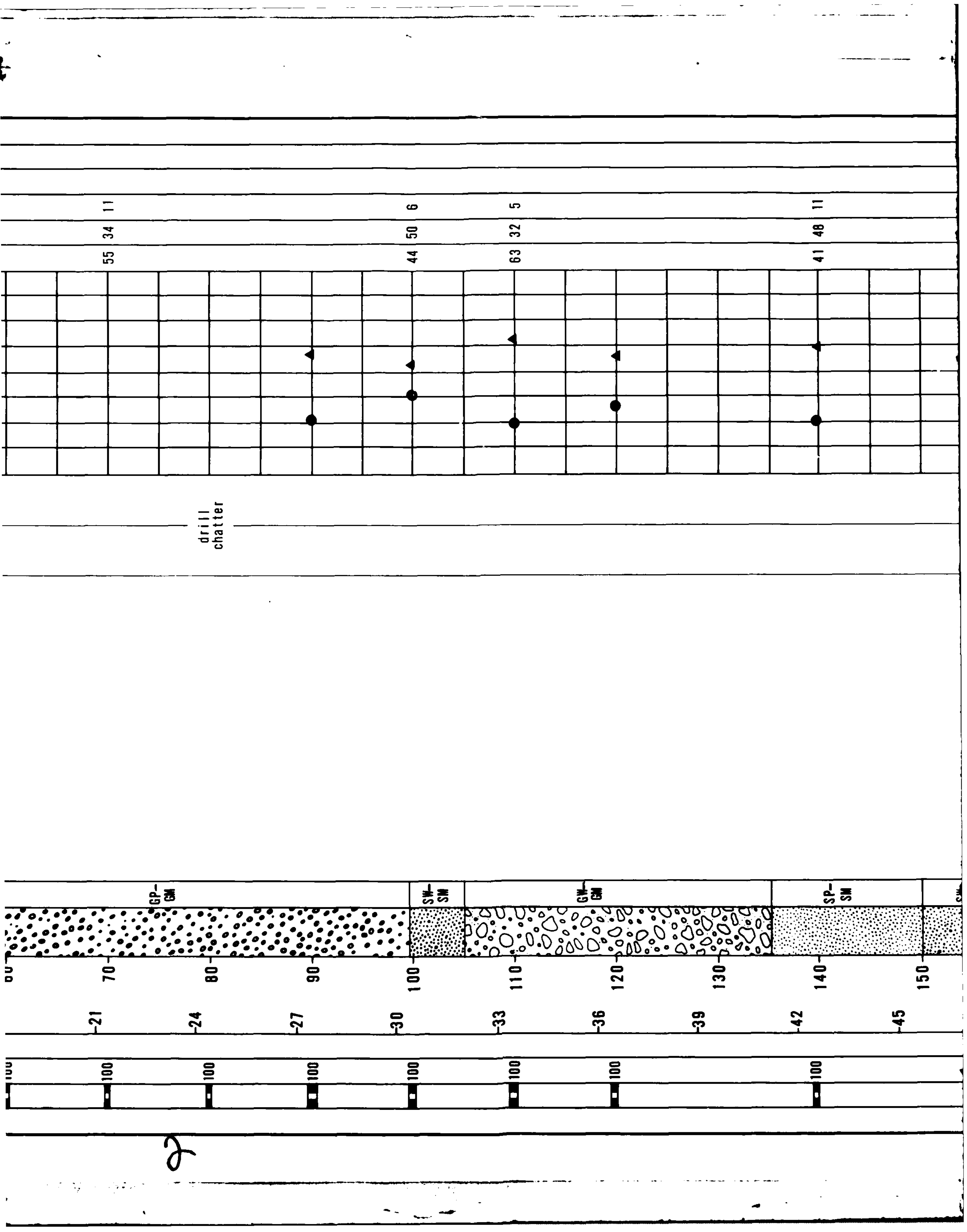
GRAVEL:

SANDY GRAVEL (GP-GM, GW-GM): brown, fine to coarse, poorly to well graded, dense to very dense, angular to subangular, calcareous; some fine to coarse angular to subangular sand; trace silt.

REMARKS

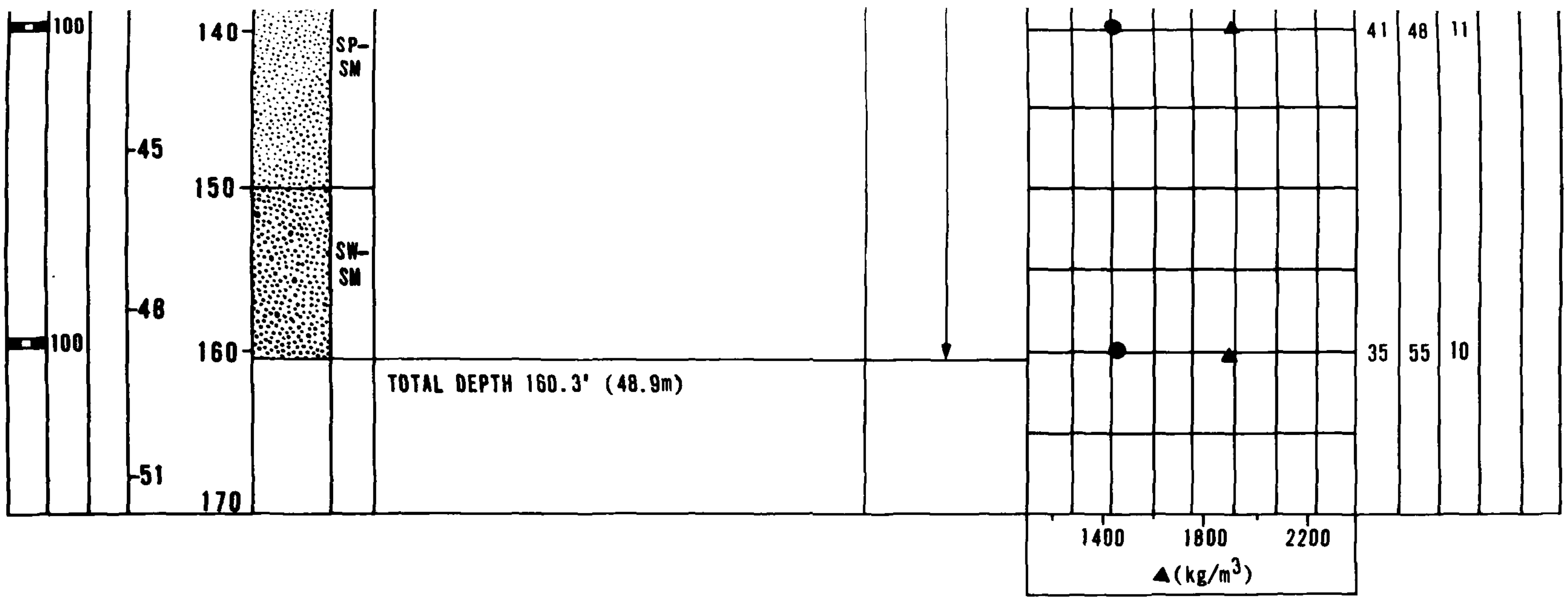


SIEVE ANALYSIS GR	SA	FI	LL	PI
39	53	8		
54	36	10		
60	32	8		
41	50	9		
22	58	20		



55
34
11
44
50
6
63
32
5
41
48
11
drill chatter
GP–GM
SW–SM
GW–GM
SP–SM
70
80
90
100
110
120
130
140
150
-21
-24
-27
-30
-33
-36
-39
-42
-45
100
100
100
100
100
100
100
100

2



3

EXPLANATION

- ◧ FUGRO DRIVE SAMPLE
- ▥ BULK SAMPLE
- ■ PITCHER TUBE SAMPLE
- ◫ STANDARD PENETRATION TEST SAMPLE
- ▨ CORE SAMPLE
- N - STANDARD PENETRATION RESISTANCE
- ▲ - DRY UNIT WEIGHT
- ● - MOISTURE CONTENT (ASTM: D-2216-71)
- NR - NO RECOVERY

BORING DETAILS

ELEVATION : 5500' (1676m)
SURFICIAL GEOLOGIC UNIT : A5i
DATE DRILLED : 25-26 March 1979
DRILLING METHOD : Rotary Wash
HOLE DIAMETER : 4 7/8" (124mm)
WATER LEVEL : Not Encountered

LOG OF BORING RR-B-5
VERIFICATION SITE
REVEILLE-RAILROAD CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE
B-6

FUGRO NATIONAL, INC.

AFV-06

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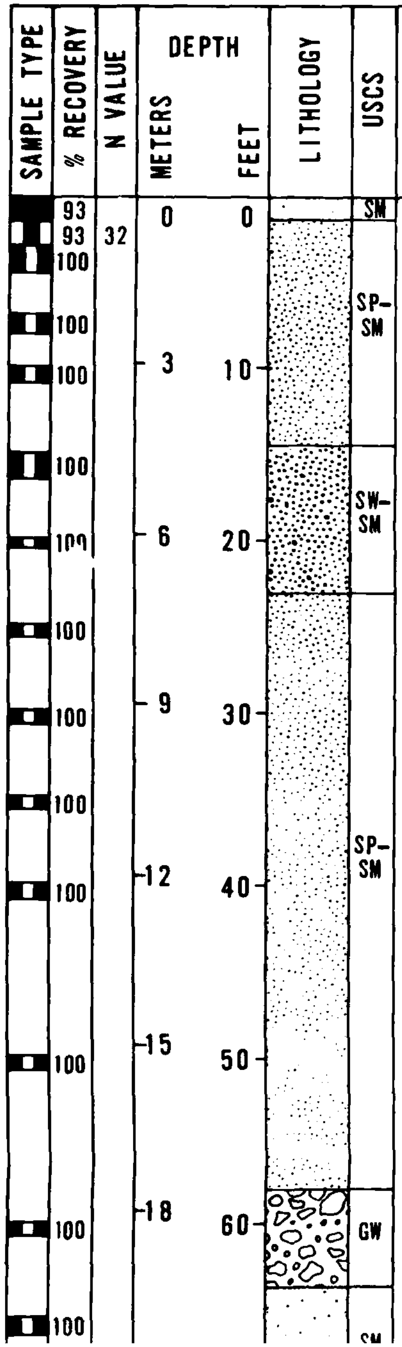


SOIL DESCRIPTION

Interbedded layers of SAND and GRAVEL:

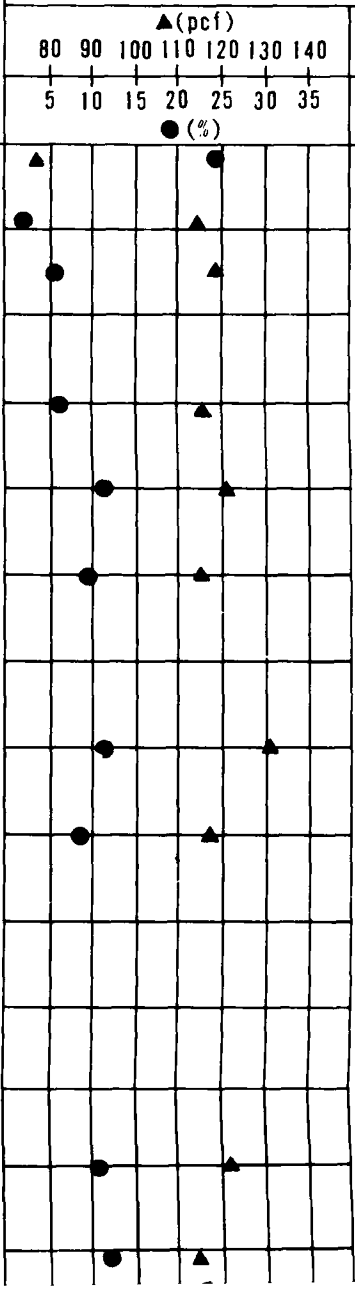
SAND:

GRAVELLY SAND (SP-SM, SW-SM), SILTY SAND (SM): brown, fine to coarse, poorly to well graded, dense to very dense, angular to subangular, calcareous; little to some fine to coarse angular to subangular gravel; trace to some silt.

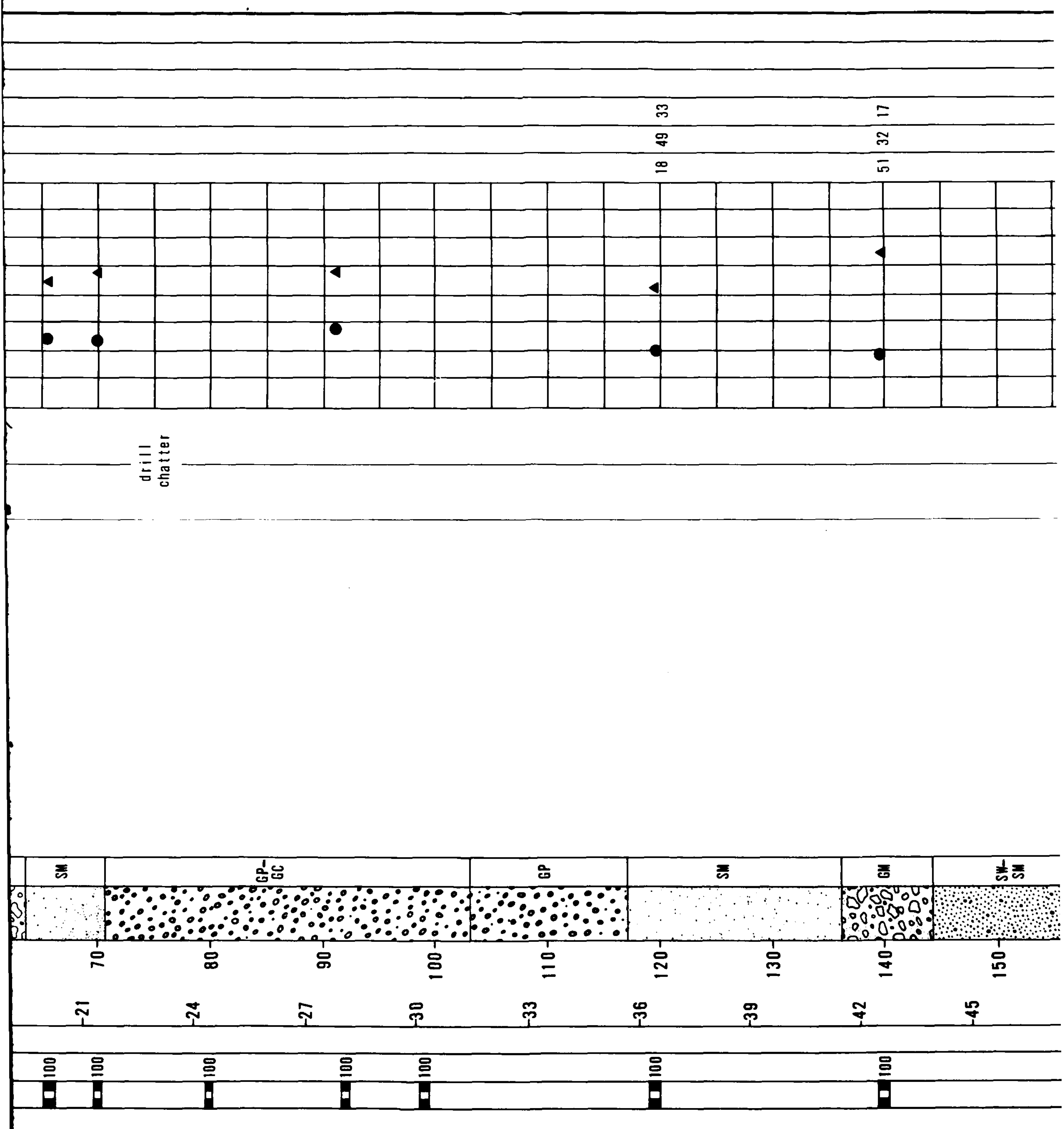
GRAVEL:

SANDY GRAVEL (GP, GW, GP-GC, GM): brown, fine to coarse, poorly to well graded, very dense, angular to subangular, calcareous; some fine to coarse angular to subangular sand; trace to little silt; occasional cobbles and boulders to 18" size (103.0'-117.0').

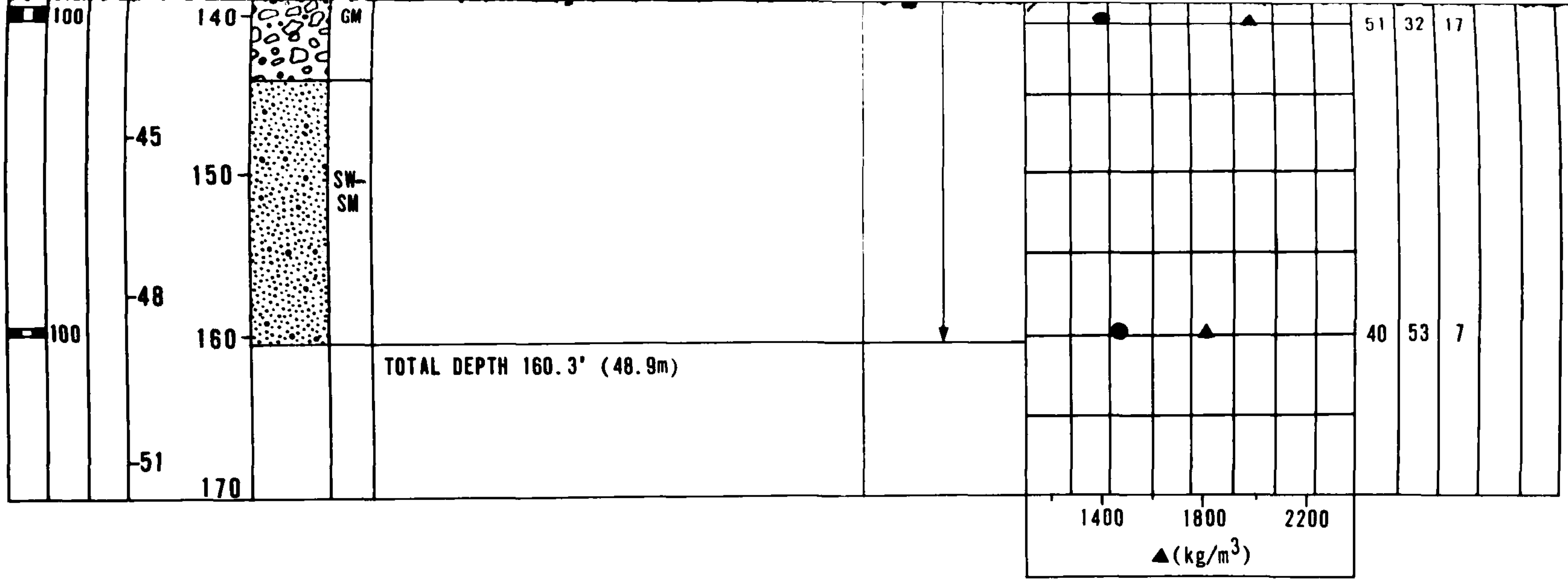
REMARKS



SIEVE ANALYSIS				
GR	SA	FI	LL	PI
31	62	7		
43	50	7		
40	49	11		
59	38	3		


18 49 33
51 32 17
drill chatter
SM
GP–GC
GP
SM
GM
SW–SM
70
80
90
100
110
120
130
140
150
-21
-24
-27
-30
-33
-36
-39
-42
-45
100
100
100
100
100
100
100

2



EXPLANATION

- ◨ FUGRO DRIVE SAMPLE
- ▥ BULK SAMPLE
- ■ PITCHER TUBE SAMPLE
- ◫ STANDARD PENETRATION TEST SAMPLE
- ▨ CORE SAMPLE
- N - STANDARD PENETRATION RESISTANCE
- ▲ - DRY UNIT WEIGHT
- ● - MOISTURE CONTENT (ASTM: D-2216-71)
- NR -- NO RECOVERY

BORING DETAILS

ELEVATION : 5030' (1533m)
SURFICIAL GEOLOGIC UNIT : A5i
DATE DRILLED : 27-28 March 1979
DRILLING METHOD : Rotary Wash
HOLE DIAMETER : 4 7/8" (124mm)
WATER LEVEL : Not Encountered

LOG OF BORING RR-B-6
VERIFICATION SITE
REVEILLE-RAILROAD CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE
B-7

FUGRO NATIONAL, INC.

AFV-06

3

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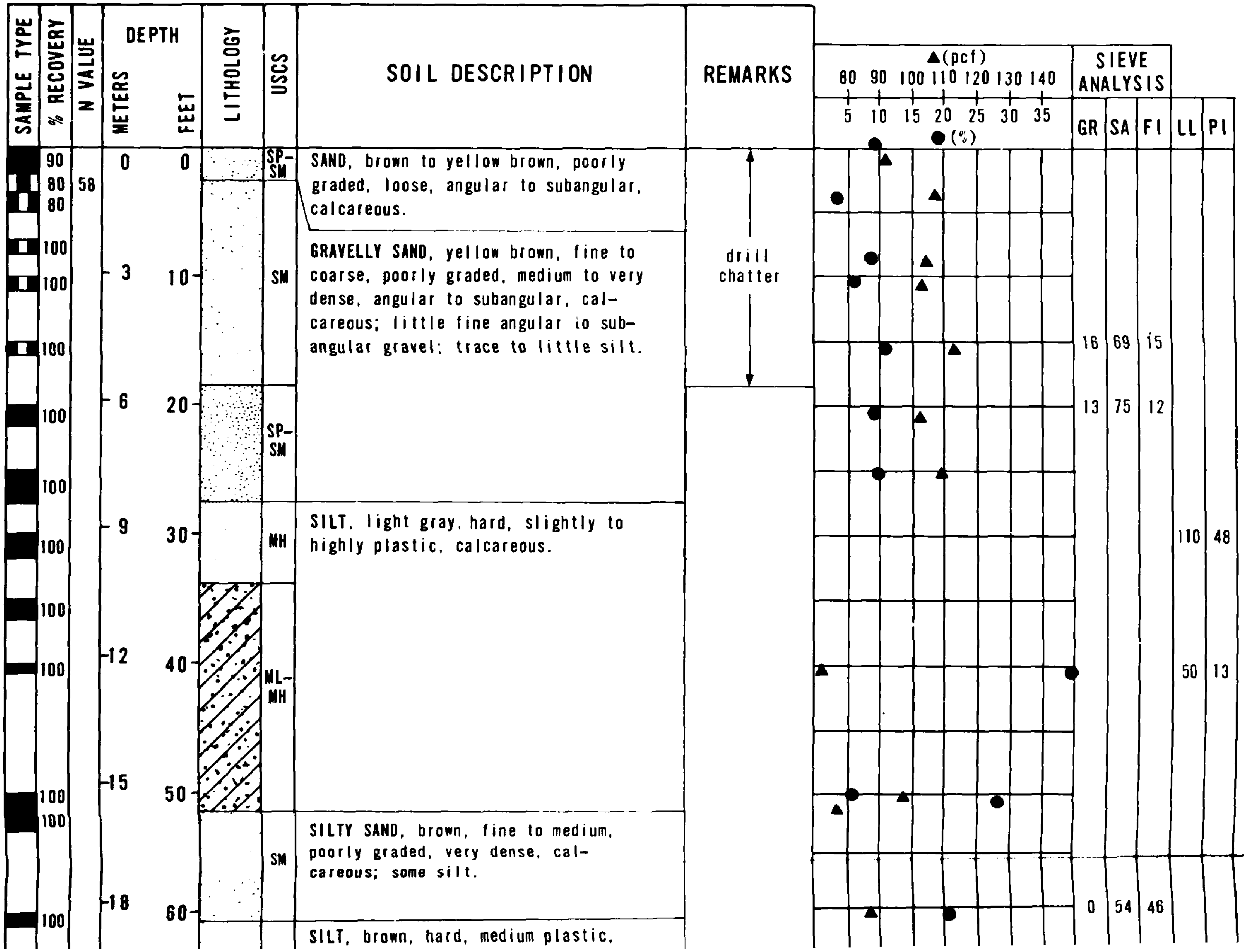

SAMPLE TYPE	% RECOVERY	N VALUE	DEPTH METERS	DEPTH FEET	USCS	SOIL DESCRIPTION	REMARKS	SIEVE ANALYSIS GR	SIEVE ANALYSIS SA	SIEVE ANALYSIS FI	LL	PI
	90		0	0	SP-SM	SAND, brown to yellow brown, poorly graded, loose, angular to subangular, calcareous.	drill chatter					
	80	58										
	80				SM	GRAVELLY SAND, yellow brown, fine to coarse, poorly graded, medium to very dense, angular to subangular, calcareous; little fine angular to subangular gravel; trace to little silt.						
	100											
	100		3	10								
	100							16	69	15		
	100		6	20	SP-SM			13	75	12		
	100											
	100		9	30	MH	SILT, light gray, hard, slightly to highly plastic, calcareous.					110	48
	100				ML-MH							
	100		12	40							50	13
	100		15	50								
	100				SM	SILTY SAND, brown, fine to medium, poorly graded, very dense, calcareous; some silt.						
	100		18	60				0	54	46		
						SILT, brown, hard, medium plastic,						

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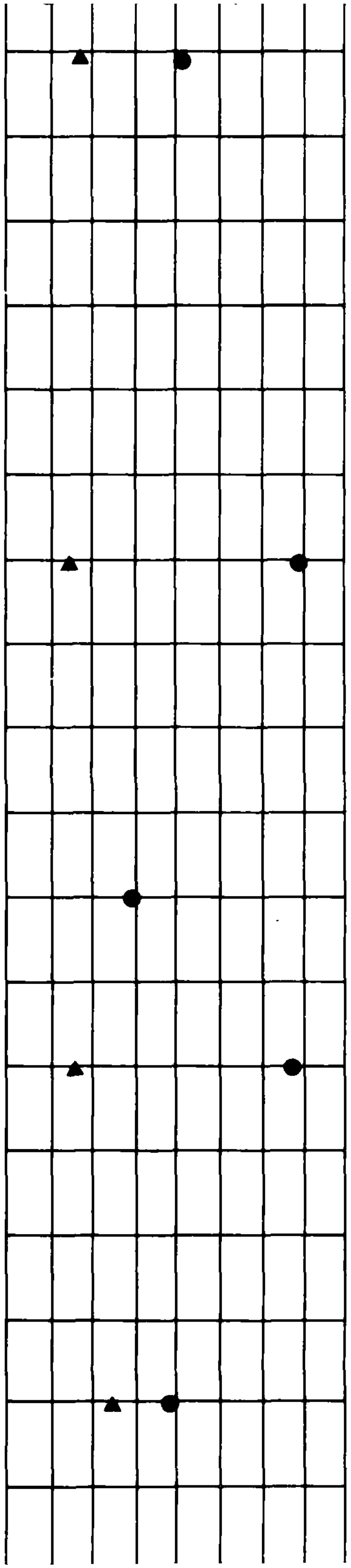
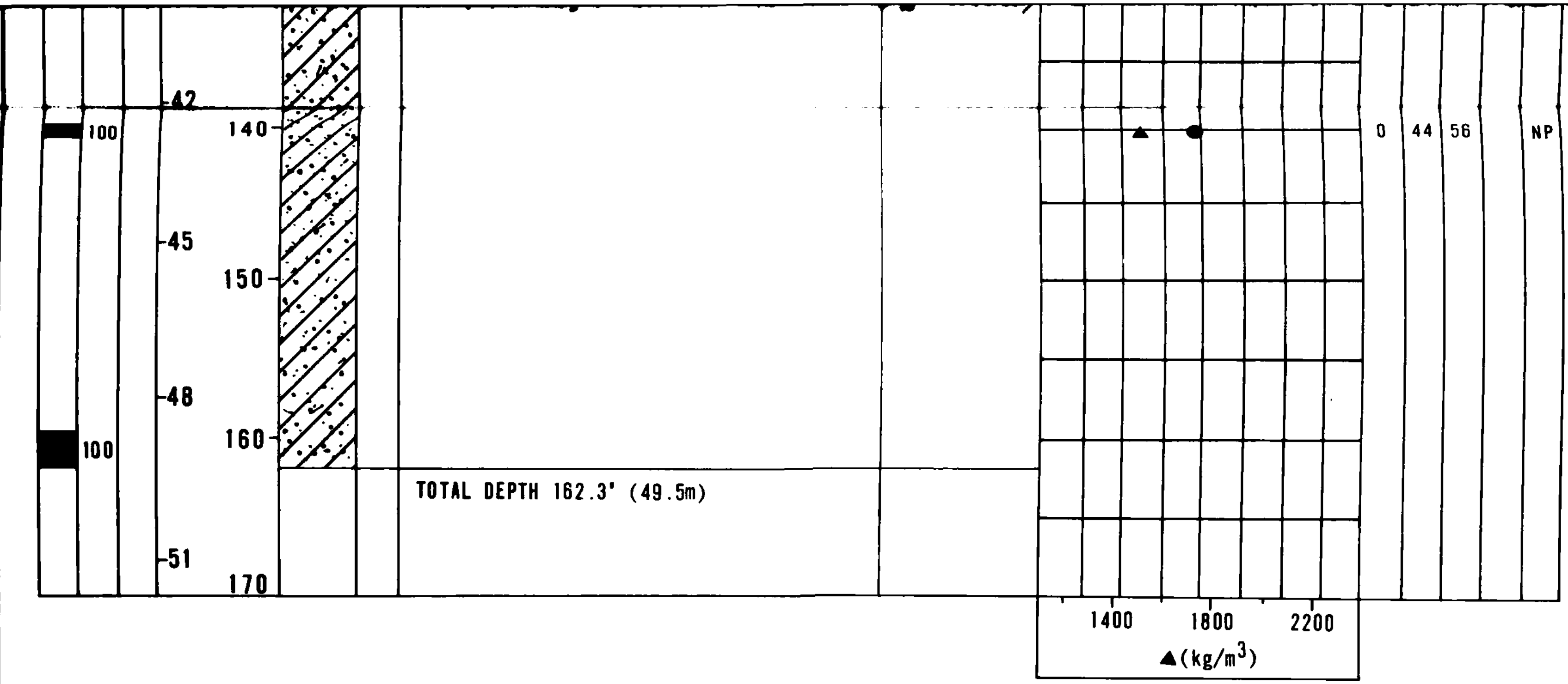
100	-18	60			0	54	46		
			MH	SILT, brown, hard, medium plastic, calcareous; cemented lenses throughout.					
100	-21	70						72	24
100	-24	80							
			CH	CLAY, brown, hard, highly plastic, calcareous; lenses of gypsum throughout.					
100	-27	90						98	63
100	-30	100							
			ML	SANDY SILT, brown to light gray, hard, slightly to highly plastic, calcareous; some fine to medium sand; lenses of silty sand throughout; lenses of gypsum (108.5'-112.0')					
100	-33	110			0	36	64		
100	-36	120							
	-39	130							
100	-42	140			0	44	56		NP
	-45								



2



3

EXPLANATION

- ◨ FUGRO DRIVE SAMPLE
- ▥ BULK SAMPLE
- ■ PITCHER TUBE SAMPLE
- ◧ STANDARD PENETRATION TEST SAMPLE
- ▨ CORE SAMPLE
- N - STANDARD PENETRATION RESISTANCE
- ▲ - DRY UNIT WEIGHT
- ● - MOISTURE CONTENT (ASTM: D-2216-71)
- NR - NO RECOVERY

BORING DETAILS

ELEVATION : 5145' (1568m)
SURFICIAL GEOLOGIC UNIT : A5y
DATE DRILLED : 4-5 April 1979
DRILLING METHOD : Rotary Wash
HOLE DIAMETER : 4 7/8" (124mm)
WATER LEVEL : Not Encountered

LOG OF BORING BS-B-1
VERIFICATION SITE, BIG SMOKY CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE
B-8

FUGRO NATIONAL, INC.

AFV-06

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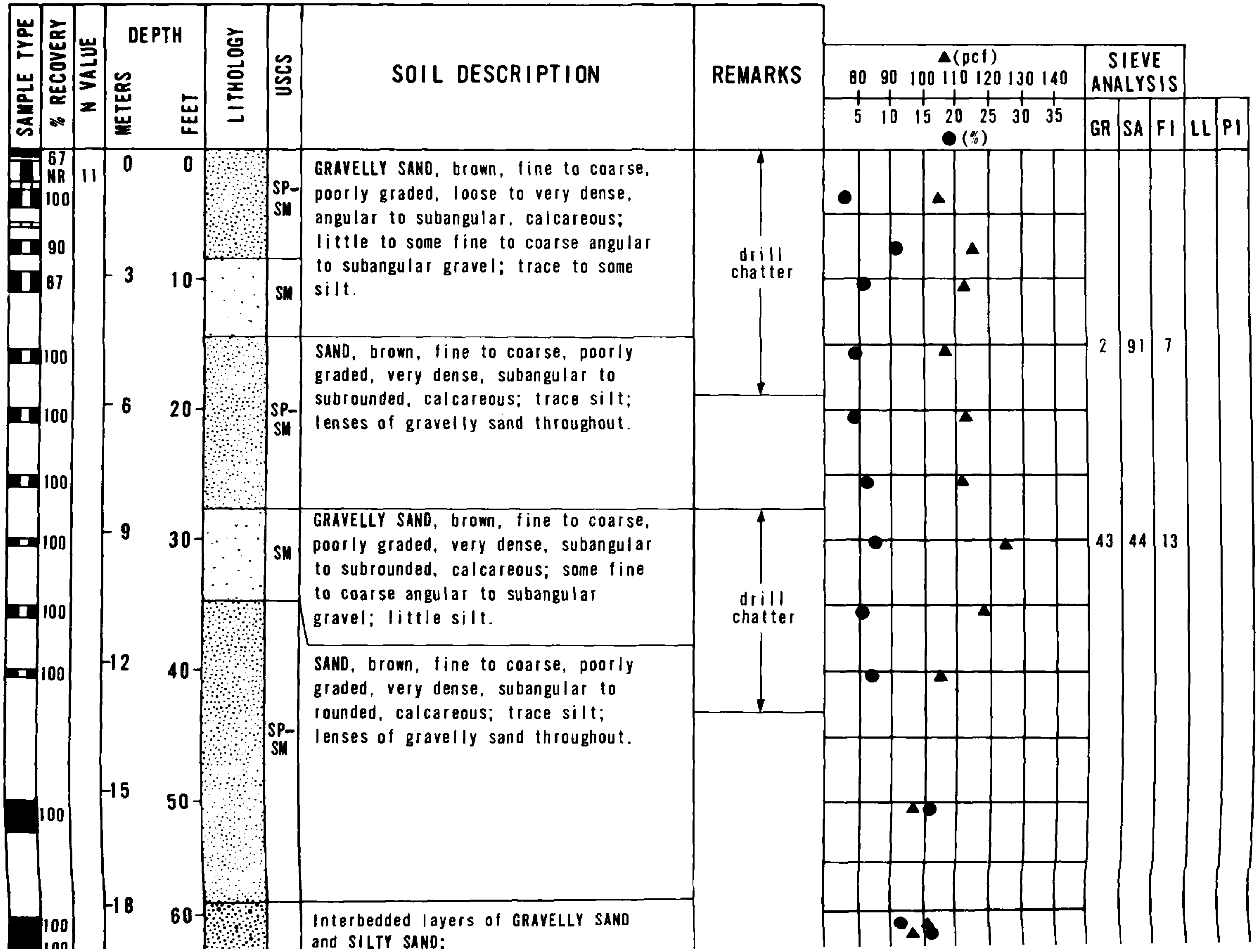

% RECOVERY	N VALUE
67 NR	11
100	
90	
87	
100	
100	
100	
100	
100	
100	
100	
100	

USCS	SOIL DESCRIPTION	REMARKS	SIEVE ANALYSIS GR	SA	FI	LL	PI
SP-SM SM	GRAVELLY SAND, brown, fine to coarse, poorly graded, loose to very dense, angular to subangular, calcareous; little to some fine to coarse angular to subangular gravel; trace to some silt.	drill chatter					
SP-SM	SAND, brown, fine to coarse, poorly graded, very dense, subangular to subrounded, calcareous; trace silt; lenses of gravelly sand throughout.		2	91	7		
SM	GRAVELLY SAND, brown, fine to coarse, poorly graded, very dense, subangular to subrounded, calcareous; some fine to coarse angular to subangular gravel; little silt.	drill chatter	43	44	13		
SP-SM	SAND, brown, fine to coarse, poorly graded, very dense, subangular to rounded, calcareous; trace silt; lenses of gravelly sand throughout.						
	Interbedded layers of GRAVELLY SAND and SILTY SAND:						

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2

	-18			
100 100		60		
	-21		SW-SM	
		70		
100				14 80 6
	-24			
100		80		
			SM	
	-27		SW-SM	
100		90		
			SM	
	-30			
100		100	SP-SM	36 54 10
			SM	
	-33			
100		110		
			SP-SC	
	-36			
100		120		2 80 18 31 10
			SC	
			SP-SC	
	-39			
		130	SC	
	-42			
100		140	SP-SC	
	-45			

Interbedded layers of GRAVELLY SAND and SILTY SAND:

GRAVELLY SAND (SP-SM, SW-SM): brown, fine to coarse, poorly to well graded, very dense, subangular to subrounded; little to some fine *subangular to subrounded gravel;* trace silt.

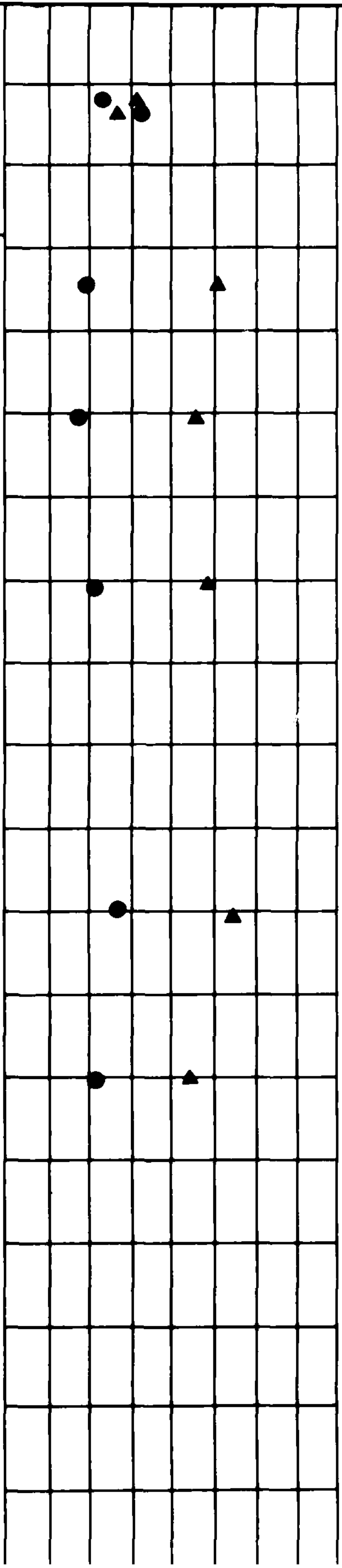
SILTY SAND (SM): brown fine to coarse, poorly graded, very dense, subangular; little silt; trace to little fine subangular gravel

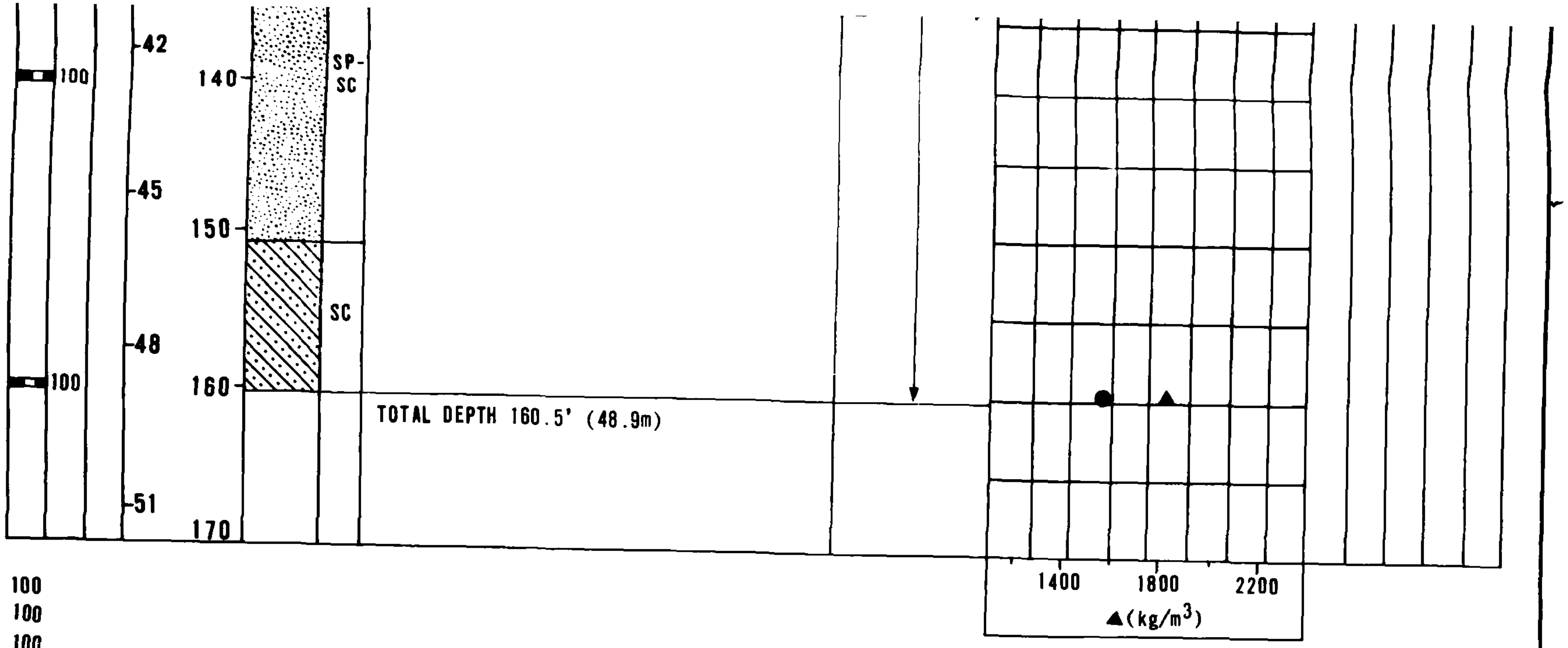
Interbedded layers of GRAVELLY SAND and CLAYEY SAND:

GRAVELLY SAND (SP-SC): brown, fine to coarse poorly graded, very dense subangular, calcareous; some fine angular to subangular gravel; trace silty clay.

CLAYEY SAND (SC): brown, fine to coarse, poorly graded, very dense, subangular, calcareous; little to some silty clay; trace fine subangular gravel.

drill chatter





3

EXPLANATION

- ◧ FUGRO DRIVE SAMPLE
- ▥ BULK SAMPLE
- ■ PITCHER TUBE SAMPLE
- ◧ STANDARD PENETRATION TEST SAMPLE
- ▨ CORE SAMPLE
- N – STANDARD PENETRATION RESISTANCE
- ▲ – DRY UNIT WEIGHT
- ● – MOISTURE CONTENT (ASTM: D-2216-71)
- NR – NO RECOVERY

BORING DETAILS

ELEVATION	: 5018' (1529m)
SURFICIAL GEOLOGIC UNIT	: A5y/A3
DATE DRILLED	: 6 – 7 April 1979
DRILLING METHOD	: Rotary Wash
HOLE DIAMETER	: 4 7/8" (124mm)
WATER LEVEL	: Not Encountered

LOG OF BORING BS-B-2
VERIFICATION SITE, BIG SMOKY CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE · SAMSO

FIGURE
B-9

FUGRO NATIONAL, INC.

AFV-06

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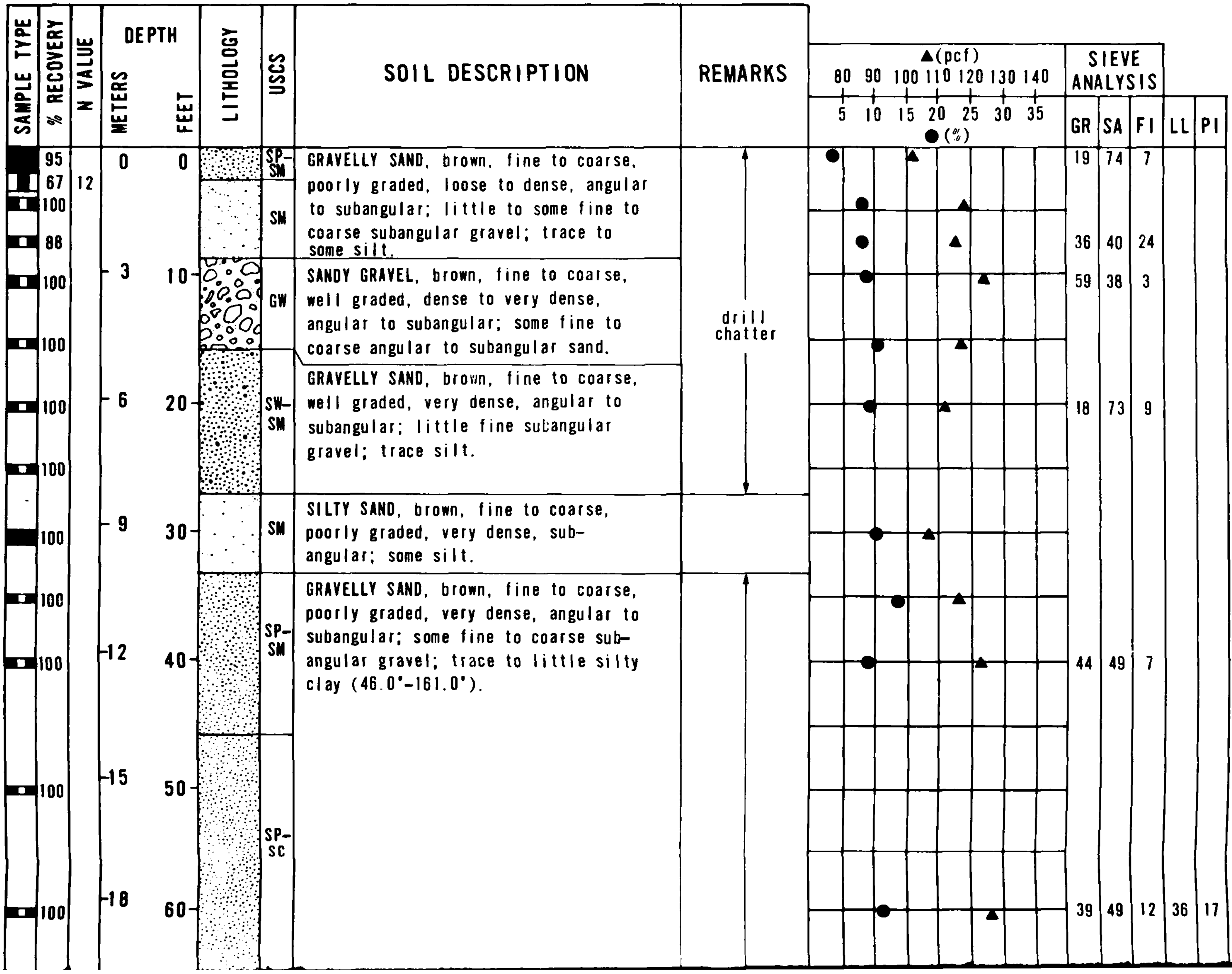


GRAVELLY SAND, brown, fine to coarse, poorly graded, loose to dense, angular to subangular; little to some fine to coarse subangular gravel; trace to some silt.

SANDY GRAVEL, brown, fine to coarse, well graded, dense to very dense, angular to subangular; some fine to coarse angular to subangular sand.

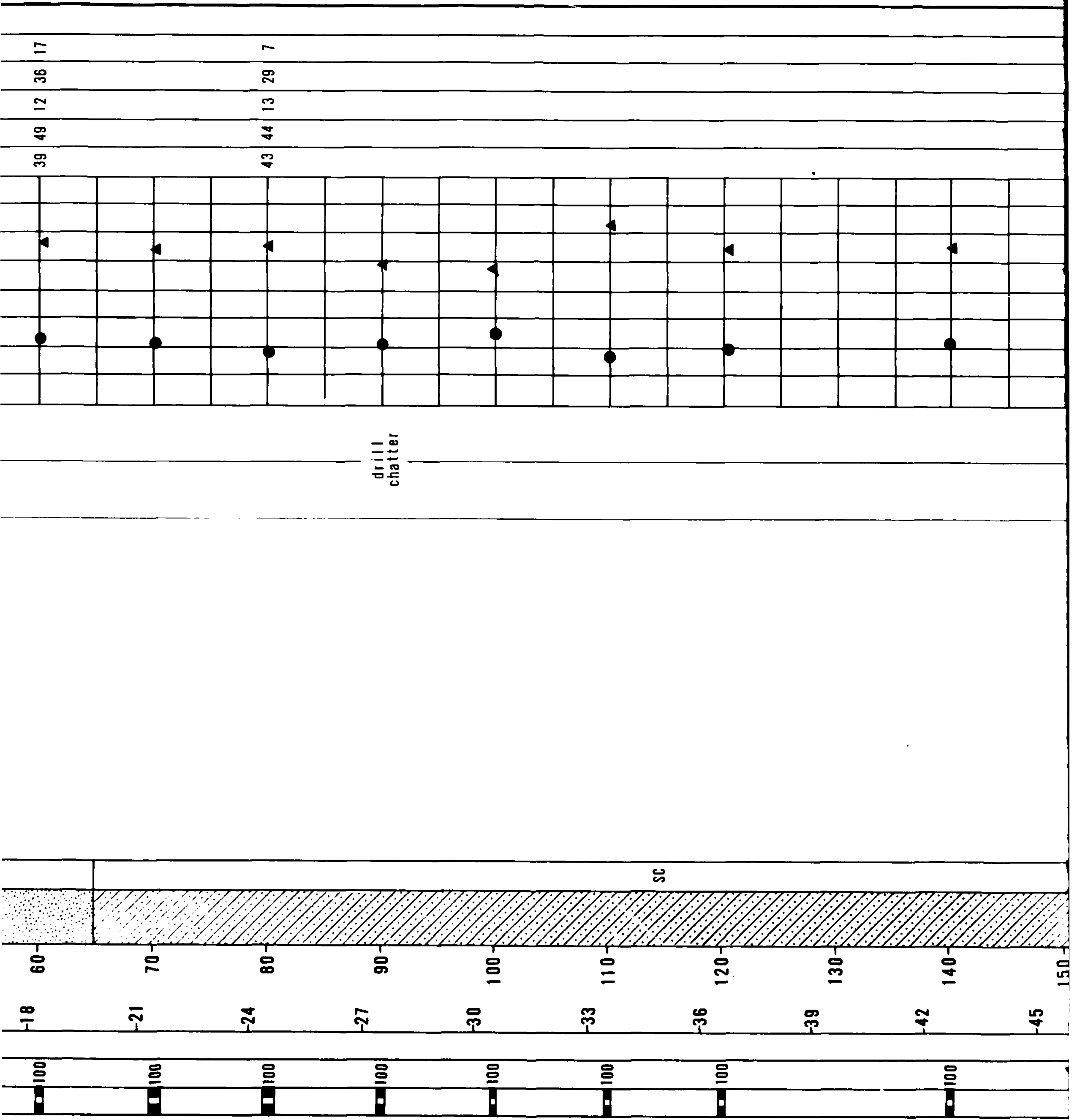
GRAVELLY SAND, brown, fine to coarse, well graded, very dense, angular to subangular; little fine subangular gravel; trace silt.

SILTY SAND, brown, fine to coarse, poorly graded, very dense, subangular; some silt.

GRAVELLY SAND, brown, fine to coarse, poorly graded, very dense, angular to subangular; some fine to coarse subangular gravel; trace to little silty clay (46.0'-161.0').

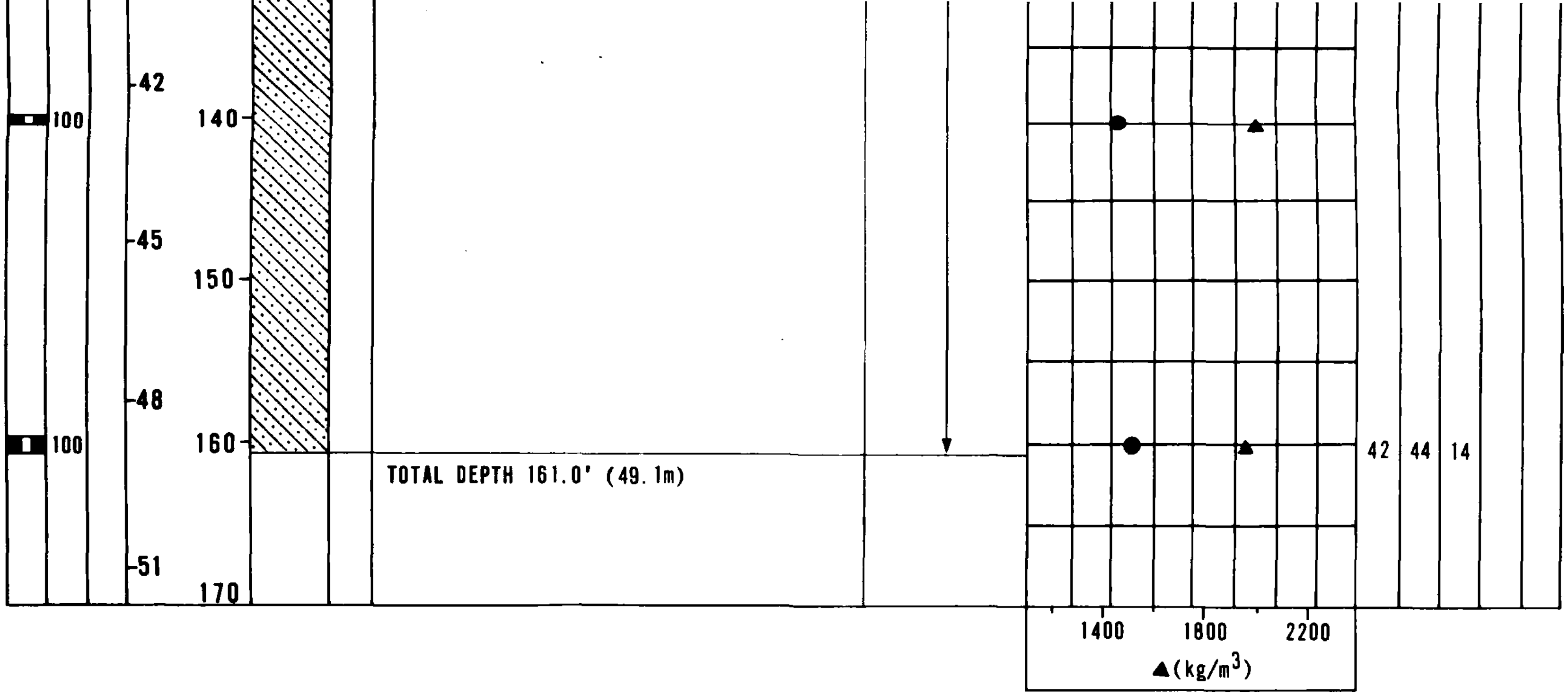
GR	SA	FI	LL	PI
19	74	7		
36	40	24		
59	38	3		
18	73	9		
44	49	7		
39	49	12	36	17

9 NOV 1979



39
49
12
36
17
43
44
13
29
7
drill chatter
sc
60
70
80
90
100
110
120
130
140
150
-18
-21
-24
-27
-30
-33
-36
-39
-42
-45
100
100
100
100
100
100
100
100

2



3

EXPLANATION

- ▮ FUGRO DRIVE SAMPLE
- ▯ BULK SAMPLE
- ■ PITCHER TUBE SAMPLE
- ◧ STANDARD PENETRATION TEST SAMPLE
- ▨ CORE SAMPLE
- N - STANDARD PENETRATION RESISTANCE
- ▲ - DRY UNIT WEIGHT
- ● - MOISTURE CONTENT (ASTM: D-2216-71)
- NR - NO RECOVERY

BORING DETAILS

ELEVATION	: 4980' (1518m)
SURFICIAL GEOLOGIC UNIT	: A1/A5y
DATE DRILLED	: 7-8 April 1979
DRILLING METHOD	: Rotary Wash
HOLE DIAMETER	: 4 7/8" (124mm)
WATER LEVEL	: Not Encountered

LOG OF BORING BS-B-3
VERIFICATION SITE, BIG SMOKY CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE
B-10

FUGRO NATIONAL, INC.

AFV-06

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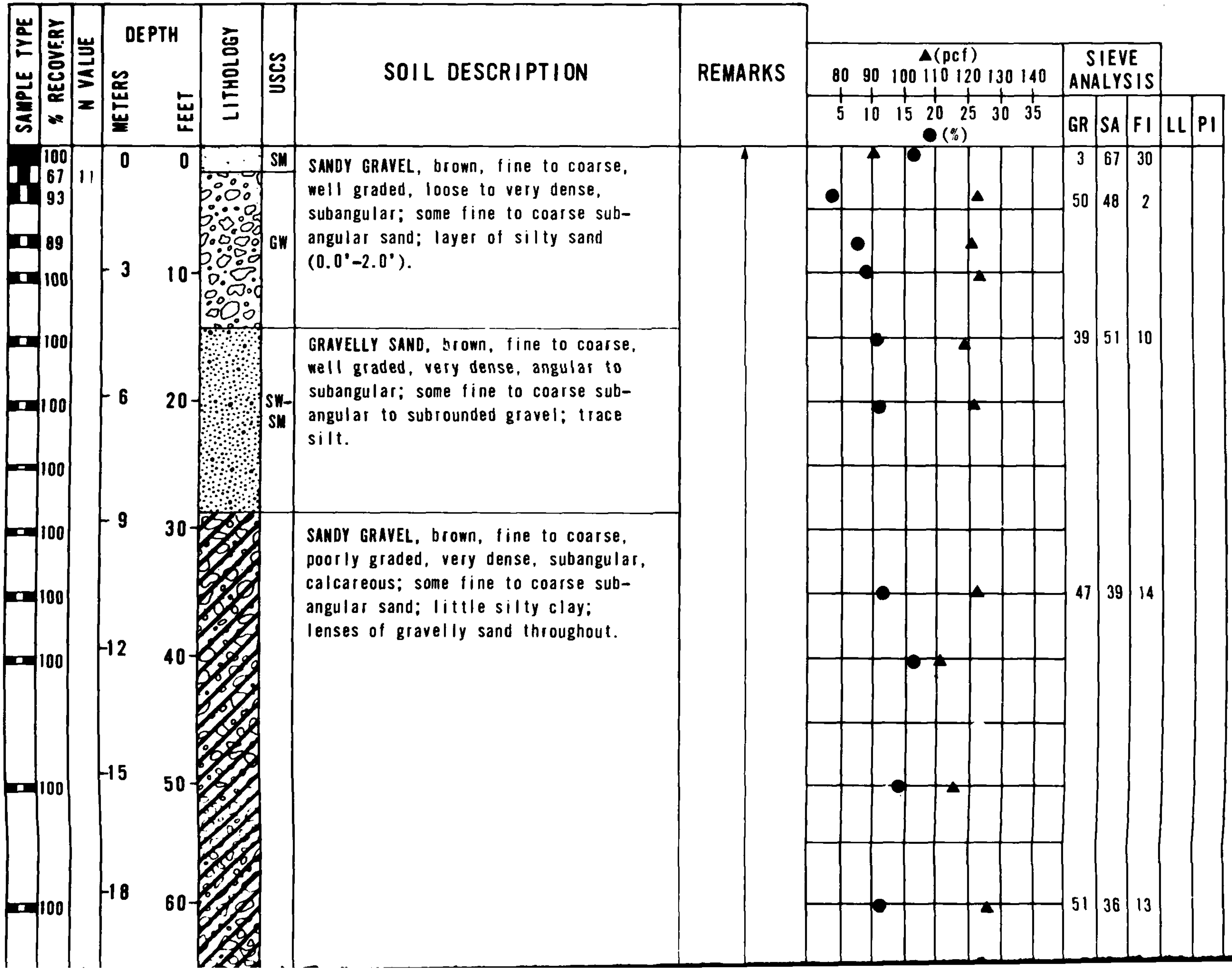
FN-TR-29



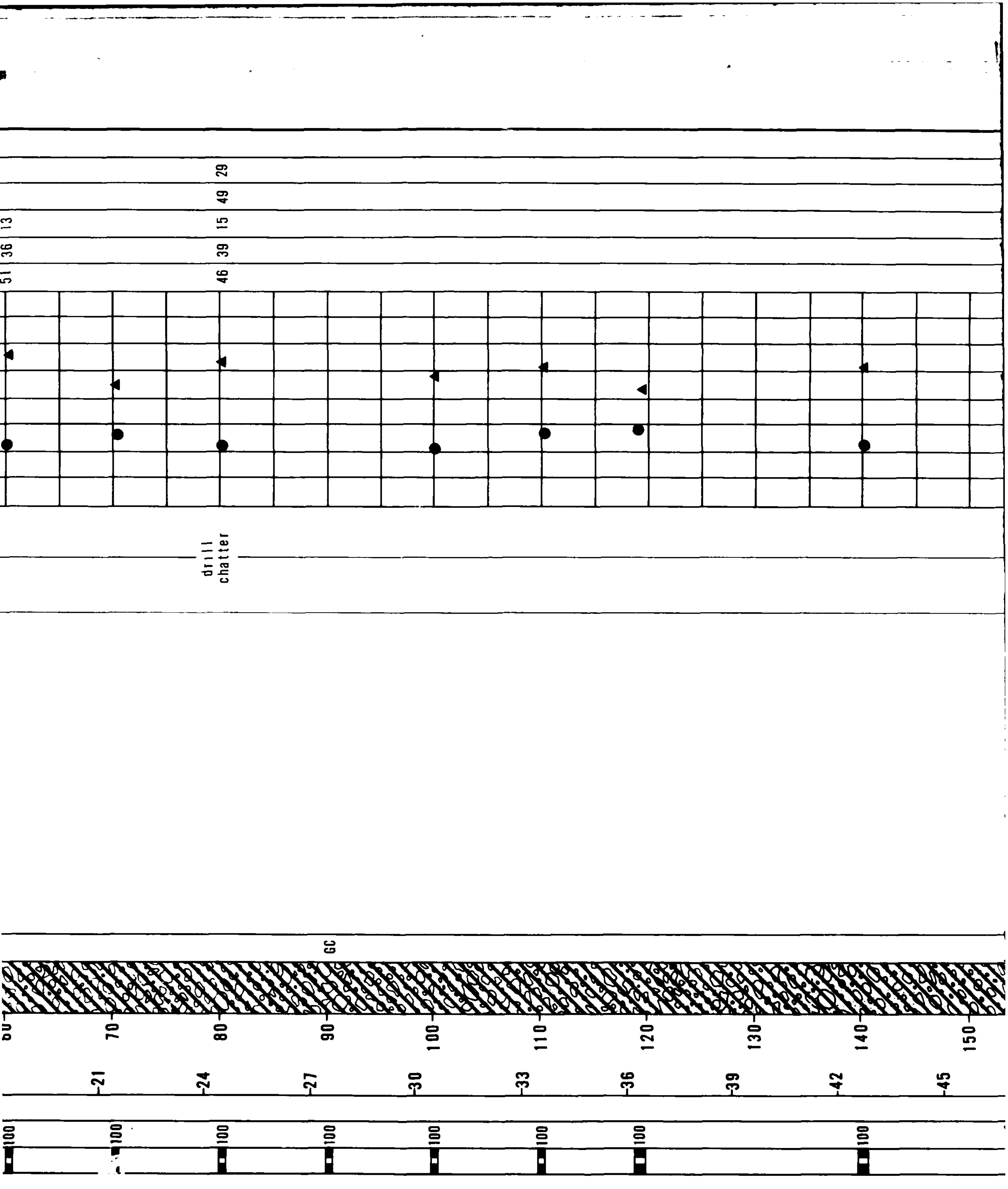
SANDY GRAVEL, brown, fine to coarse, well graded, loose to very dense, subangular; some fine to coarse subangular sand; layer of silty sand (0.0'-2.0').

GRAVELLY SAND, brown, fine to coarse, well graded, very dense, angular to subangular; some fine to coarse subangular to subrounded gravel; trace silt.

SANDY GRAVEL, brown, fine to coarse, poorly graded, very dense, subangular, calcareous; some fine to coarse subangular sand; little silty clay; lenses of gravelly sand throughout.

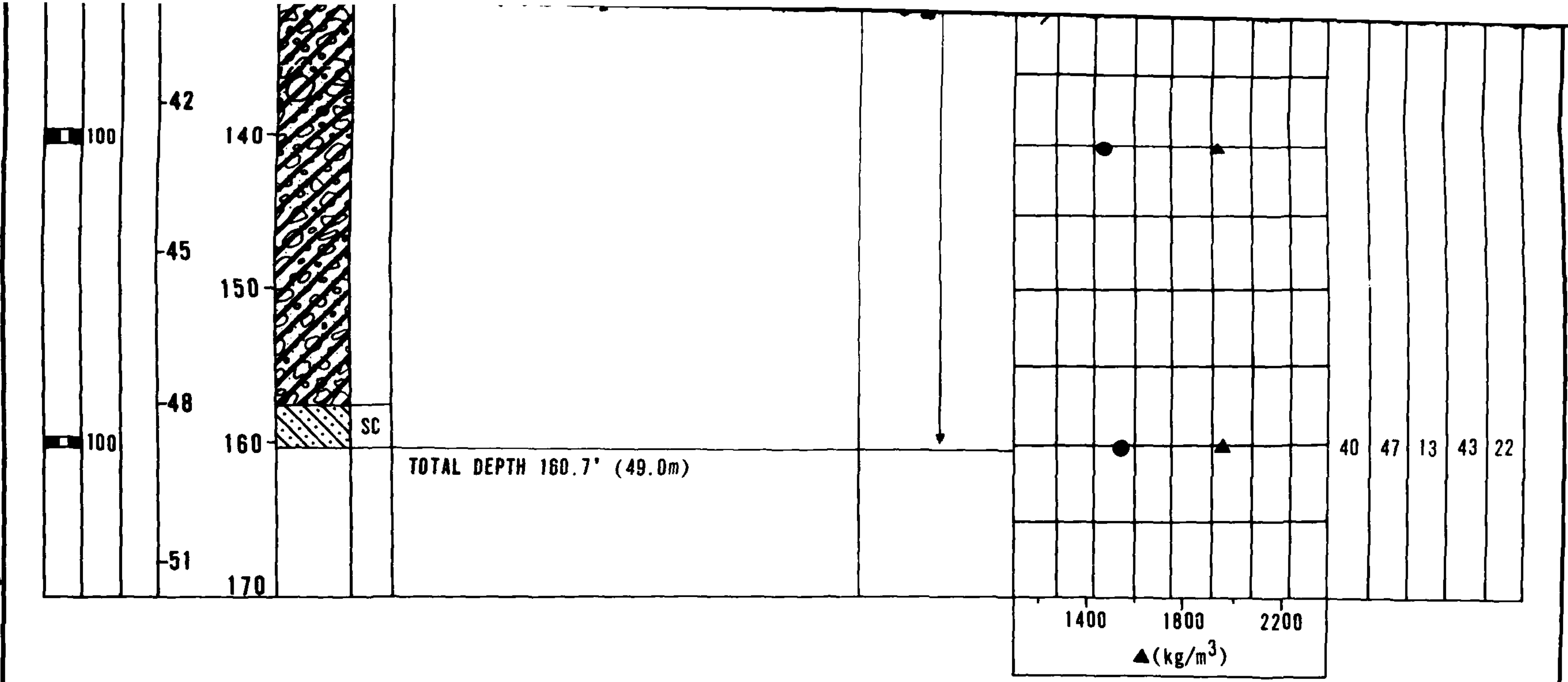
GR	SA	FI	LL	PI
3	67	30		
50	48	2		
39	51	10		
47	39	14		
51	36	13		

9 NOV 1979



13
36
51
29
49
15
39
46
drill chatter
GC
70
80
90
100
110
120
130
140
150
-21
-24
-27
-30
-33
-36
-39
-42
-45
100
100
100
100
100
100
100
100
100

2



3

EXPLANATION

- ▮ FUGRO DRIVE SAMPLE
- ☐ BULK SAMPLE
- ■ PITCHER TUBE SAMPLE
- ◧ STANDARD PENETRATION TEST SAMPLE
- ▨ CORE SAMPLE
- N - STANDARD PENETRATION RESISTANCE
- ▲ - DRY UNIT WEIGHT
- ● - MOISTURE CONTENT (ASTM: D-2216-71)
- NR - NO RECOVERY

BORING DETAILS

ELEVATION	: 5108' (1557m)
SURFICIAL GEOLOGIC UNIT	: A1
DATE DRILLED	: 8-9 April 1979
DRILLING METHOD	: Rotary Wash
HOLE DIAMETER	: 4 7/8" (124mm)
WATER LEVEL	: Not Encountered

LOG OF BORING BS-B-4
VERIFICATION SITE, BIG SMOKY CDP, NEVADA

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DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE
B-11

FUGRO NATIONAL, INC.

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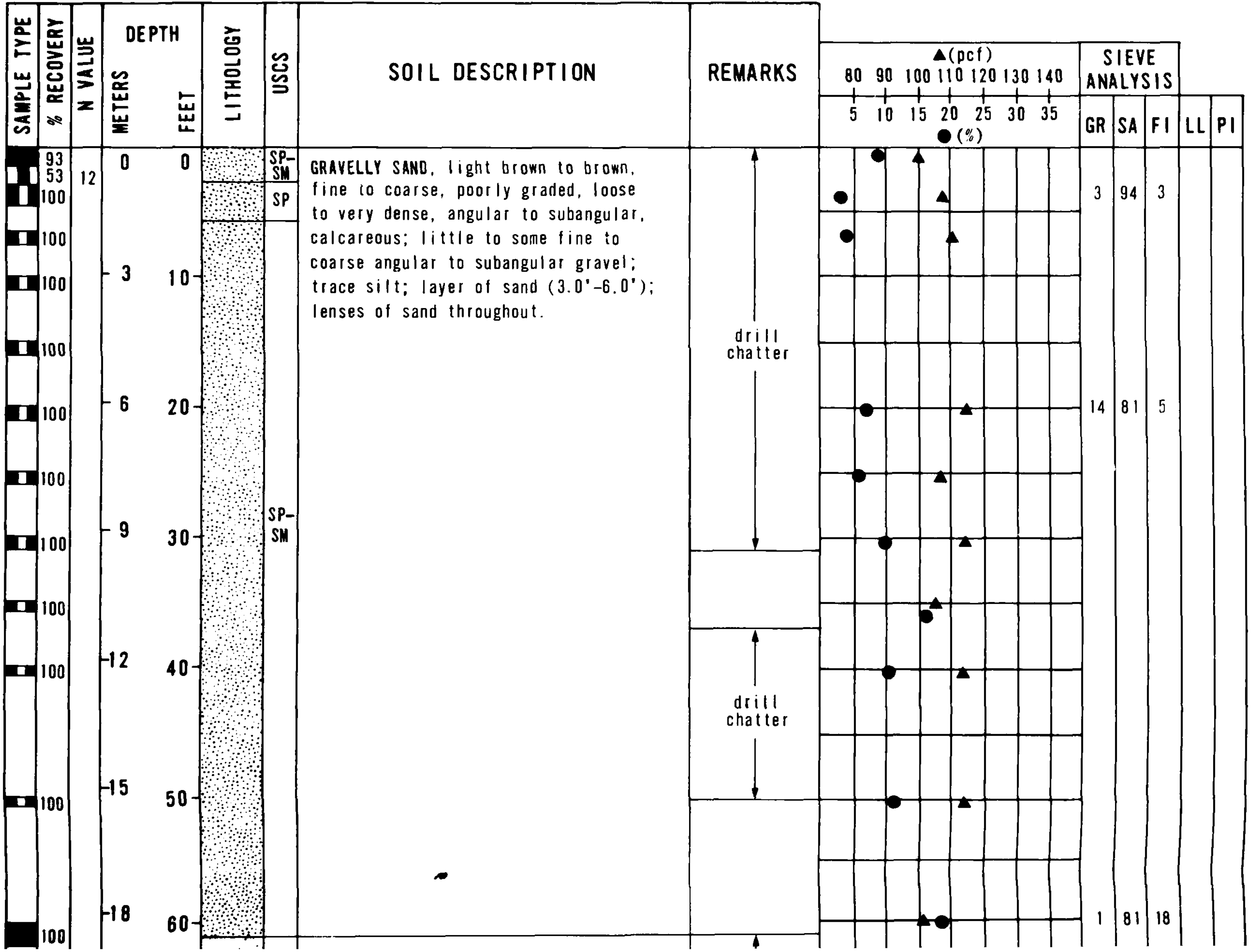
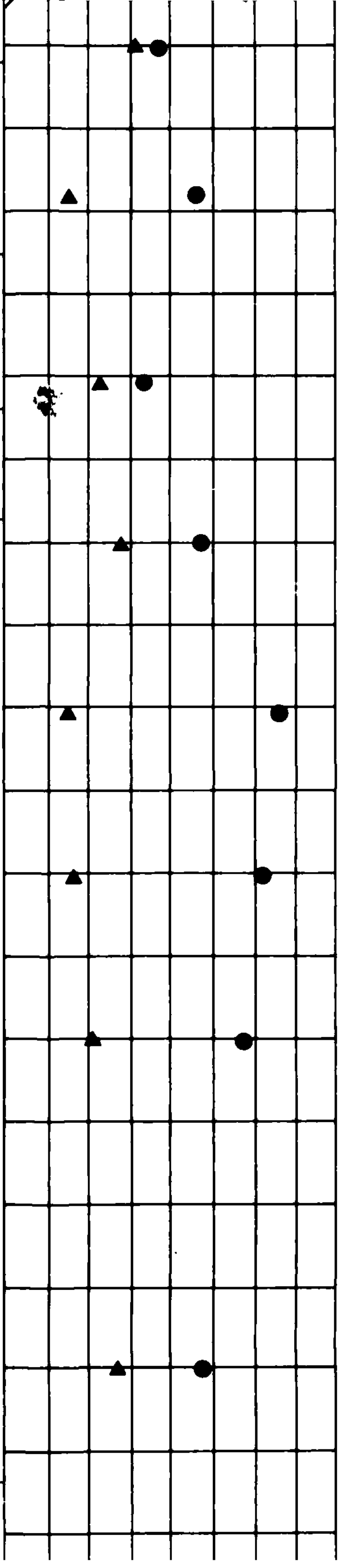
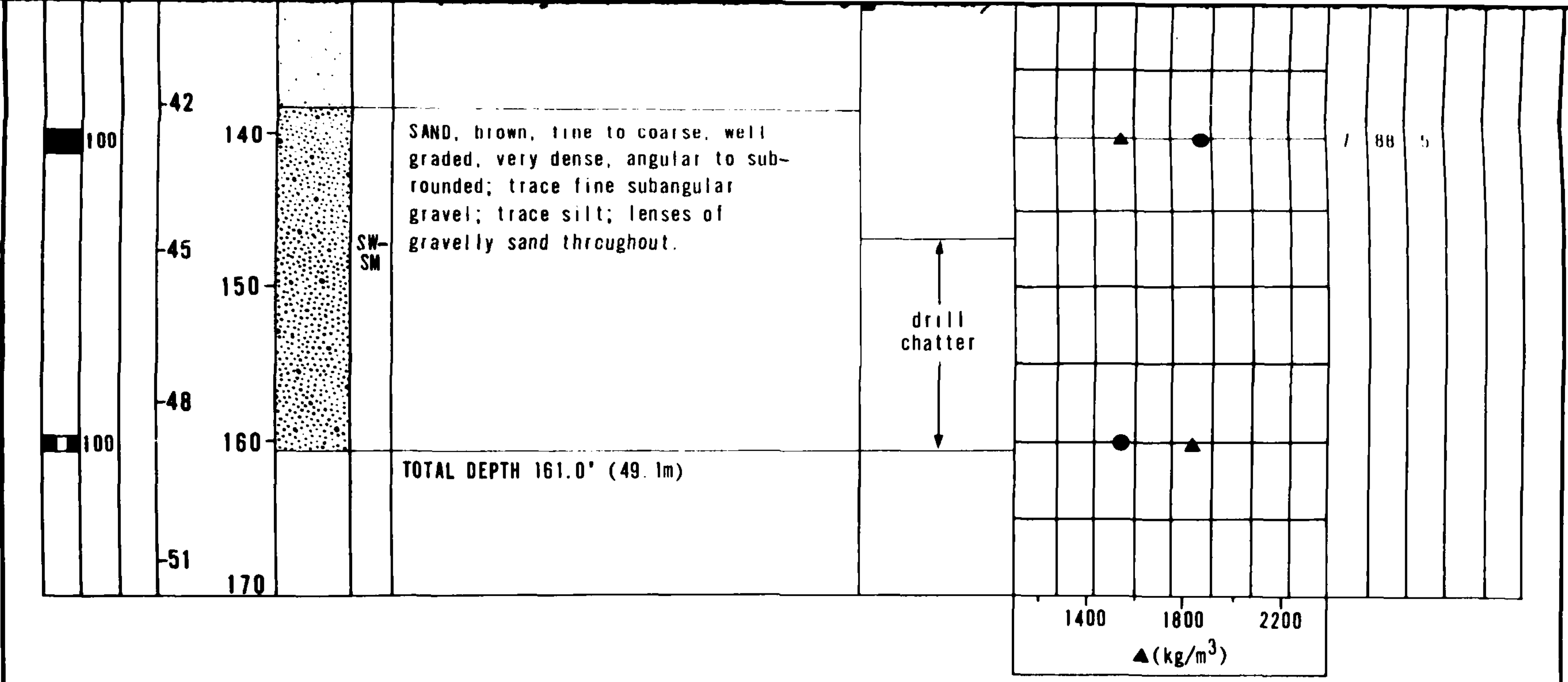


GRAVELLY SAND, light brown to brown, fine to coarse, poorly graded, loose to very dense, angular to subangular, calcareous; little to some fine to coarse angular to subangular gravel; trace silt; layer of sand (3.0'-6.0'); lenses of sand throughout.

			1	81	18
SM	**SILTY SAND**, brown to dark brown, fine to coarse, poorly graded, very dense, subangular to subrounded; little silt; lenses of gravelly sand throughout.	drill chatter			
SP	**SAND**, brown, fine to coarse, poorly graded, very dense, subangular to subrounded; lenses of gravelly sand throughout.	drill chatter	3	96	1
SM	**SILTY SAND**, brown, fine to coarse, poorly graded, very dense, angular to subrounded; some silt; lenses of gravelly sand throughout.		1	60	39
SW-SM	**SAND**, brown, fine to coarse, well graded, very dense, angular to subrounded; trace fine subangular gravel; trace silt; lenses of gravelly sand throughout.		7	88	5





SAND, brown, fine to coarse, well graded, very dense, angular to subrounded; trace fine subangular gravel; trace silt; lenses of gravelly sand throughout.

TOTAL DEPTH 161.0' (49.1m)

EXPLANATION

- ◧ FUGRO DRIVE SAMPLE
- ▥ BULK SAMPLE
- ■ PITCHER TUBE SAMPLE
- ◨ STANDARD PENETRATION TEST SAMPLE
- ▨ CORE SAMPLE
- N - STANDARD PENETRATION RESISTANCE
- ▲ - DRY UNIT WEIGHT
- ● - MOISTURE CONTENT (ASTM: D-2216-71)
- NR - NO RECOVERY

BORING DETAILS

ELEVATION : 5460' (1664m)
SURFICIAL GEOLOGIC UNIT : A5y
DATE DRILLED : 9 - 10 April 1979
DRILLING METHOD : Rotary Wash
HOLE DIAMETER : 4 7/8" (124mm)
WATER LEVEL : Not Encountered

LOG OF BORING BS-B-5
VERIFICATION SITE, BIG SMOKY CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
B-12

FUGRO NATIONAL, INC.

AFV-06

3

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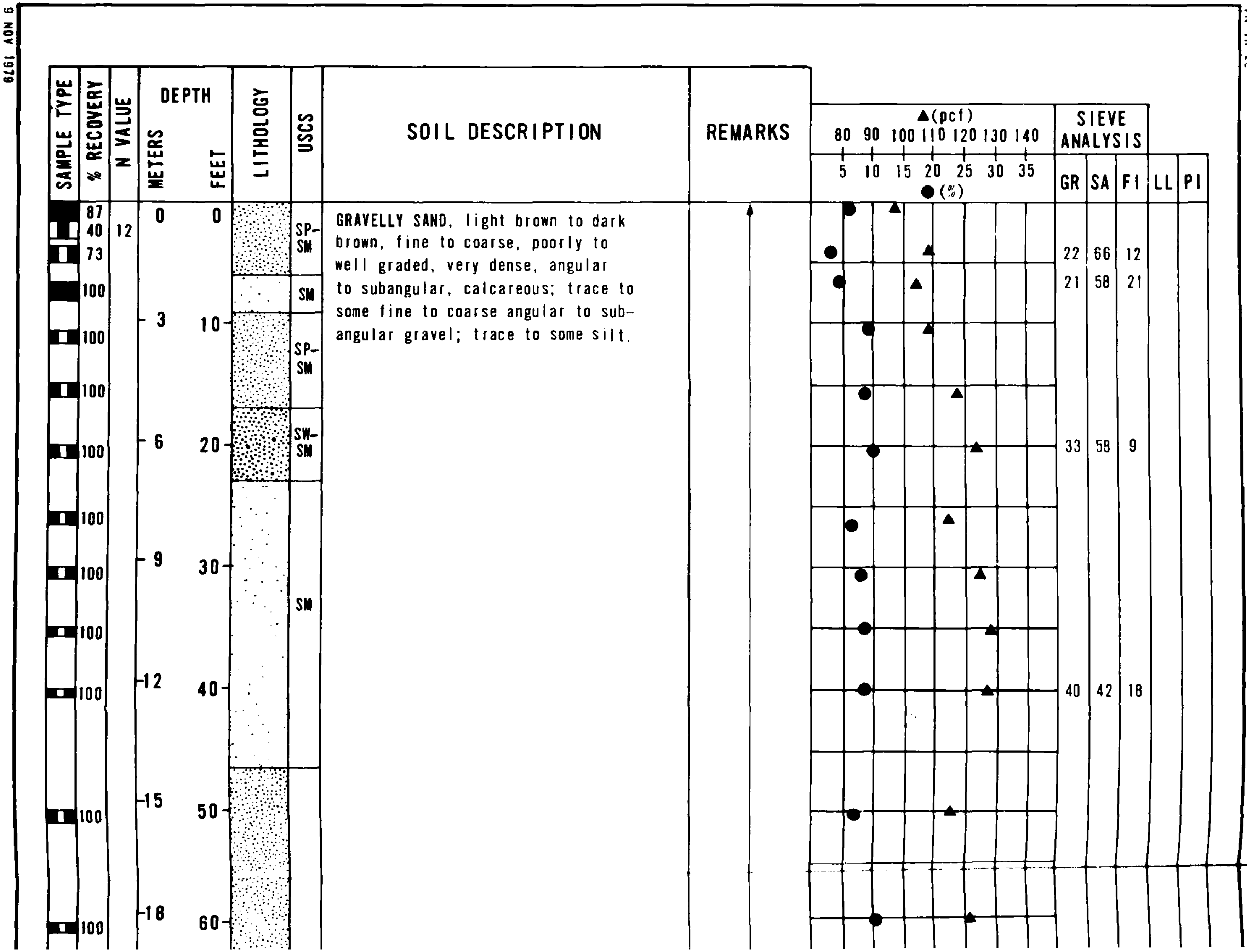
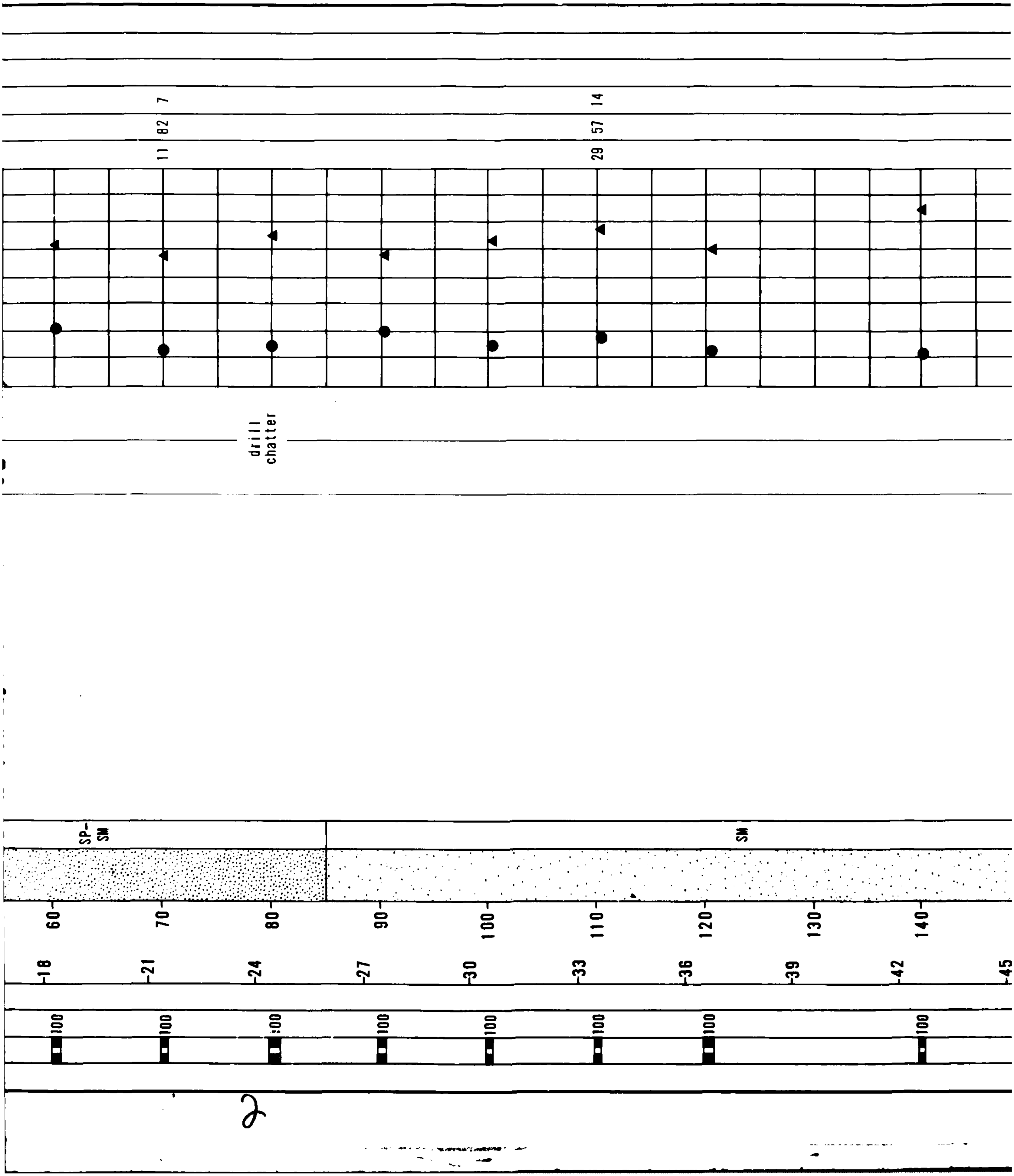
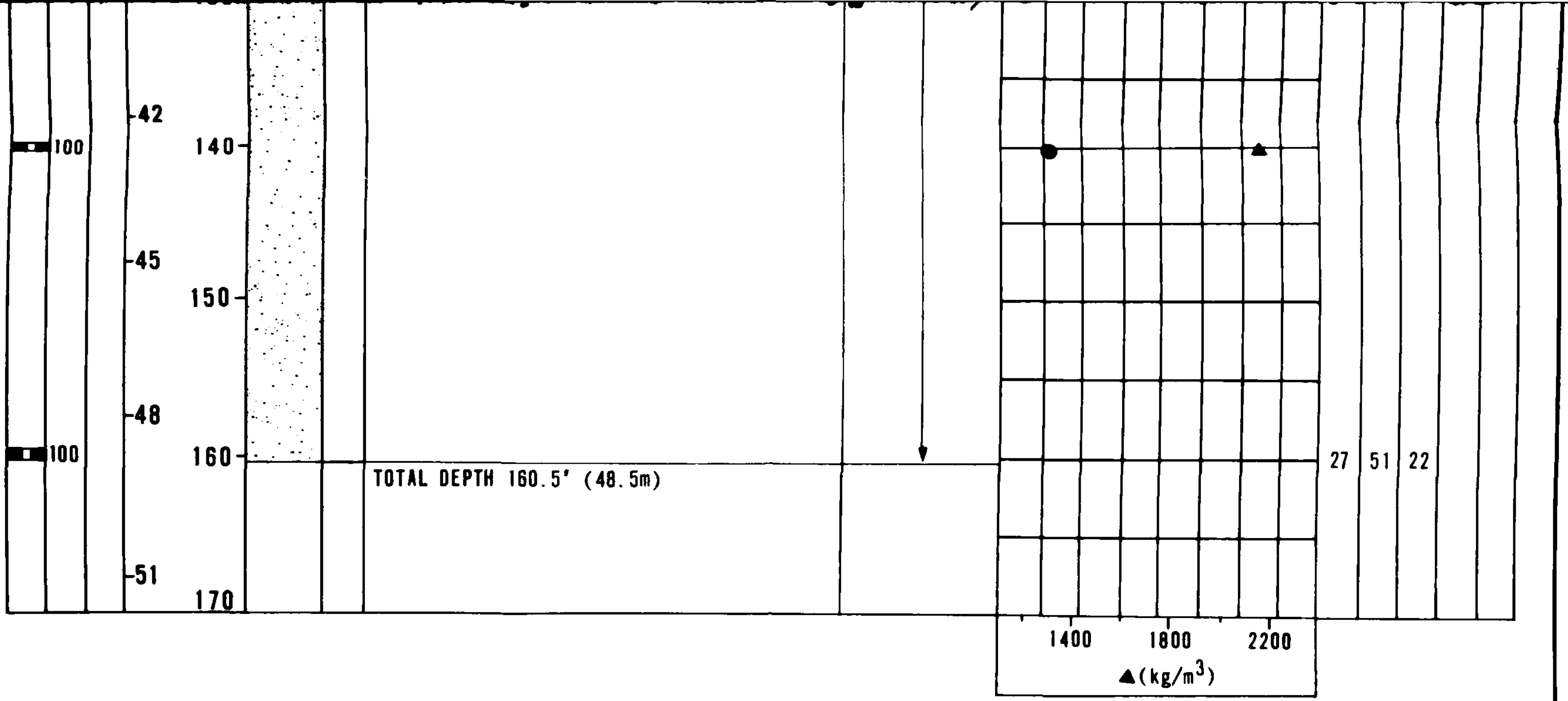


GRAVELLY SAND, light brown to dark brown, fine to coarse, poorly to well graded, very dense, angular to subangular, calcareous; trace to some fine to coarse angular to subangular gravel; trace to some silt.



11
82
7
29
57
14
drill chatter
SP-SM
SM
60
70
80
90
100
110
120
130
140
-18
-21
-24
-27
-30
-33
-36
-39
-42
-45
100
100
100
100
100
100
100
100
2



3

EXPLANATION

- ◧ FUGRO DRIVE SAMPLE
- ▥ BULK SAMPLE
- ■ PITCHER TUBE SAMPLE
- ◨ STANDARD PENETRATION TEST SAMPLE
- ▨ CORE SAMPLE
- N - STANDARD PENETRATION RESISTANCE
- ▲ - DRY UNIT WEIGHT
- ● - MOISTURE CONTENT (ASTM: D-2216-71)
- NR - NO RECOVERY

BORING DETAILS

ELEVATION : 5832' (1778m)
SURFICIAL GEOLOGIC UNIT : A5y
DATE DRILLED : 11 April 1979
DRILLING METHOD : Rotary Wash
HOLE DIAMETER : 4 7/8" (124mm)
WATER LEVEL : Not Encountered

LOG OF BORING BS-B-6
VERIFICATION SITE, BIG SMOKY CDP, NEVADA

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DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
B-13

FUGRO NATIONAL, INC.

AFV-06

APPENDIX C

THERMAL RESISTIVITY

TABLE OF CONTENTS

LIST OF FIGURES

PLATES

C1.0 THEORY

Soil thermal resistivity was measured in the laboratory using a thermal needle. The thermal needle method is based on the measurement of the rate of temperature rise along a line heat source within an infinite, homogeneous medium. The temperature θ at any time t at the heat source is:

$$\theta = \frac{Q}{4\pi k} E_i (-\chi) \text{ .... (Carlslaw and Jaeger, 1959) [1]}$$

where

Q = heat input per unit length per unit time;
k = thermal conductivity = $1/\rho$;
ρ = thermal resistivity;
$\chi = -r^2/(4at)$;
a = thermal diffusivity;
r = radial distance from heat source; and
$E_i (-\chi) = -\int_x^\infty (e^{-u}/u) du.$

For small values of χ and large values of t, Eq. [1] becomes:

$$\theta = \frac{Q}{4\pi k} (\ln \frac{4at}{r^2} - 0.5772) \text{ .... [2]}$$

therefore,

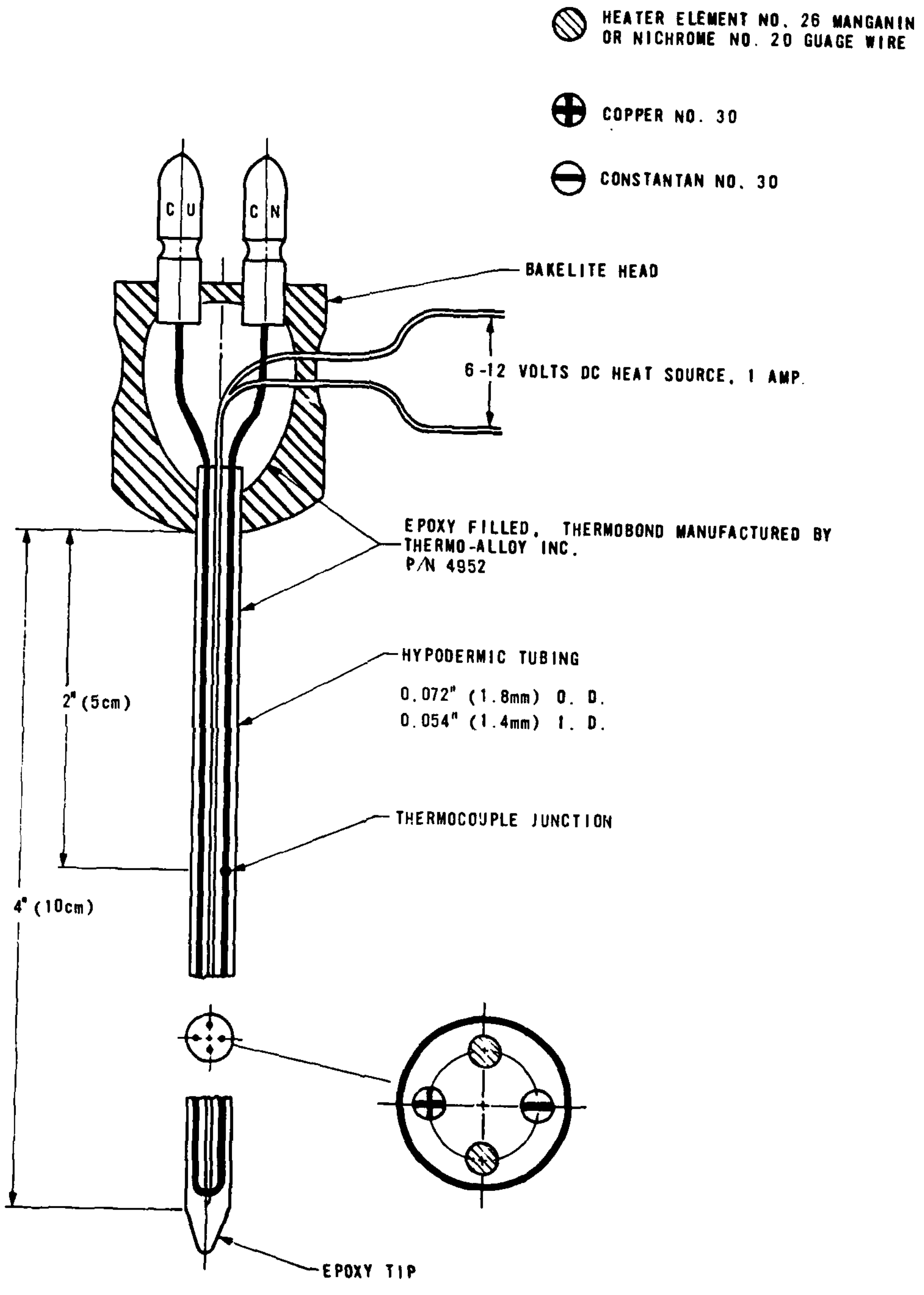
$$\Delta\theta = \frac{Q}{4\pi k}(\Delta \ln t) = \frac{Q}{4\pi} \rho(\Delta \ln t) \text{ .... [3]}$$

Thus, if heat is applied at a known constant rate to a line embedded in the medium of interest and the temperature of the line is measured as a function of time, a straight-line relationship is indicated between θ and ln t, with a slope proportional to the thermal resistivity, ρ. In practice, the line heat source is approximated by a small diameter needle, and the relationship in Eq. [3] is valid after heating times of only a few seconds.

C2.0 THERMAL NEEDLE

C2.1 COMPONENTS AND ASSEMBLY

The thermal needle consisted of a stainless steel hypodermic tubing containing a heater element and a thermocouple as shown in Figure C-1. Its components and assembly were similar to the one constructed in the University of California at Berkeley (Mitchell, 1979). The hypodermic tubing was cut to 4-1/2 inches (114 mm) in length. The end that would be inserted into the thermocouple jack was roughened for a length of 0.5 inch (13 mm). A copper-constantan thermocouple wire junction previously coated with an insulating varnish was threaded into the hypodermic needle with the junction 2 inches (51 mm) from the end of the needle. At the same time, a manganin heater element was inserted with approximately 3-inch (76 mm) pigtails extending from the needle as shown in Figure C-1. The uncut end of the needle was then inserted into an evacuating flask through a rubber stopper and the other end was placed in a reservoir of epoxy primer as shown in Figure C-2. A vacuum pump connected to the evacuating flask drew the epoxy up through the needle. When epoxy appeared at the top of the needle, the vacuum pump was shut off. The needle was removed from the reservoir and flask and a blob of putty placed at the end to hold in the epoxy for hardening. After hardening of the epoxy, the thermocouple wires were soldered to the pins of a polarized thermocouple jack and the roughened end of the needle was placed in the jack. The heater leads were brought out through two holes drilled in the back of the bakelite head (see Figure C-1).



LABORATORY THERMAL RESISTIVITY NEEDLE

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DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
C-1

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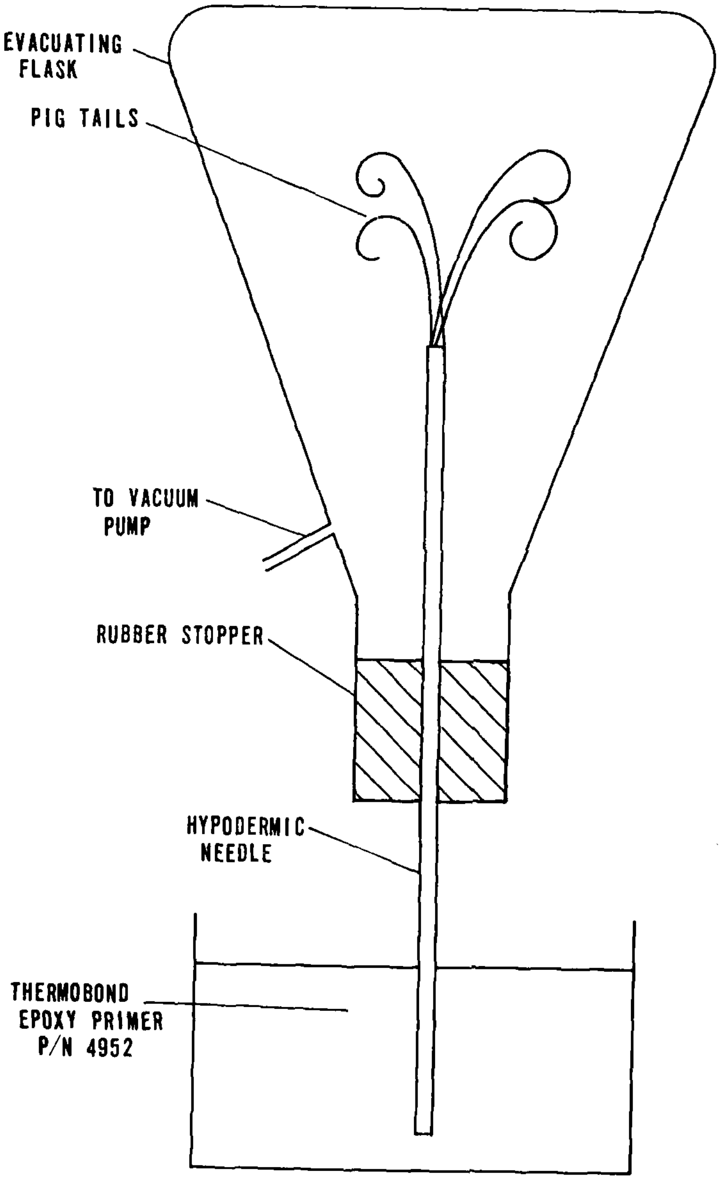

THERMAL RESISTIVITY NEEDLE CONSTRUCTION

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DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
C-2

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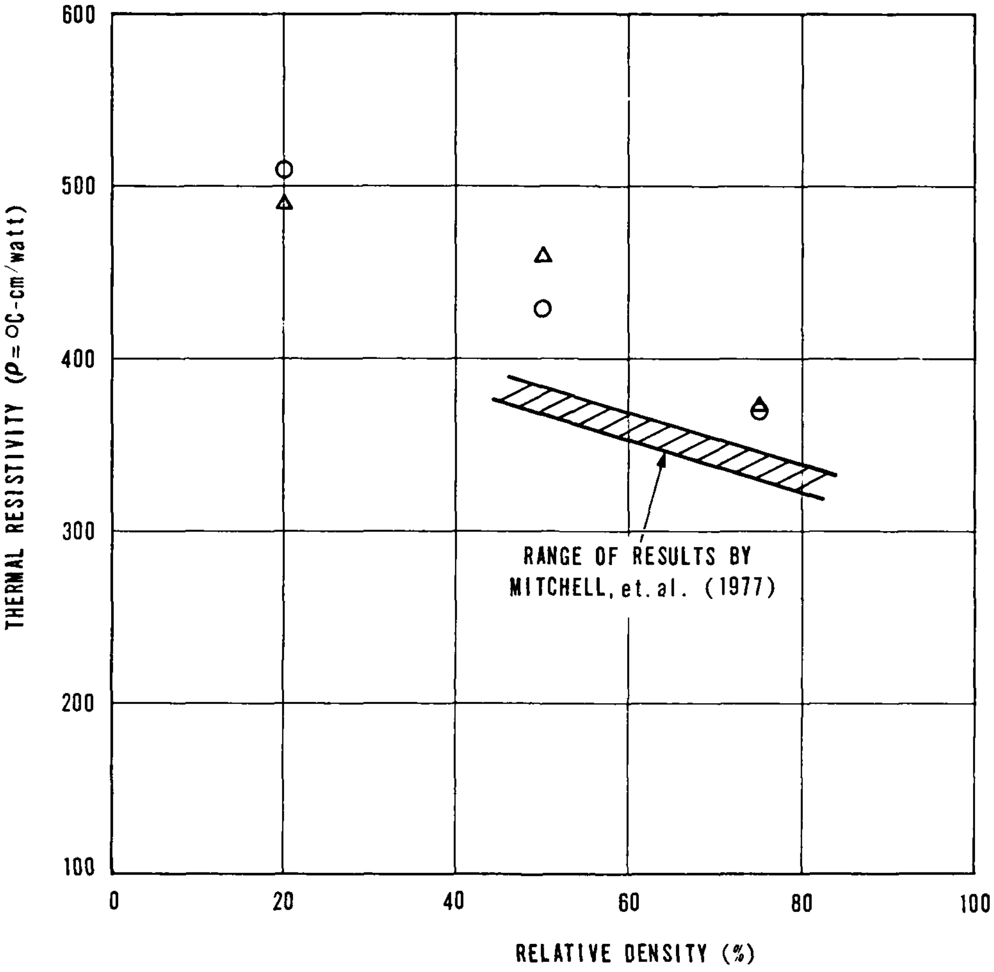
9 NOV 1979

C2.2 CALIBRATION

The thermal needle was calibrated before its use by comparing its determination of the thermal resistivity of Monterey No. 0 sand with data published by Mitchell et al. (1977). The results are shown in Figure C-3. After completion of the thermal resistivity tests on soil samples, the needle was again calibrated. These results are also shown in Figure C-3.

A review of Figure C-3 indicates that the thermal resistivity values of Monterey No. 0 sand as determined by Fugro National are slightly higher than those reported by Mitchell et al. (1977). The difference can be attributed to the method of calibration sample preparation and probable presence of a small amount of moisture in the sample. In the study performed by Mitchell et al. (1977), the thermal needle was rigidly held in the compaction mold first and the sand was placed around it. In the Fugro National study, the sand was compacted in the mold first and then the needle was inserted. The difference in the method of sample preparation would affect the density of the soil around the needle which would result in variation in thermal resistivity. In addition, there could have been a slight difference in the amount of moisture present in the sand (though sand is oven-dried, humidity of the air could affect the moisture in sand during sample preparation) in the two studies which could result in substantial variation of electrical resistivities.



EXPLANATION

○ BEFORE TESTS

△ AFTER TESTS

NOTE:
OVEN-DRIED MONTEREY NO. 0
SAND WAS USED FOR CALIBRATION.

RESULTS OF CALIBRATION TESTS
THERMAL RESISTIVITY NEEDLE

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DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
C-3

FUGRO NATIONAL, INC.

9 NOV 1979

C3.0 APPARATUS

The test apparatus consisted of the following:

1. Thermal Needle - the components and construction are described in Section C2.0.
2. Constant Current Source - HP 6201 constant current power supply.
3. Readout Unit - Fluke 2100A digital thermometer.
4. Timer - stopwatch.
5. Electric drill and 0.09-inch (2.3-mm) drill bit.
6. Thermal grease manufactured by 3M (thermal conductivity = 0.520-0.923 gm-cal/sec cm°C).

C4.0 TEST PROCEDURE

The laboratory test procedure used in determining thermal resistivity of a soil sample is as follows:

1. An 8-inch-, ±1-inch, long (20-cm ±3-cm) undisturbed soil sample was trimmed with ends flush with the sampling tube (Pitcher sample) or brass rings (Fugro Drive sample).
2. The sample with the tube (or rings) was weighed.
3. A longitudinal hole at the center of the soil sample was drilled to a depth of 4 inches (10 cm) using the 0.09-inch (2.3-mm) electric drill and the 0.09-inch-diameter drill bit (see Photo 1 in Plate C-1).
4. The thermal needle was coated with thermal grease (Photo 2 in Plate C-1) to ensure good contact between the needle and the soil and then inserted into the hole to a depth of 4 inches (102 mm).

PHOTO 1 - DRILLING HOLE IN SAMPLE FOR THERMAL PROBE INSERTION

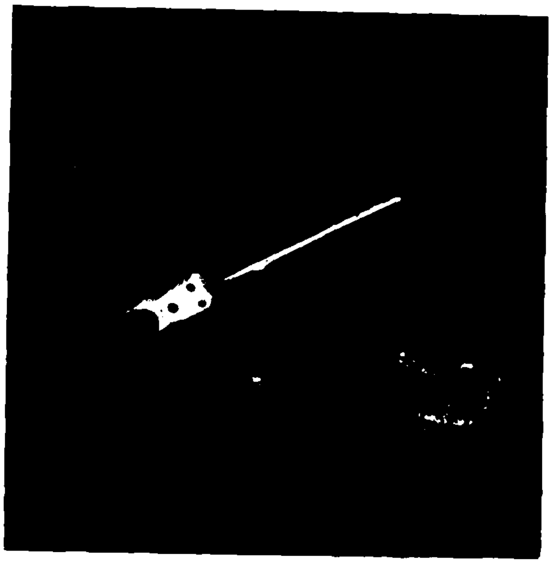

PHOTO 2 - THERMAL NEEDLE WITH THERMAL GREASE APPLIED

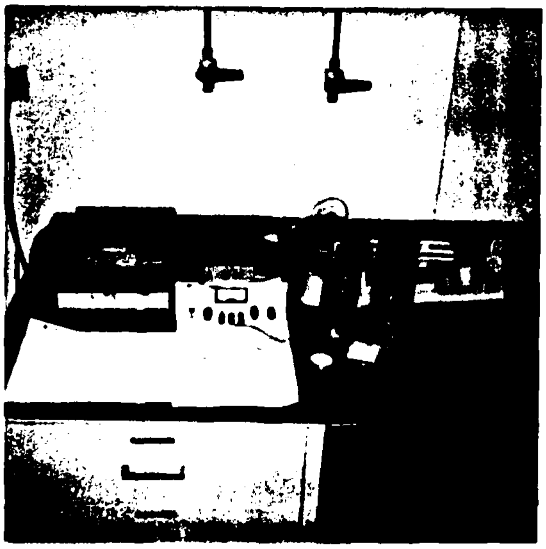

PHOTO 3 - TEST SETUP

THERMAL RESISTIVITY TEST SETUP

5. The heater wire of the thermal needle was connected to the constant heat source and the thermocouple to the readout unit.
6. A known constant current (1 amp) was applied to the heater wire and then the temperature of the needle was measured at various intervals of time. The test set up is shown in Photo 3 of Plate C-1.
7. Measurements made during the test were recorded on a data sheet as shown in Figure C-4. Then a plot of temperature versus log time was prepared (see Figure C-5). Using data from two points on the straight-line portion of the plot, thermal resistivity of the soil sample was computed. Computations are shown in Figure C-6 and are explained in detail in Section C5-0.

C5.0 CALCULATIONS

The thermal resistivity of the soil sample was computed as explained below:

$$\Delta\theta = \frac{Q}{4\pi k} (\Delta \ln t) \quad [3]$$

where

$\Delta\theta$ = change in temperature;

Q = heat input per unit length per unit time;

$k = \frac{1}{\rho}$ = thermal conductivity; and

t = time.

In the test, assume that during time interval from t_1 to t_2 the temperature increased from T_1 to T_2.

LABORATORY THERMAL NEEDLE RESISTIVITY TEST

PROJECT NAME AIR FORCE TESTED BY RC DATE 6-11-79
PROJECT NUMBER 78-290-52 COMPUTED BY RC DATE 6-11-79
BORING NUMBER BS-8-1 , D-4 CHECKED BY RL DATE 6/17/79
DEPTH (FEET) 71-7.5
SOIL DESCRIPTION SM w/ 5-10% gravel
used oversized drilled with Thermal mix

TEST CONDITIONS
A. THERMAL NEEDLE NO. Fugro #1
B. CURRENT (AMP) 1 Amp V= 3.05
C. HOW WAS NEEDLE INSERTED INTO SAMPLE
☐ PUSHED
☒ PRE-DRILLED over sized

SAMPLE CONDITIONS
DRY UNIT WEIGHT 106.2 (PCF)
WATER CONTENT 7.1 (%)

REMARKS

TIME	ELAPSED TIME (SEC)	THERMOCOUPLE READING (°F)
1620	0	56.3
	10	103.0
	30	105.3
	60	110.8
	90	112.2
	120	113.1
	150	113.7
	180	114.2
	210	114.5
	240	114.7
	270	114.9
	300	115.0
	330	115.1
	360	115.2
	390	115.3
	420	115.3
	450	
	480	
	510	
	540	
	570	
	600	
	630	
	660	
	690	

TYPICAL TEST DATA SHEET
THERMAL RESISTIVITY TEST

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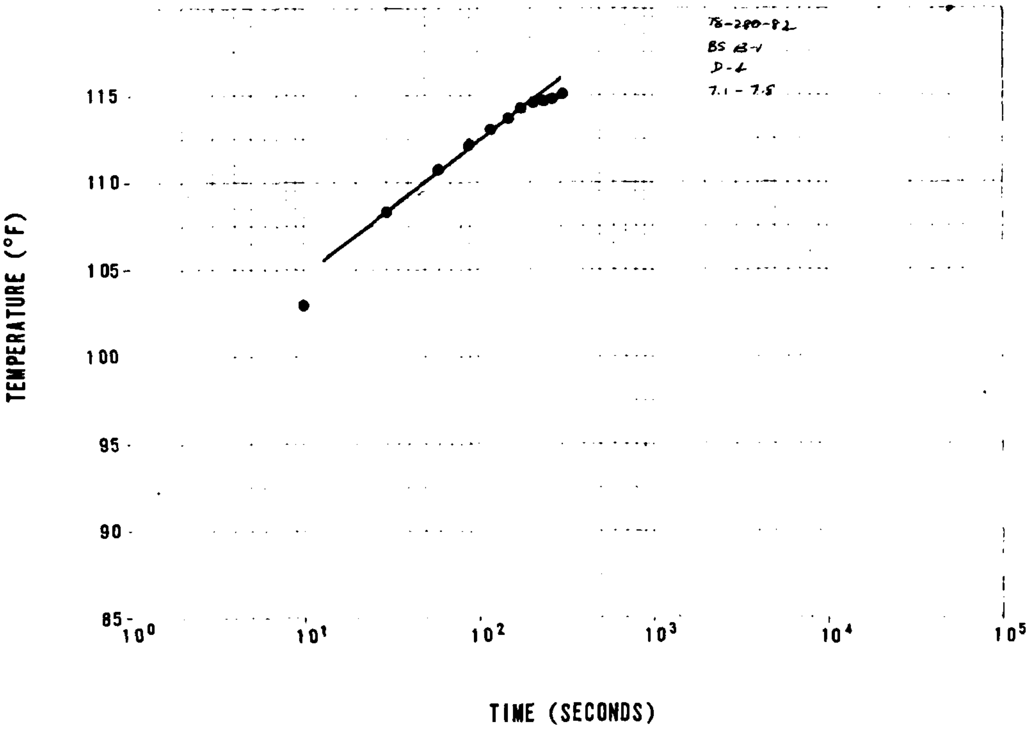
FIGURE
C-4

FUGRO NATIONAL, INC.



BORING NO. BS-B-1
SAMPLE NO. D-4
DEPTH 7.1'-7.8' (2.2-2.4m)
USCS: SM

TYPICAL TEST PLOT
THERMAL RESISTIVITY TEST

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FIGURE
C-5

FUGRO NATIONAL, INC.

9 NOV 1979

THERMAL RESISTIVITY COMPUTATION

PROJECT NAME Thermal A.F. TESTED BY P.K. DATE 6/11/79
FILE NUMBER 78-280-82 COMPUTED BY PK DATE 6/11/79
[illegible] NUMBER BS-B-1, D4 CHECKED BY EL DATE 6/17/79
DEPTH (FEET) 7.1 - 7.8 NEEDLE NUMBER #1
SOIL DESCRIPTION SM - silty sand, 5-10% gravel

$$K = \frac{0.03537}{\Delta\theta} \; LOG_{10} \left(t_2 / t_1\right)$$

NOTE: VALID ONLY FOR FUGRO NO. 1 THERMAL NEEDLE, 1 AMP,
E = 3.15 VOLTS L = 15.3cm

T_2 = 45.4 C 113.7 °F
T_1 = 42.4 C 108.3 °F
$\Delta\theta = T_2 - T_1$ = 3.0 C
t_2 = 150 SEC
t_1 = 30 SEC

$K = \frac{0.03537}{3.0} \times LOG_{10} (150 / 30)$

$K = 8.24 \times 10^{-3}$ WATT/C-cm

$\rho = \frac{1}{K}$ = C-cm/WATT = 121.3 °c-cm/watt

6-75

TYPICAL COMPUTATIONS
THERMAL RESISTIVITY TEST

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
C-6

FUGRO NATIONAL, INC.

$$\Delta\theta = T_2 - T_1 = \frac{Q}{4\pi k} (\ln t_2 - \ln t_1)$$

$$= \frac{2.3Q}{4\pi k} (\log_{10} t_2 - \log_{10} t_1)$$

$$k = \frac{2.3Q}{4\pi\Delta\theta} \log_{10}\frac{t_2}{t_1} \quad \ldots\ldots\ldots\ldots \quad [4]$$

Heat input $Q = \frac{I^2R}{L} = \frac{EI}{L}$ (Winterkorn, 1970)

(Q = power consumption of heater wire in watts per unit length, which is assumed to be the equivalent of heat output per unit length of wire)

where

I = current flowing through heater wire, in amps;
R = total resistance of heater wire, in ohms;
L = length of heater wire, in cms; and
E = voltage measured.

therefore,

$$k = \frac{2.3\ EI}{4\pi\Delta\theta L} \log_{10}\frac{t_2}{t_1} \quad \ldots\ldots\ldots\ldots \quad [5]$$

For the tests (standardized test conditions) conducted in the laboratory,

E = 3.15 volts;
I = 1.0 amp; and
L = 16.3 cm.

Using these values, Eq. [5] will be

$$k = \frac{0.03537}{\Delta\theta} \log_{10}\frac{t_2}{t_1}\text{, in watt/}^{\circ}\text{C-cm} \quad \ldots\ldots\ldots\ldots \quad [6]$$

This equation was used in computing thermal conductivity values of the soil samples (see Figure C-6). Thermal resistivity of the soil samples was then computed using the relationship $\rho = \frac{1}{k}$.

$$\Delta\theta = T_2 - T_1 = \frac{Q}{4\pi}\rho\ (\ln t_2 - \ln t_1)$$

$$= \frac{2.3Q}{4\pi}\rho\ (\log_{10} t_2 - \log_{10} t_1)$$

$$\rho = \frac{4\pi\Delta\theta}{2.3Q} \log_{10} \frac{t_1}{t_2} \text{ .... } [4]$$

Heat input $Q = \frac{I^2R}{L} = \frac{EI}{L}$ (Winterkorn, 1970)

(Q = power consumption of heater wire in watts per unit length, which is assumed to be the equivalent of heat output per unit length of wire)

where

I = current flowing through heater wire, in amps;
R = total resistance of heater wire, in ohms;
L = length of heater wire, in cms; and
E = voltage measured.

therefore,

$$\rho = \frac{4\pi\Delta\theta L}{2.3\ EI} \log_{10} \frac{t_1}{t_2} \text{ .... } [5]$$

For the tests (standardized test conditions) conducted in the laboratory,

E = 3.15 volts;
I = 1.0 amp; and
L = 16.3 cm.

Using these values, Eq. [5] will be

$$\rho = \frac{\Delta\theta}{0.03537} \log_{10}\left(\frac{t_1}{t_2}\right), \text{ in } {}^{o}C - cm/watt \text{ .... } [6]$$

This equation was used in computing thermal resistivity values of the soil samples (see Figure C-6).

APPENDIX D

SUPPLEMENTARY TESTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Cont.)

D1.0 INTRODUCTION

Supplementary tests consisted of the following:

Moisture Content
Dry Density
Particle-Size Analysis

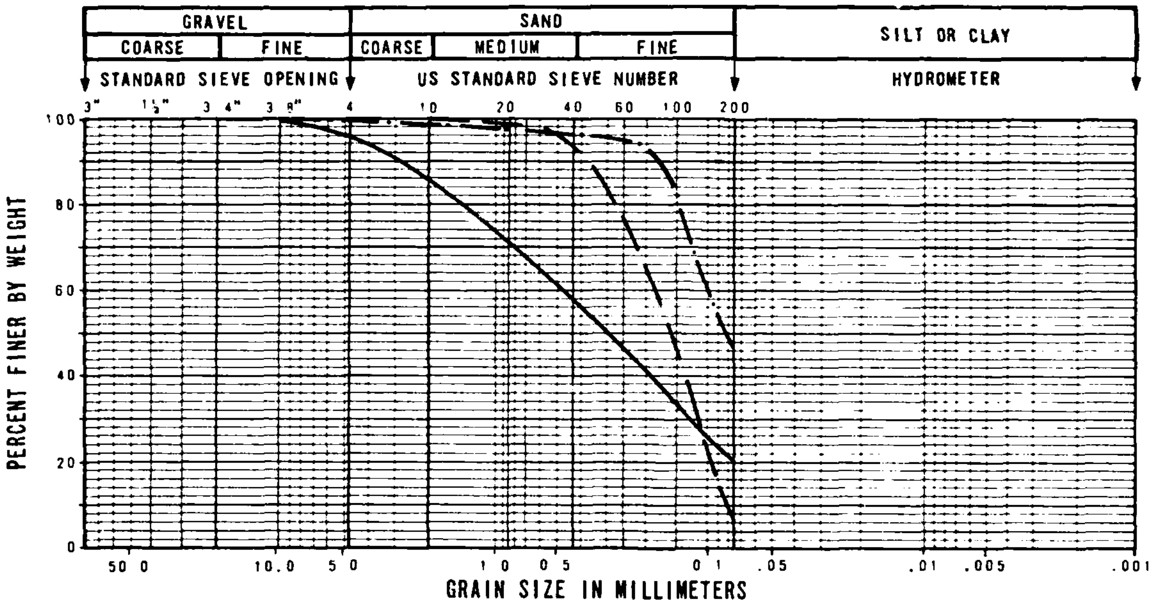
The tests were performed in general accordance with procedures of the American Society for Testing and Materials (ASTM). These test procedures are presented in this appendix.

D2.0 MOISTURE-DENSITY DETERMINATION

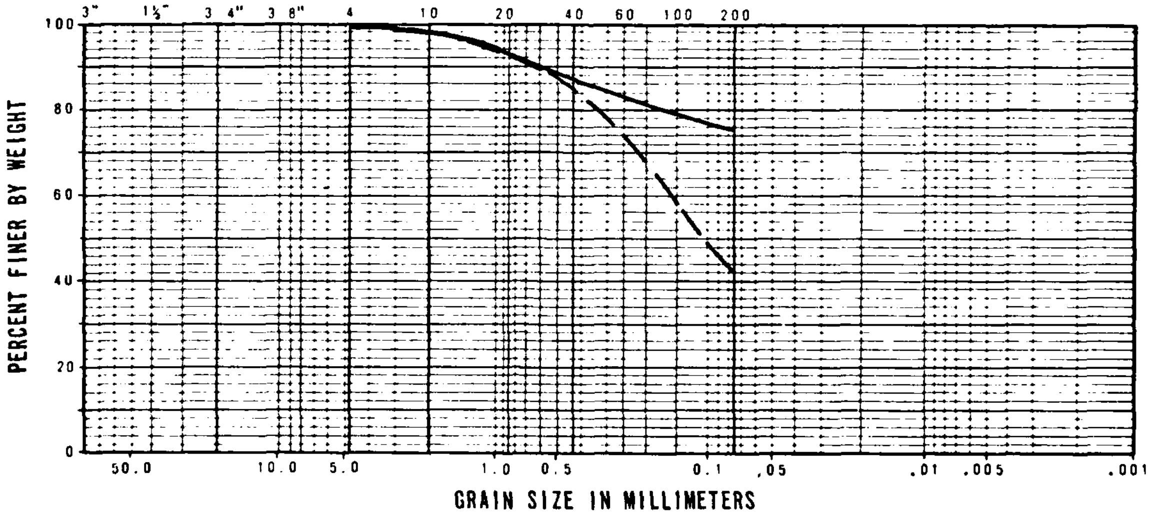
Standardized test procedure (Fugro Test Procedure No. 200) was used in determination of wet and dry densities of soil samples. Moisture content of the soil sample was determined in accordance with ASTM D 2216-71, Laboratory Determination of Moisture Content of Soil. These test procedures and typical test data sheets are presented in Subappendix D1.

D3.0 PARTICLE-SIZE ANALYSIS

Fugro test procedure No. 190 was used for particle-size analysis of soil samples. Distribution of particle sizes larger than 75 microns (retained on No. 200 sieve) was determined by sieving. Distribution of particle sizes finer than 75 microns was not determined. The test procedure and typical data sheets are presented in Subappendix D2. Results of particle-size analysis tests on soil samples used in thermal properties tests are presented graphically in Figures D-1 through D-11.



SYMBOL	BORING NO.	SAMPLE NO.	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				
——	RR-B-2	P-2	3.0-3.9	0.9-1.2				SM
— —	RR-B-2	D-8	30.4-30.9	9.3-9.4				SP-SM
—·—	RR-B-2	D-9	35.3-35.8	10.8-10.9				SM



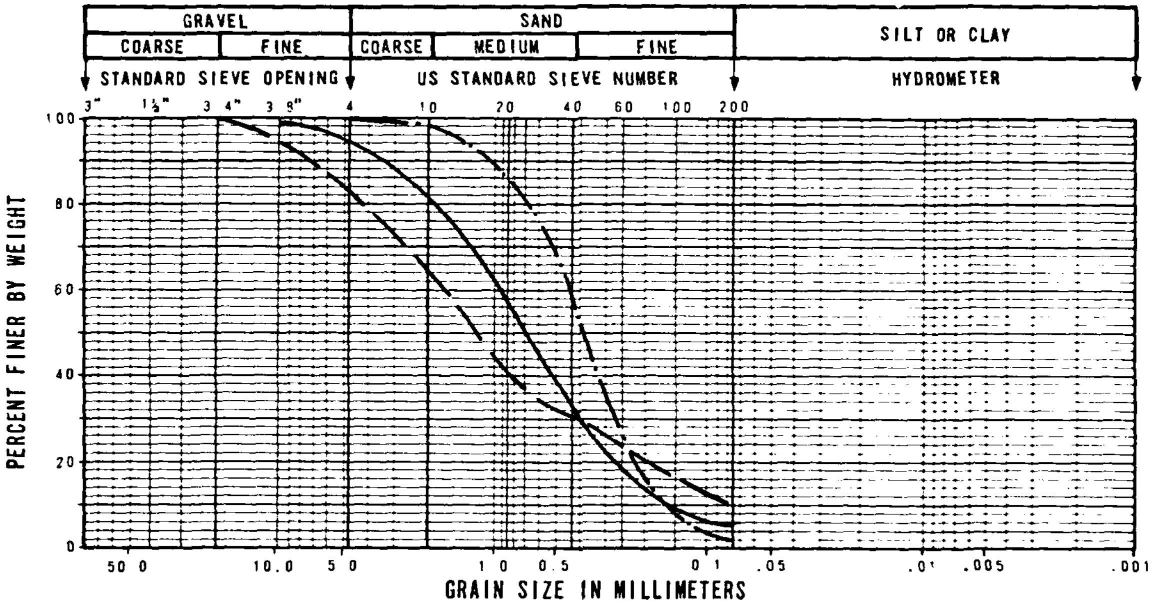
SYMBOL	BORING NO.	SAMPLE NO	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				
——	RR-B-2	P-13	59.0-59.9	18.0-18.3	29	24	5	ML
— —	RR-B-2	P-18	109.0-110.7	33.2-33.8				SM

PARTICLE-SIZE ANALYSES
BORING RR-B-2
REVEILLE-RAILROAD CDP, NEVADA

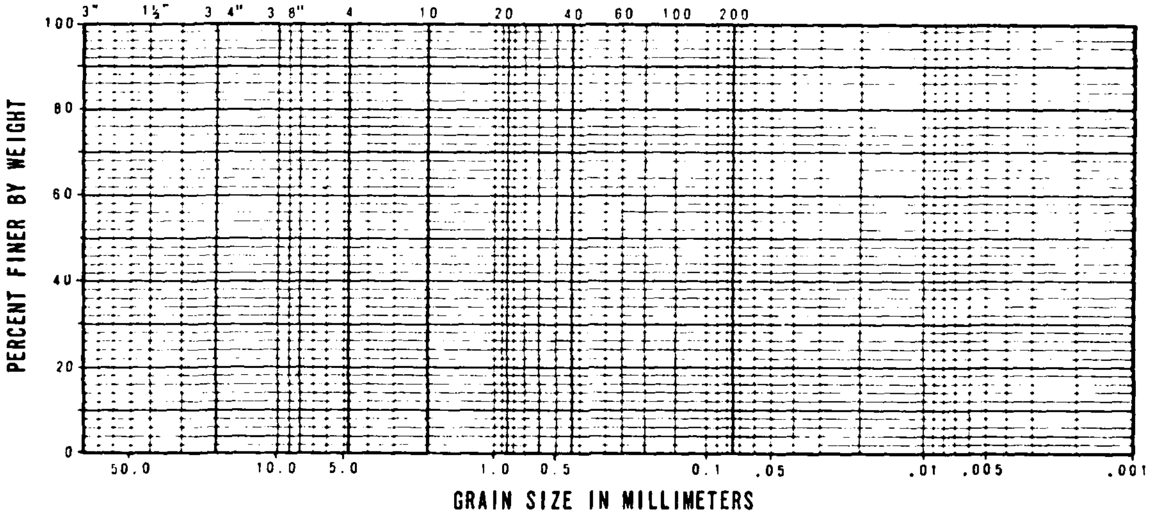
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
D-1

FUGRO NATIONAL, INC.



SYMBOL	BORING NO.	SAMPLE NO.	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				
———	RR-B-3	D-4	7.2-7.9	2.2-2.4				SP-SM
— — —	RR-B-3	P-13	60.0-61.7	18.3-18.5				SP-SM
—·—	RR-B-3	P-18	110.0-111.6	33.5-34.2				SP



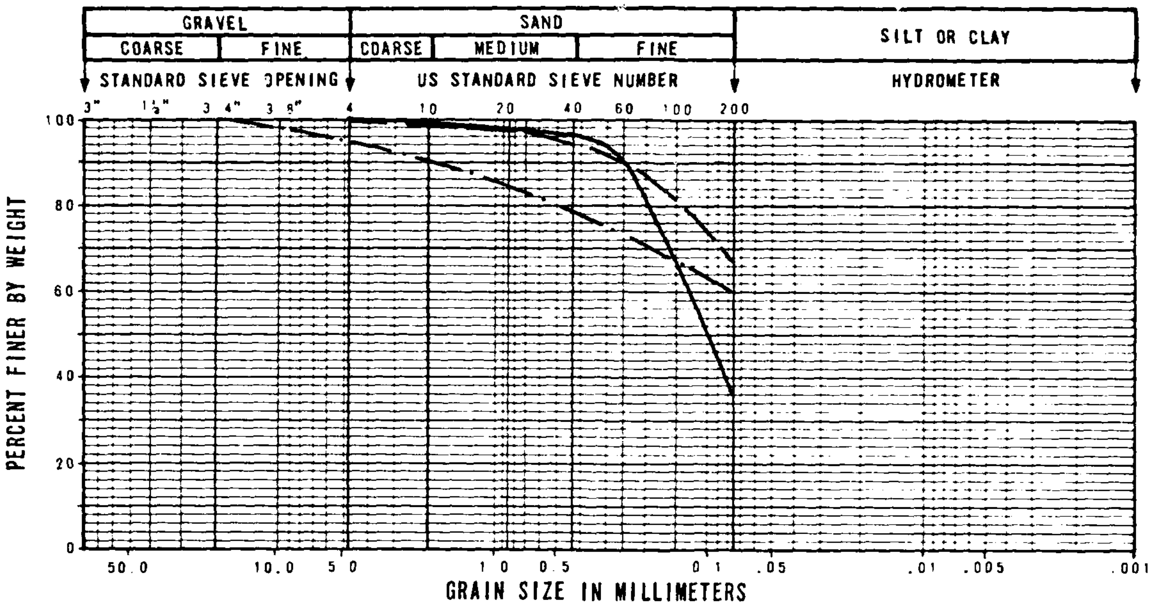
SYMBOL	BORING NO.	SAMPLE NO	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				

PARTICLE-SIZE ANALYSES
BORING RR-B-3
REVEILLE-RAILROAD CDP, NEVADA

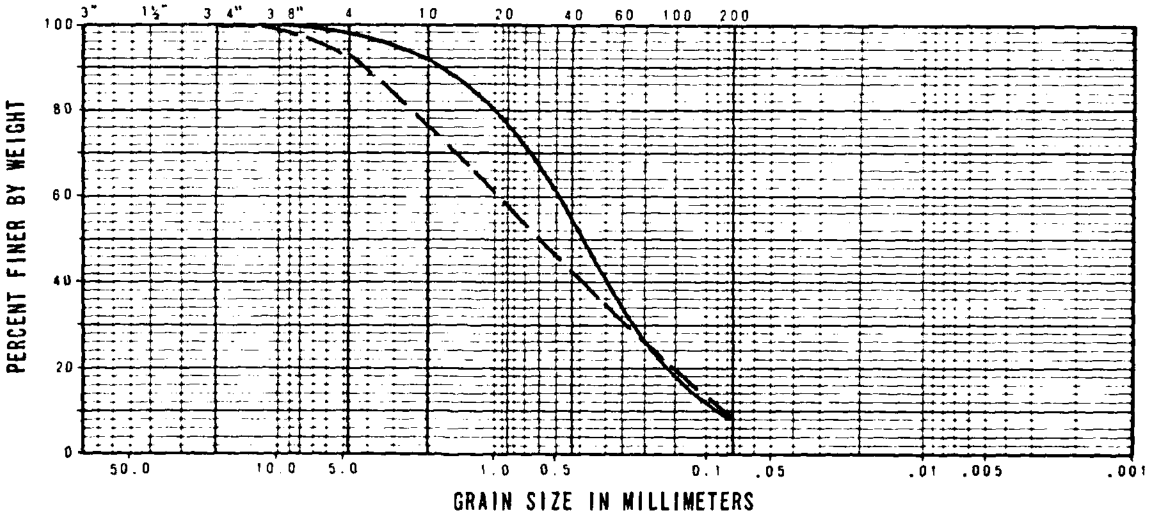
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
D-2

FUGRO NATIONAL, INC.



SYMBOL	BORING NO.	SAMPLE NO.	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				
———	RR-B-3A	P-3	7.5-9.1	2.3-2.8				SM
— — —	RR-B-3A	P-4	10.0-11.8	3.1-3.6				ML
—·—	RR-B-3A	P-8	50.0-50.9	15.3-15.5				ML



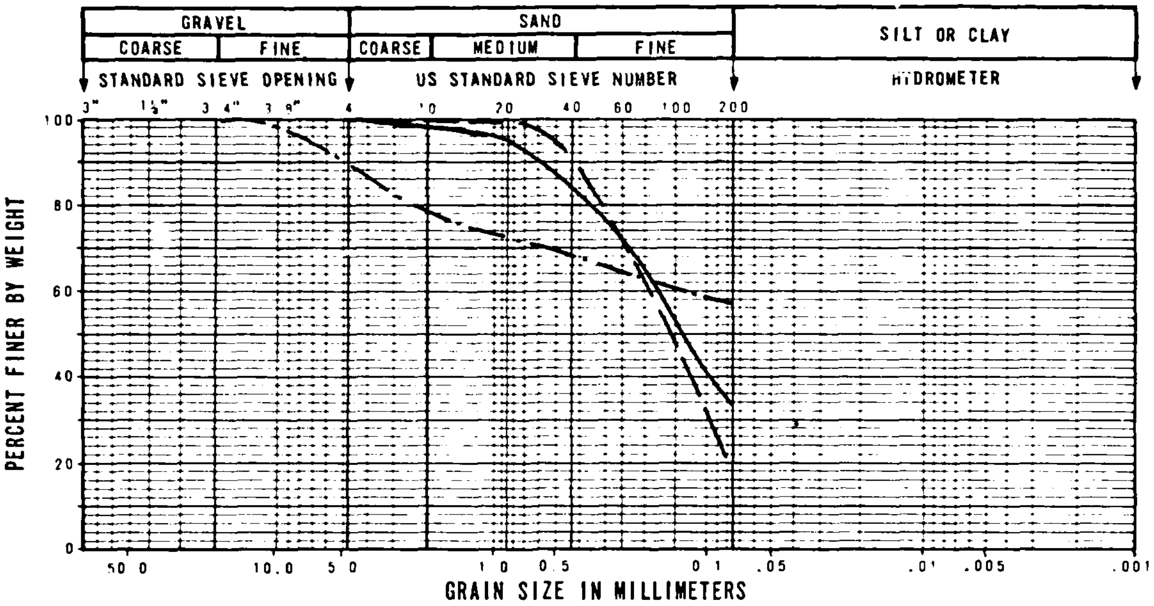
SYMBOL	BORING NO.	SAMPLE NO	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				
———	RR-B-3A	P-9	76.9-77.7	23.5-23.7				SP-SM
— — —	RR-B-3A	P-12	126.5-127.2	38.6-38.8				SP-SM

PARTICLE-SIZE ANALYSES
BORING RR-B-3A
REVEILLE-RAILROAD CDP, NEVADA

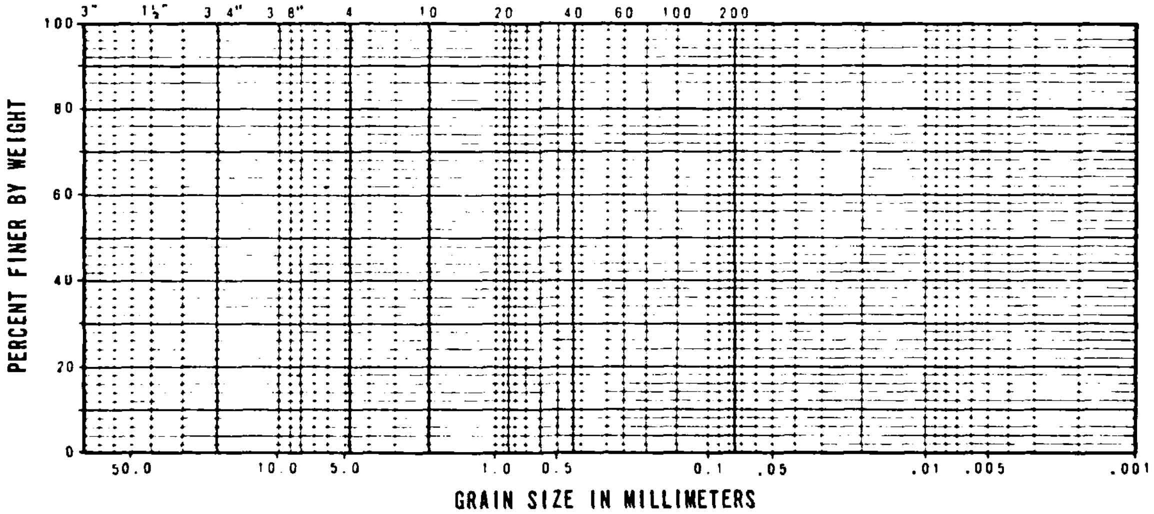
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
D-3

FUGRO NATIONAL, INC.



SYMBOL	BORING NO	SAMPLE NO.	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				
———	RR-B-4	P-4	7.0-8.9	2.1-2.7				SM
— —	RR-B-4	P-13	50.0-51.7	15.3-15.8				SM
	RR-B-4	P-18	101.5-102.4	31.0-31.2				ML



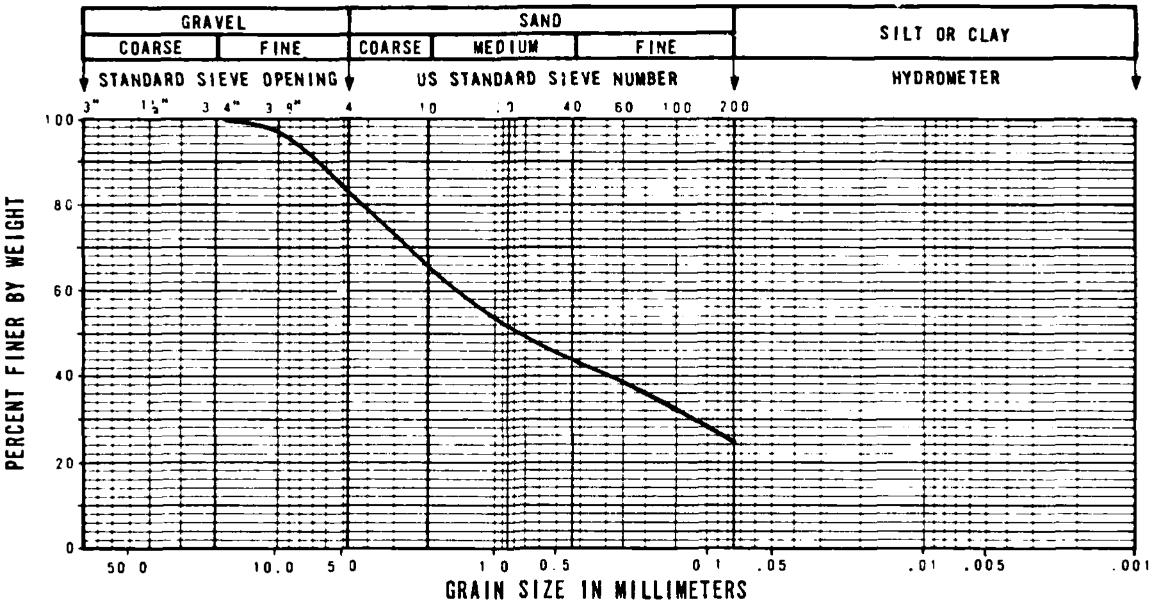
SYMBOL	BORING NO.	SAMPLE NO	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				

PARTICLE-SIZE ANALYSES
BORING RR-B-4
REVEILLE-RAILROAD CDP, NEVADA

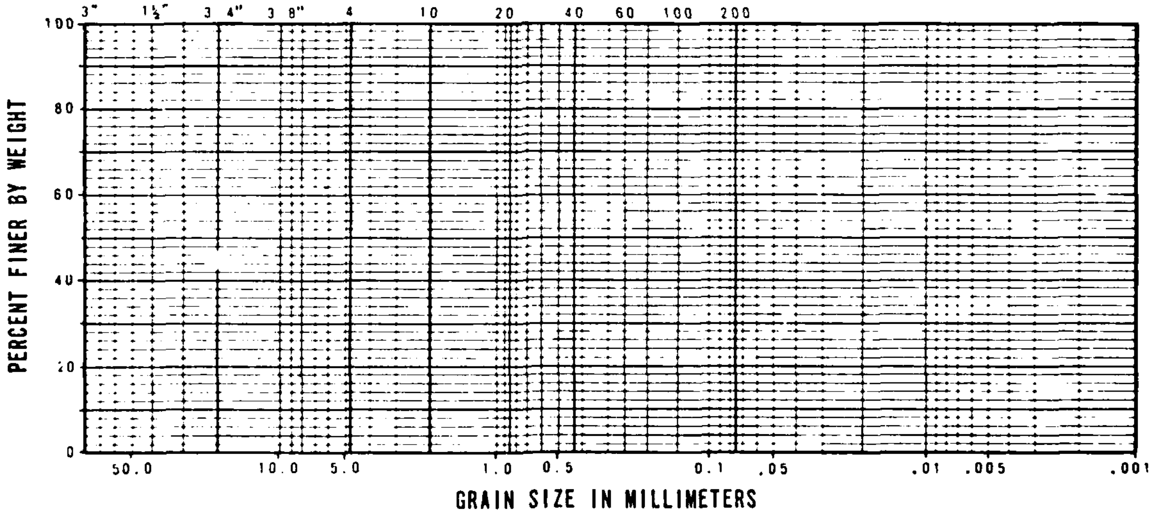
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE
D-4

FUGRO NATIONAL, INC.



SYMBOL	BORING NO	SAMPLE NO.	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				
——	RR-B-5	D-12	50.2-50.9	15.3-15.5				SM



SYMBOL	BORING NO.	SAMPLE NO	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				

PARTICLE-SIZE ANALYSIS
BORING RR-B-5
REVEILLE-RAILROAD CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
D-5

FUGRO NATIONAL, INC.

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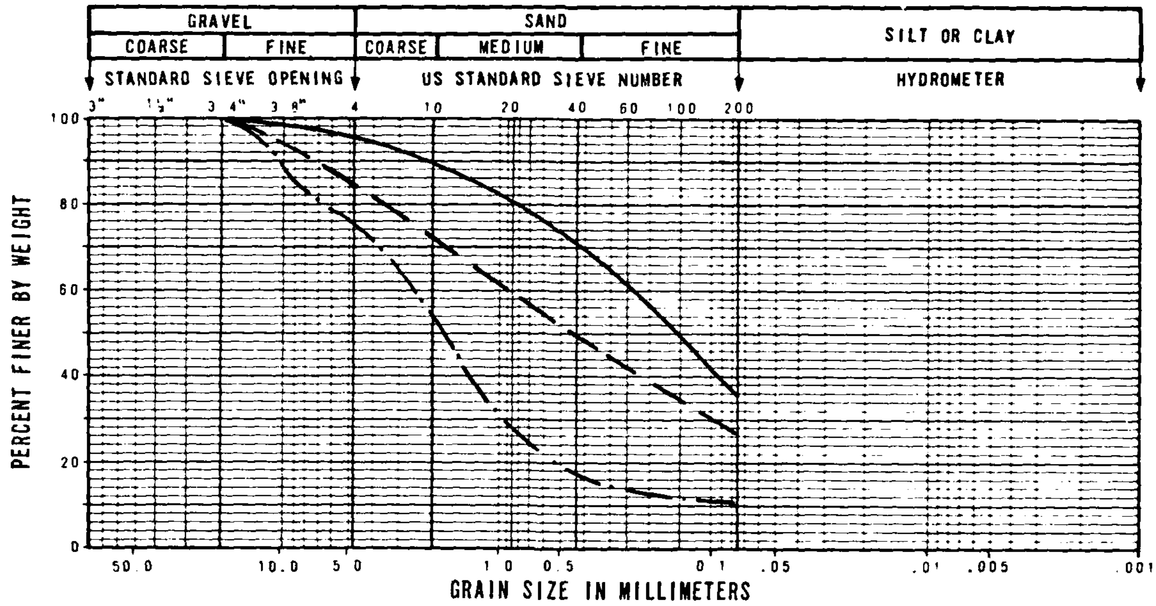
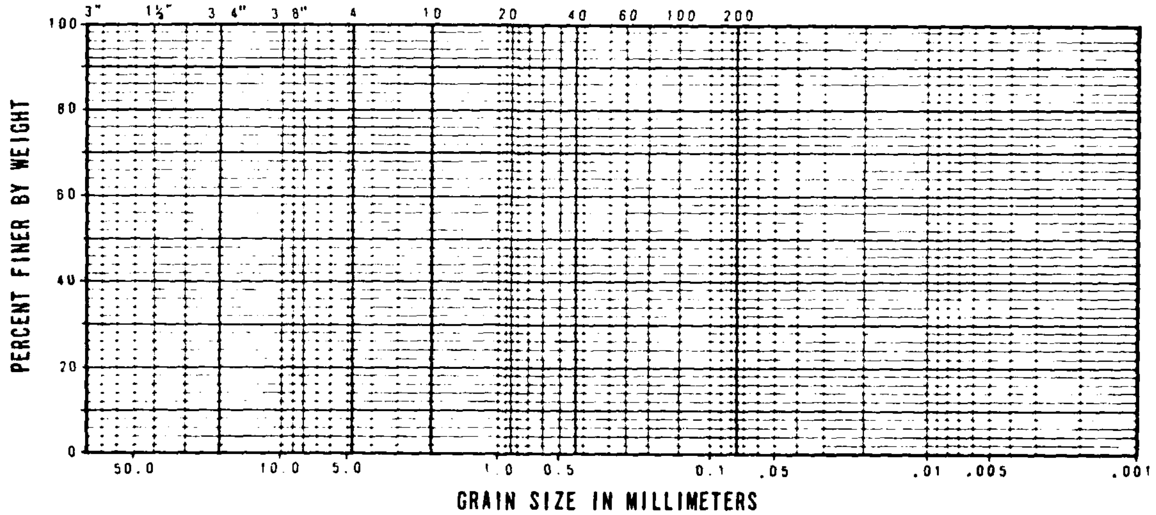
FN-TR-29



SYMBOL	BORING NO.	SAMPLE NO.	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				
────	RR-B-6	P-1	0.0-0.7	0.0-0.2				SM
— —	RR-B-6	D-14	65.7-66.4	20.0-20.2				SM
—·—	RR-B-6	D-17	92.0-92.6	28.1-28.2				SP-SM



SYMBOL	BORING NO.	SAMPLE NO	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				

PARTICLE-SIZE ANALYSES
BORING RR-B-6
REVEILLE-RAILROAD CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
D-6

FUGRO NATIONAL, INC.

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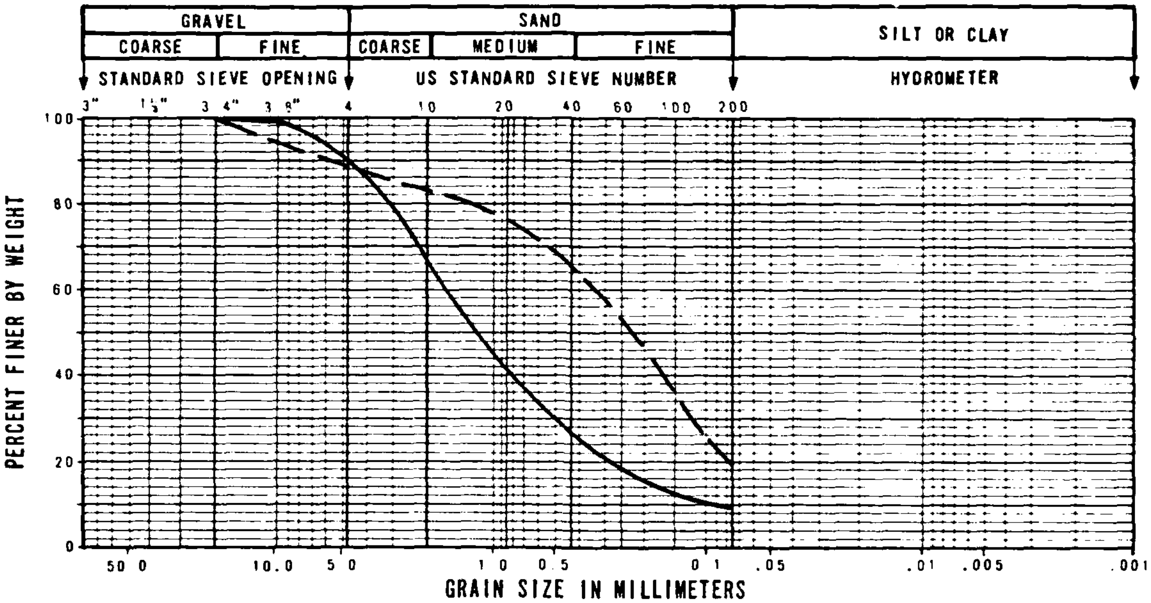
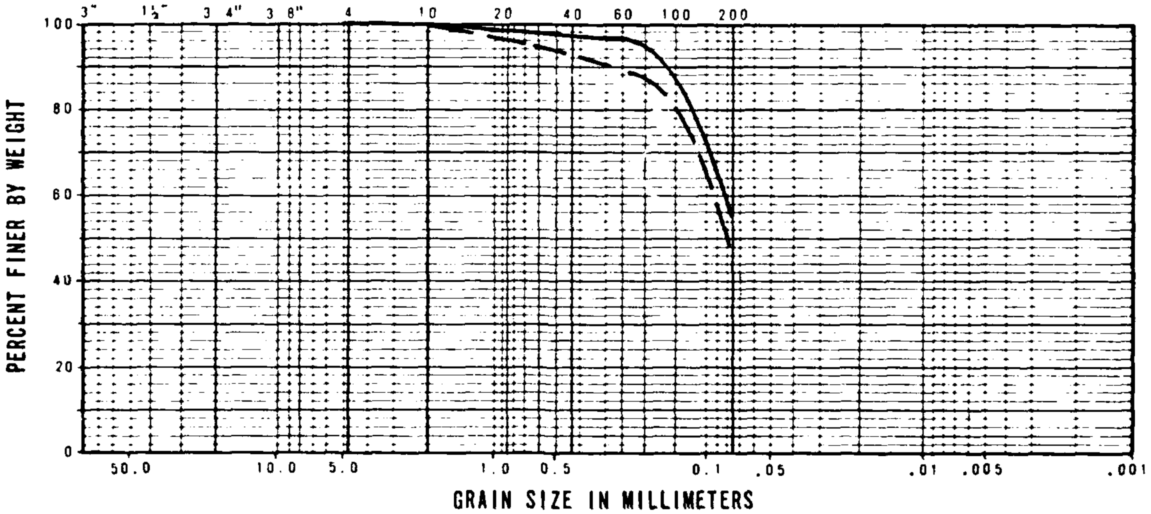


SYMBOL	BORING NO.	SAMPLE NO.	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				
——	BS-B-1	D-3	3.9-4.6	1.2-1.4				SP-SM
– –	BS-B-1	D-4	7.1-7.8	2.2-2.4				SM



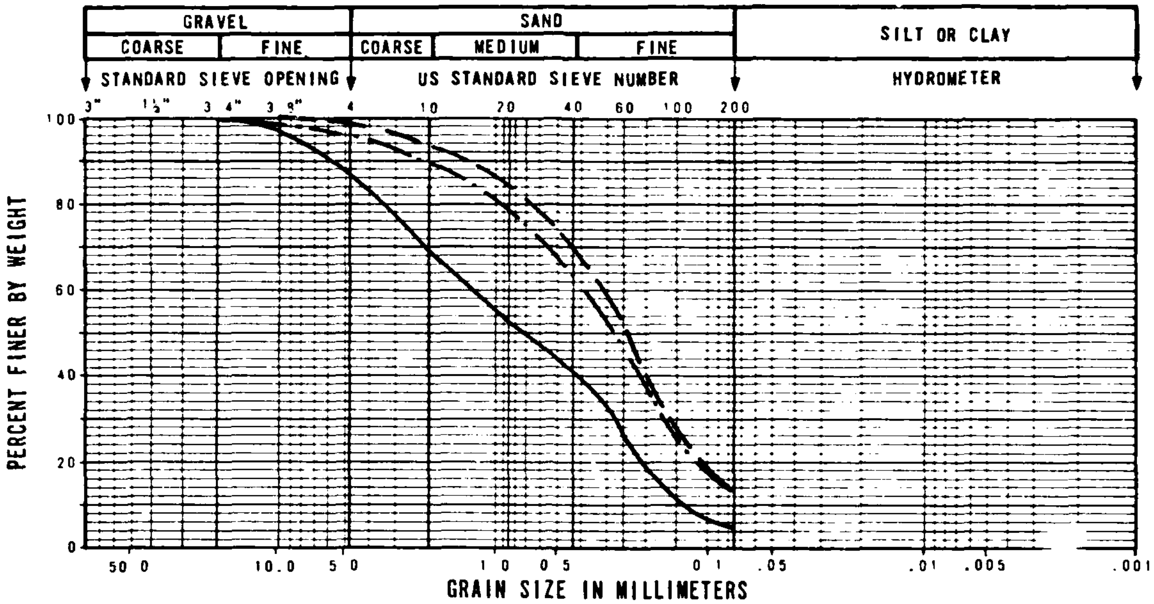
SYMBOL	BORING NO.	SAMPLE NO.	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				
——	BS-B-1	P-13	50.4-51.3	15.4-15.6				ML
– –	BS-B-1	P-14	60.0-61.0	18.3-18.6				SM

PARTICLE-SIZE ANALYSES
BORING BS-B-1
BIG SMOKY CDP, NEVADA

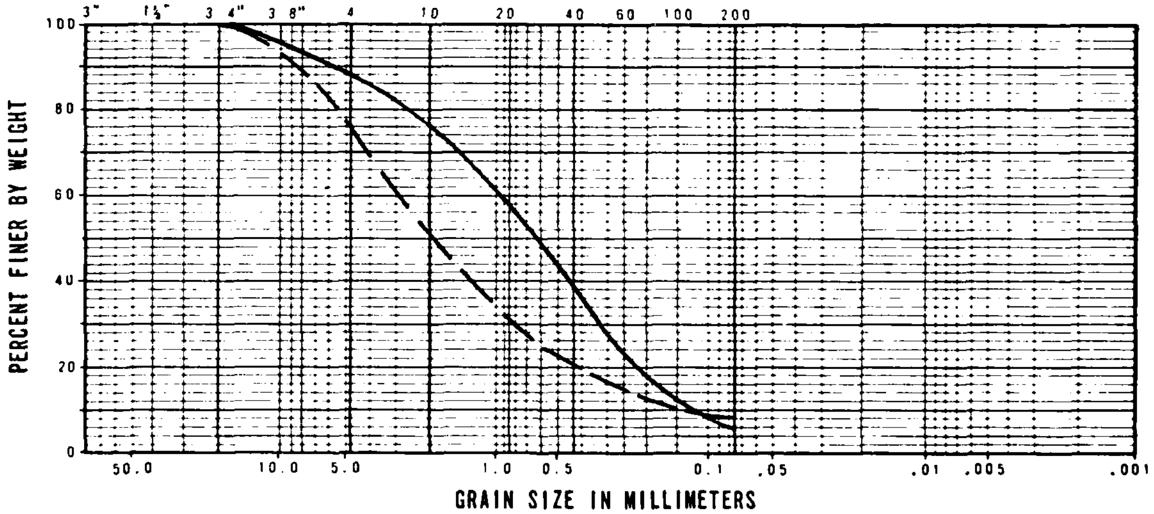
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
D-7

FUGRO NATIONAL, INC.



SYMBOL	BORING NO.	SAMPLE NO.	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				
——	BS-B-2	D-6	7.0-7.5	2.1-2.3				SP-SM
— —	BS-B-2	D-7	10.0-10.7	3.1-3.3				SM
— · —	BS-B-2	P-14	50.0-52.7	15.3-16.1				SM



SYMBOL	BORING NO.	SAMPLE NO	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				
——	BS-B-2	P-15	60.0-61.4	18.3-18.7				SP-SM
— —	BS-B-2	D-24	160.0-160.5	48.8-49.0				SP-SM

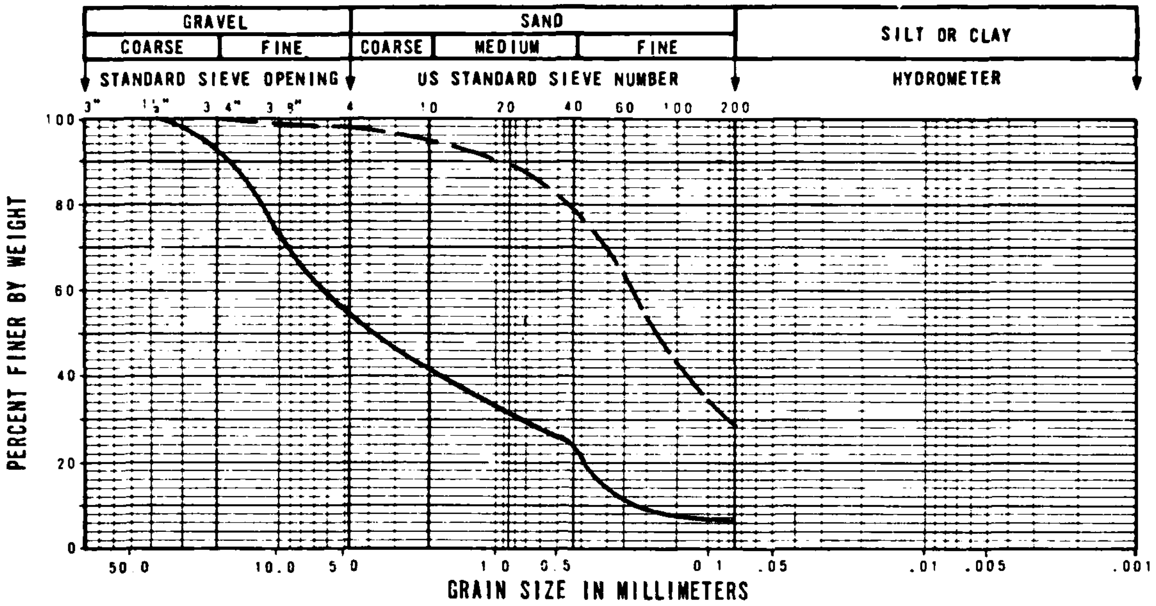
PARTICLE-SIZE ANALYSES
BORING BS-B-2
BIG SMOKY CDP,NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
D-8

FUGRO NATIONAL, INC.

9 NOV 1979



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<tr><th>FEET</th><th>METERS</th></tr>
<tr><td>———</td><td>BS-B-3</td><td>D-3</td><td>4.2-4.9</td><td>1.3-1.5</td><td></td><td></td><td></td><td>SP-SM</td></tr>
<tr><td>— — —</td><td>BS-B-3</td><td>P-9</td><td>30.0-31.2</td><td>9.1-9.5</td><td></td><td></td><td></td><td>SM</td></tr>
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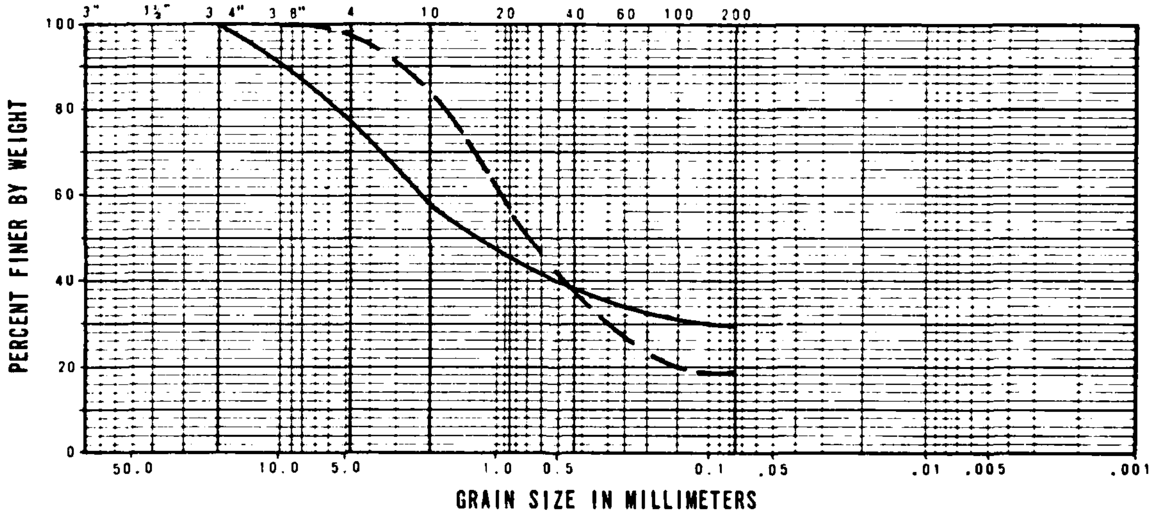

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<tr><th>FEET</th><th>METERS</th></tr>
<tr><td>———</td><td>BS-B-3</td><td>D-14</td><td>70.2-70.9</td><td>21.4-21.6</td><td></td><td></td><td></td><td>SM</td></tr>
<tr><td>— — —</td><td>BS-B-3</td><td>D-16</td><td>90.0-90.7</td><td>27.5-27.7</td><td></td><td></td><td></td><td>SM</td></tr>
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PARTICLE-SIZE ANALYSES
BORING BS-B-3
BIG SMOKY CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
D-9

FUGRO NATIONAL, INC.

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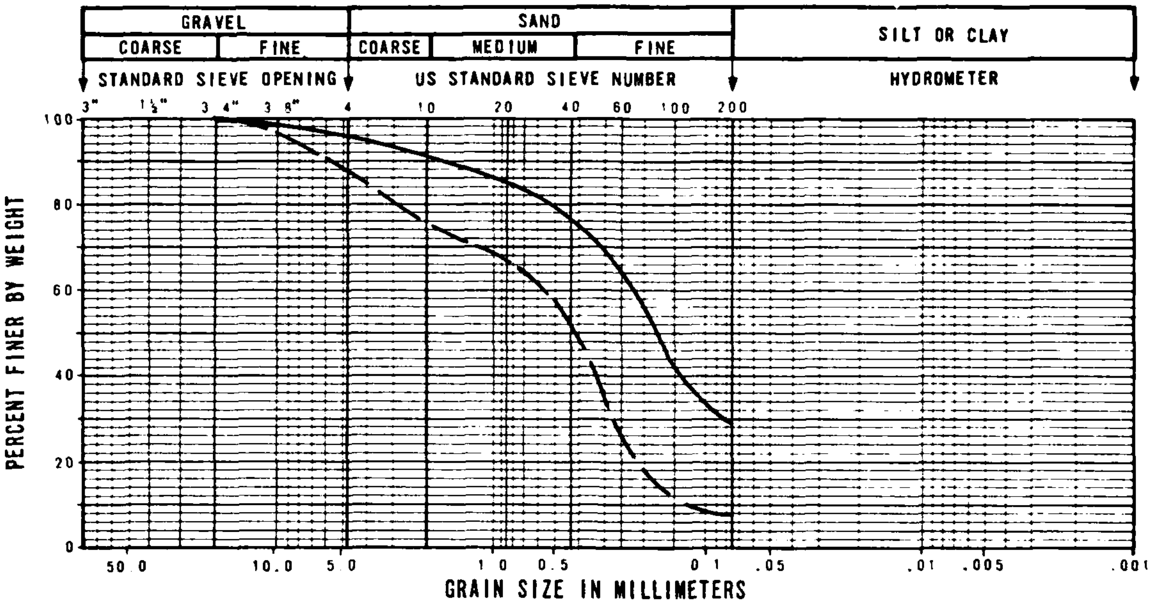
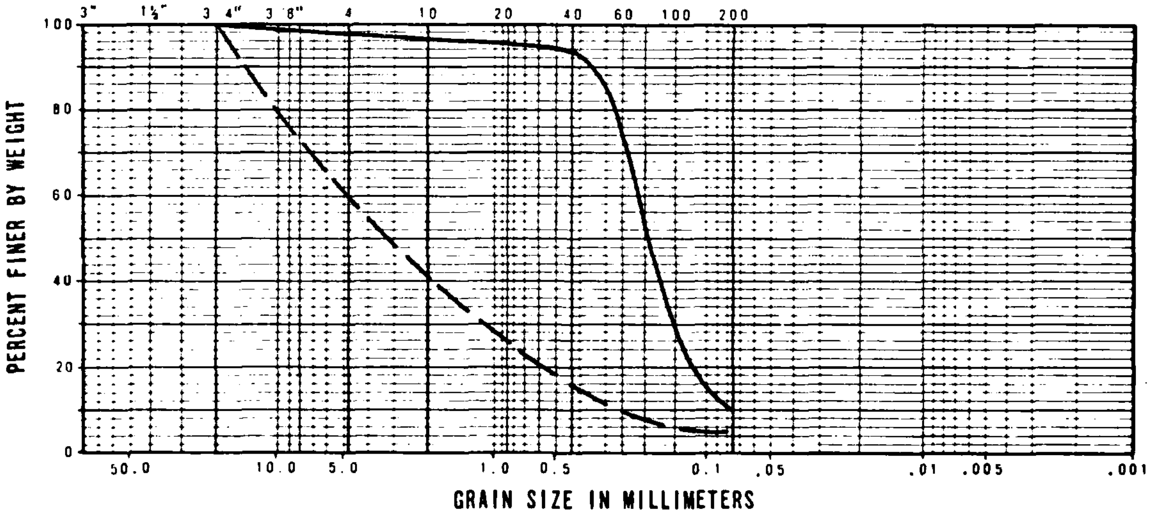


SYMBOL	BORING NO	SAMPLE NO.	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				
———	BS-B-5	P-1	0.6-1.3	0.2-0.4				SM
— —	BS-B-5	D-10	35.0-35.6	10.7-10.9				SP-SM



SYMBOL	BORING NO.	SAMPLE NO	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				
———	BS-B-5	P-15	80.0-81.1	24.4-24.7				SP-SM
— —	BS-B-5	D-21	160.2-160.9	48.9-49.1				SP

PARTICLE-SIZE ANALYSES
BORING BS-B-5
BIG SMOKY CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
D-10

FUGRO NATIONAL, INC.

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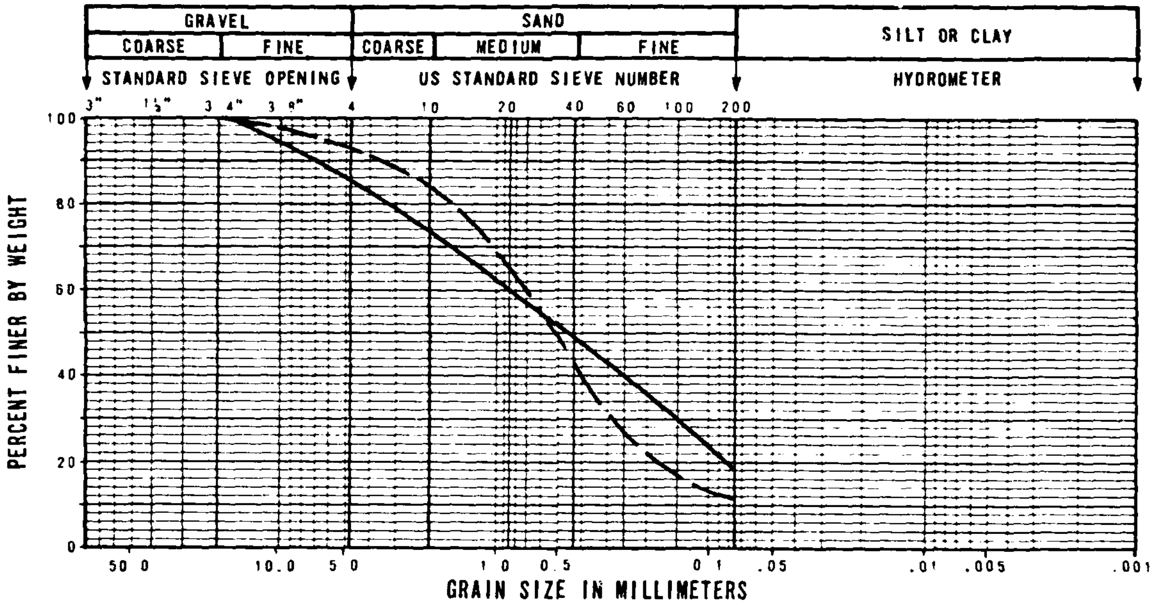
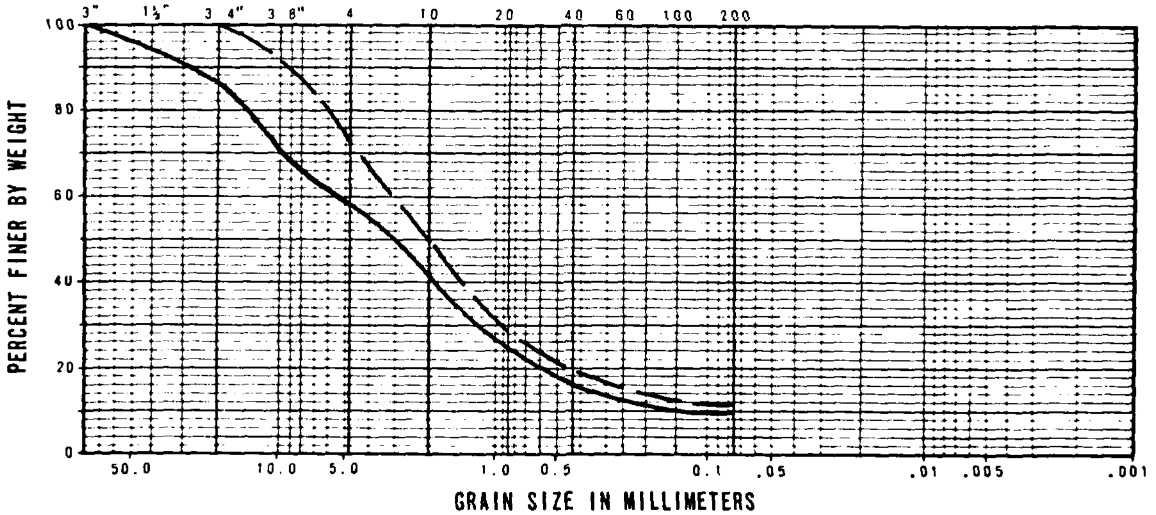


SYMBOL	BORING NO.	SAMPLE NO.	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				
——	BS-B-6	P-1	0.7-1.4	0.2-0.4				SM
— —	BS-B-6	D-8	25.7-26.4	7.8-8.1				SP-SM



SYMBOL	BORING NO.	SAMPLE NO.	SAMPLE INTERVAL		LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
			FEET	METERS				
——	BS-B-6	D-9	30 2-30.9	9.2-9.4				SP-SM
— —	BS-B-6	D-19	120.4-120.9	36.7-36.9				SP-SM

PARTICLE-SIZE ANALYSES
BORING BS-B-6
BIG SMOKY CDP, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
D-11

FUGRO NATIONAL, INC.

SUBAPPENDIX D1

MOISTURE-DENSITY DETERMINATION

FUGRO TEST PROCEDURE NO. 200
PROCEDURE FOR MOISTURE-DENSITY DETERMINATION

Scope

This procedure covers laboratory determination of the wet density, moisture content, and dry density of soils.

Equipment

1. A thermostatically controlled oven capable of being heated continuously at 230 ±9°F (110 ±5°C);
2. Balances sensitive to 0.025 gram for samples weighing 100 grams or less, to 0.2 gram for samples weighing 100 to 1000 grams, and to 2 grams for samples weighing over 1000 grams;
3. Containers which are corrosion-resistant and not subject to change in weight or disintegration on repeated heating; and
4. Scales capable of reading to 0.01 inch (0.25 mm) and a spatula.

Procedure

1. Trim samples carefully as they arrive in the laboratory, usually in metal tubes or rings, and determine their dimensions to the nearest hundredth of an inch so that their volumes may be computed. The samples shall then be weighed with the containers. The containers' weight shall be determined separately.
2. Perform moisture content test on a representative portion of the samples as detailed in Section 5 of ASTM Standard D 2216-71 for "Laboratory Determination of Moisture Content of Soil," as modified by the following.

Containers used need not have lids, but weighing of samples shall be performed immediately after extrusion from original container and after removal from oven.

Calculations

The wet density, moisture content, and dry density shall be calculated per the following formulas:

1. $$\text{Wet Density} = \frac{\text{Wet Weight of Soil}}{\text{Volume of Soil}}$$

$$= \frac{\text{Total Wet Weight - Weight of Container}}{\text{Volume of Soil}}$$

2. $$\text{Moisture Content } (w) = \frac{\text{Weight of Moisture}}{\text{Weight of Oven-dry Soil}} \times 100$$

$$w = \frac{W_1 - W_2}{W_2 - W_c} \times 100$$

where:

w = moisture content in percent

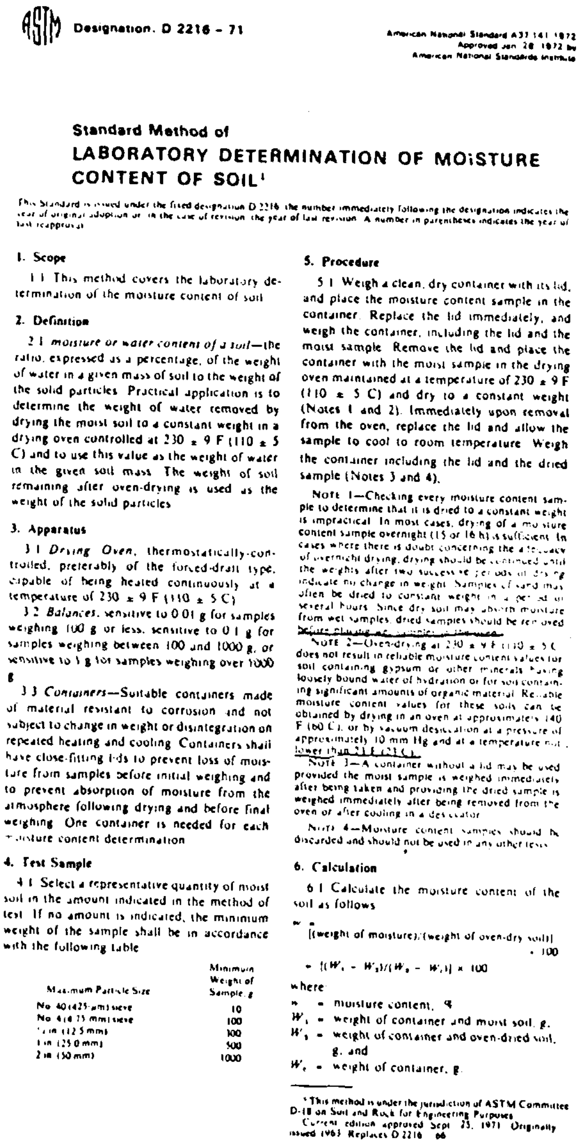
W_1 = weight of container and moist soil

W_2 = weight of container and dry soil

W_c = weight of container

3. $$\text{Dry Density} = \frac{\text{Wet Density}}{1 + \text{Moisture Content}}$$

ASTM D 2216-71 test procedure and typical test data sheet are presented in Figures D-12 and D-13.



ASTM Designation. D 2216 – 71

American National Standard A37.141-1972
Approved Jan. 28, 1972 by
American National Standards Institute

Standard Method of

LABORATORY DETERMINATION OF MOISTURE CONTENT OF SOIL[1]

This Standard is issued under the fixed designation D 2216; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This method covers the laboratory determination of the moisture content of soil.

2. Definition

2.1 *moisture or water content of a soil*—the ratio, expressed as a percentage, of the weight of water in a given mass of soil to the weight of the solid particles. Practical application is to determine the weight of water removed by drying the moist soil to a constant weight in a drying oven controlled at 230 ± 9 F (110 ± 5 C) and to use this value as the weight of water in the given soil mass. The weight of soil remaining after oven-drying is used as the weight of the solid particles.

3. Apparatus

3.1 *Drying Oven*, thermostatically-controlled, preferably of the forced-draft type, capable of being heated continuously at a temperature of 230 ± 9 F (110 ± 5 C).

3.2 *Balances*, sensitive to 0.01 g for samples weighing 100 g or less, sensitive to 0.1 g for samples weighing between 100 and 1000 g, or sensitive to 1 g for samples weighing over 1000 g.

3.3 *Containers*—Suitable containers made of material resistant to corrosion and not subject to change in weight or disintegration on repeated heating and cooling. Containers shall have close-fitting lids to prevent loss of moisture from samples before initial weighing and to prevent absorption of moisture from the atmosphere following drying and before final weighing. One container is needed for each moisture content determination.

4. Test Sample

4.1 Select a representative quantity of moist soil in the amount indicated in the method of test. If no amount is indicated, the minimum weight of the sample shall be in accordance with the following table:

Maximum Particle Size	Minimum Weight of Sample, g
No. 40 (425-μm) sieve	10
No. 4 (4.75-mm) sieve	100
½ in. (12.5 mm)	300
1 in. (25.0 mm)	500
2 in. (50 mm)	1000

5. Procedure

5.1 Weigh a clean, dry container with its lid, and place the moisture content sample in the container. Replace the lid immediately, and weigh the container, including the lid and the moist sample. Remove the lid and place the container with the moist sample in the drying oven maintained at a temperature of 230 ± 9 F (110 ± 5 C) and dry to a constant weight (Notes 1 and 2). Immediately upon removal from the oven, replace the lid and allow the sample to cool to room temperature. Weigh the container including the lid and the dried sample (Notes 3 and 4).

NOTE 1—Checking every moisture content sample to determine that it is dried to a constant weight is impractical. In most cases, drying of a moisture content sample overnight (15 or 16 h) is sufficient. In cases where there is doubt concerning the adequacy of overnight drying, drying should be continued until the weights after two successive periods of drying indicate no change in weight. Samples of sand may often be dried to constant weight in a period of several hours. Since dry soil may absorb moisture from wet samples, dried samples should be removed before placing wet samples in the oven.

NOTE 2—Oven-drying at 230 ± 9 F (110 ± 5 C) does not result in reliable moisture content values for soil containing gypsum or other minerals having loosely bound water of hydration or for soil containing significant amounts of organic material. Reliable moisture content values for these soils can be obtained by drying in an oven at approximately 140 F (60 C), or by vacuum desiccation at a pressure of approximately 10 mm Hg and at a temperature not lower than 73 F (23 C).

NOTE 3—A container without a lid may be used provided the moist sample is weighed immediately after being taken and providing the dried sample is weighed immediately after being removed from the oven or after cooling in a desiccator.

NOTE 4—Moisture content samples should be discarded and should not be used in any other tests.

6. Calculation

6.1 Calculate the moisture content of the soil as follows:

$$w = [(\text{weight of moisture})/(\text{weight of oven-dry soil})] \times 100$$

$$= [(W_1 - W_2)/(W_2 - W_c)] \times 100$$

where:

w = moisture content, %
W_1 = weight of container and moist soil, g,
W_2 = weight of container and oven-dried soil, g, and
W_c = weight of container, g.

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[1] This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock for Engineering Purposes.
Current edition approved Sept. 25, 1971. Originally issued 1963. Replaces D 2216 – 66.

STANDARD METHOD OF LABORATORY DETERMINATION
OF MOISTURE CONTENT OF SOIL

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
D-12

FUGRO NATIONAL, INC.

PROJECT NO.: 78-250-62
PROJECT:
BORING NUMBER: BS-B-2

TEST PROCEDURE NO. 200
MOISTURE-DENSITY SHEET
THERMAL TESTS

Sheet ____ of ____
Tested by: PH Date: [illegible]
Computed by: [illegible] Date: [illegible]
Checked by: RC Date: [illegible]

Sample Type	D	D	P.T	P.T	D		
Sample Number	D-6	D-7	P-14 (1/2)	P-15	D-24		
Sample Depth Ft	7.0-7.5	10.0-10.7	50.0-50.7	60-61.5	160		
Wet Density, PCF (A)	130.8	120.1	110.4	112.7	121.1		
Moisture Content, % (B)	10.7	5.7	13.6	16.7	13.2		
Dry Density PCF (C)	118.1	113.4	97.2	96.9	115.4		
Void Ratio (D)	.427	.486	.734	.748	.459		
Saturation, % (E)	62.6	32.8	50.0	61.0	70.1		
SOIL DESCRIPTION							
U S C S	SP-SM	SM	SM	SM	SP-SM		
Color		[illegible]					
Gr. size distr. GR SA FI							
Sand Size							
Grain Shape							
Plasticity							
Consistency Rel. Density							
Reaction to HCL							
CONTAINER NUMBER	62	28	115	156	15		
Wt. Wet Soil Tube Rings, gm. (1)	1060	991	2831	1450.0	637.8		
Length of Sample, in. (2)	5	5	10.7	5.4	[illegible]		
Wt. Wet Soil + Cont. gm. (3)	211.4	195.6	192.2	174.3	[illegible]		
Wt. Dry Soil + Cont. gm. (4)	197.0	188.0	175.7	157.1	[illegible]		
Wt. Container gm. (5)	61.2	57.2	54.4	52.3	[illegible]		
Wt. Tube or Rings inch, gm. (6)	212.5	212.5	218.6	410.1	[illegible]		
Avg. Tube or Ring I.D. (7)	2.5	2.5	2.875	2.875	[illegible]		
Avg. Cut Diam. in.							
Tube Clearance Ratio, %							
Tube Number							
Specific Gravity (8)	2.7	2.7	2.7	2.7	2.7		

REV 2-8-76 L-0114

TYPICAL TEST DATA SHEET MOISTURE-DENSITY TESTS

MX SITING INVESTIGATION
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FIGURE
D-13

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SUBAPPENDIX D2

PARTICLE-SIZE ANALYSIS

FUGRO TEST PROCEDURE NO. 190
PARTICLE-SIZE ANALYSIS

Scope

This procedure covers laboratory quantitative determination of the distribution of particle sizes in soils.

Procedure

Particle-size analysis of soils shall be performed according to the following ASTM Standards as modified by this test procedure:

A. ASTM Standard D 421-58 for "Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants," and

B. ASTM Standard D 422-673 for "Particle-Size Analysis of Soils."

Modifications:

A. Samples shall be prepared per the particle-size analysis sample requirements of ASTM Standard D 421-58. A porcelain pestle shall be used in lieu of a rubber-covered pestle in preparing samples.

B. Sieve analyses shall be performed using the following set of sieves:

Inch	Number	Size
3	4	4.750 mm
2	10	2.000 mm
1-1/2	20	0.850 mm
3/4	40	0.420 mm
3/8	60	0.250 mm
	100	0.150 mm
	and 200	0.075 mm

C. A balance sensitive to 0.25 g shall be used for weighing material passing the No. 10 sieve.

ASTM D 421-58 and D 422-673 test procedures and typical test data sheet are presented in Figures D-14 through D-16.

Designation: D 421 - 58 (Reapproved 1972)

American National Standard A37 144-1972
Approved March 2 1972
By American National Standards Institute

Standard Method for

DRY PREPARATION OF SOIL SAMPLES FOR PARTICLE-SIZE ANALYSIS AND DETERMINATION OF SOIL CONSTANTS[1]

This Standard is issued under the fixed designation D 421; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This method covers the dry preparation of soil samples as received from the field for particle-size analysis and the determination of the soil constants.

2. Apparatus

2.1 *Balance*—A balance sensitive to 0.1 g.

2.2 *Mortar*—A mortar and rubber-covered pestle suitable for breaking up the aggregations of soil particles.

2.3 *Sieves*—A series of sieves, of square mesh woven wire cloth, conforming to ASTM Specification E 11, for Wire-Cloth Sieves for Testing Purposes.[2] The sieves required are as follows:

No. 4 (4.75-mm)
No. 10 (2.00-mm)
No. 40 (425-μm)

2.4 *Sampler*—A riffle sampler or sample splitter, for quartering the samples.

3. Sampling

3.1 Expose the soil sample as received from the field to the air at room temperature until dried thoroughly. Break up the aggregations thoroughly in the mortar with a rubber-covered pestle. Select a representative sample of the amount required to perform the desired tests by the method of quartering or by the use of a sampler. The amounts of material required to perform the individual tests are as follows.

3.1.1 *Particle-Size Analysis*—For the particle-size analysis, material passing a No. 10 (2.00-mm) sieve is required in amounts equal to 115 g of sandy soils and 65 g of either silt or clay soils.

3.1.2 *Tests for Soil Constants*—For the tests for soil constants, material passing the No. 40 (425-μm) sieve is required in total amount of 220 g, allocated as follows:

Test	Grams
Liquid limit	100
Plastic limit	15
Centrifuge moisture equivalent	10
Volumetric shrinkage	30
Check tests	65

4. Preparation of Test Sample

4.1 Select that portion of the air-dried sample selected for purpose of tests and record the mass as the mass of the total test sample uncorrected for hygroscopic moisture. Separate the test sample by sieving with a No. 10 (2.00-mm) sieve. Grind that fraction retained on the No. 10 sieve in a mortar with a rubber-covered pestle until the aggregations of soil particles are broken up into the separate grains. Then separate the ground soil into two fractions by sieving with a No. 10 sieve.

4.2 Wash that fraction retained after the second sieving free of all fine material, dry, and weigh. Record this mass as the mass of coarse material. Sieve the coarse material after being washed and dried, on the No. 4 (4.75-mm) sieve and record the mass retained on the No. 4 sieve.

5. Test Sample for Particle-Size Analysis

5.1 Mix the fractions passing the No. 10 (2.00-mm) sieve in both sieving operations thoroughly together, and by the method of quartering or the use of a sampler, select a portion weighing approximately 115 g for sandy soils and approximately 65 g for silt and clay soil for particle-size analysis.

6. Test Sample for Soil Constants

6.1 Separate the remaining portion of the material passing the No. 10 (2.00-mm) sieve into two parts by means of a No. 40 (425-μm) sieve. Discard the fraction retained on the No. 40 sieve. Use the fraction passing the No. 40 sieve for the determination of the soil constants.

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[1] This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock for Engineering Purposes.
Current edition approved Sept. 22, 1958. Originally issued 1935. Replaces D 421 - 38.

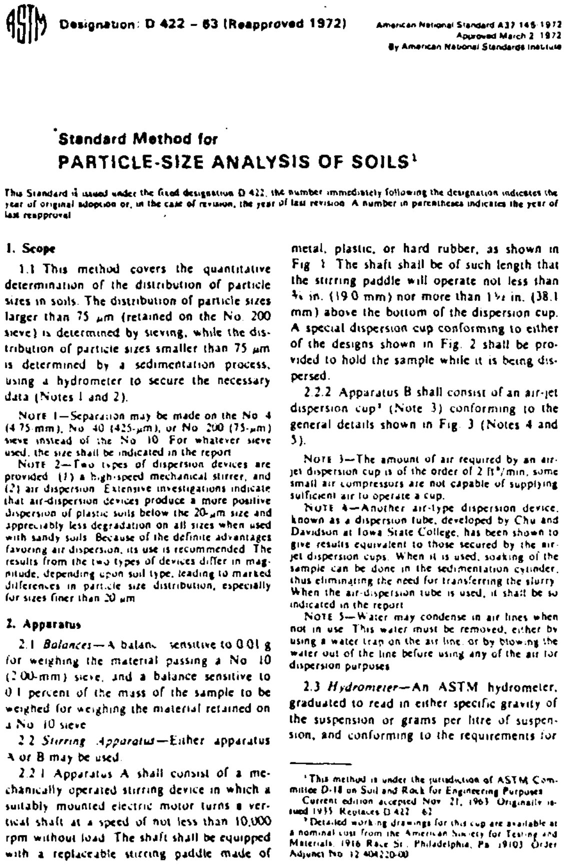
[2] *Annual Book of ASTM Standards*, Part 41.

STANDARD METHOD FOR DRY PREPARATION OF
SOIL SAMPLES FOR PARTICLE-SIZE ANALYSIS
AND DETERMINATION OF SOIL CONSTANTS

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
D-14

FUGRO NATIONAL, INC.



Designation: D 422 – 63 (Reapproved 1972)

American National Standard A37.145-1972
Approved March 2, 1972
By American National Standards Institute

Standard Method for
PARTICLE-SIZE ANALYSIS OF SOILS[1]

This Standard is issued under the fixed designation D 422; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This method covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes larger than 75 µm (retained on the No. 200 sieve) is determined by sieving, while the distribution of particle sizes smaller than 75 µm is determined by a sedimentation process, using a hydrometer to secure the necessary data (Notes 1 and 2).

NOTE 1—Separation may be made on the No. 4 (4.75-mm), No. 40 (425-µm), or No. 200 (75-µm) sieve instead of the No. 10. For whatever sieve used, the size shall be indicated in the report.

NOTE 2—Two types of dispersion devices are provided: (*1*) a high-speed mechanical stirrer, and (*2*) air dispersion. Extensive investigations indicate that air-dispersion devices produce a more positive dispersion of plastic soils below the 20-µm size and appreciably less degradation on all sizes when used with sandy soils. Because of the definite advantages favoring air dispersion, its use is recommended. The results from the two types of devices differ in magnitude, depending upon soil type, leading to marked differences in particle size distribution, especially for sizes finer than 20 µm.

2. Apparatus

2.1 *Balances*—A balance sensitive to 0.01 g for weighing the material passing a No. 10 (2.00-mm) sieve, and a balance sensitive to 0.1 percent of the mass of the sample to be weighed for weighing the material retained on a No. 10 sieve.

2.2 *Stirring Apparatus*—Either apparatus A or B may be used.

2.2.1 Apparatus A shall consist of a mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a speed of not less than 10,000 rpm without load. The shaft shall be equipped with a replaceable stirring paddle made of metal, plastic, or hard rubber, as shown in Fig. 1. The shaft shall be of such length that the stirring paddle will operate not less than ¾ in. (19.0 mm) nor more than 1½ in. (38.1 mm) above the bottom of the dispersion cup. A special dispersion cup conforming to either of the designs shown in Fig. 2 shall be provided to hold the sample while it is being dispersed.

2.2.2 Apparatus B shall consist of an air-jet dispersion cup[2] (Note 3) conforming to the general details shown in Fig. 3 (Notes 4 and 5).

NOTE 3—The amount of air required by an air-jet dispersion cup is of the order of 2 ft³/min; some small air compressors are not capable of supplying sufficient air to operate a cup.

NOTE 4—Another air-type dispersion device, known as a dispersion tube, developed by Chu and Davidson at Iowa State College, has been shown to give results equivalent to those secured by the air-jet dispersion cups. When it is used, soaking of the sample can be done in the sedimentation cylinder, thus eliminating the need for transferring the slurry. When the air-dispersion tube is used, it shall be so indicated in the report.

NOTE 5—Water may condense in air lines when not in use. This water must be removed, either by using a water trap on the air line, or by blowing the water out of the line before using any of the air for dispersion purposes.

2.3 *Hydrometer*—An ASTM hydrometer, graduated to read in either specific gravity of the suspension or grams per litre of suspension, and conforming to the requirements for

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[1] This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock for Engineering Purposes.
Current edition accepted Nov. 21, 1963. Originally issued 1935. Replaces D 422 – 62.

[2] Detailed working drawings for this cup are available at a nominal cost from the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103. Order Adjunct No. 12-404220-00.

STANDARD METHOD FOR
PARTICLE-SIZE ANALYSIS OF SOILS

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE
D-15
1 OF 11

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hydrometers 151H or 152H in ASTM Specification E 100, for ASTM Hydrometers.[3] Dimensions of both hydrometers are the same, the scale being the only item of difference.

2.4 *Sedimentation Cylinder*—A glass cylinder essentially 18 in. (457 mm) in height and $2\frac{1}{2}$ in. (63.5 mm) in diameter, and marked for a volume of 1000 ml. The inside diameter shall be such that the 1000-ml mark is 36 ± 2 cm from the bottom on the inside.

2.5 *Thermometer*—A thermometer accurate to 1 F (0.5 C).

2.6 *Sieves*—A series of sieves, of square-mesh woven-wire cloth, conforming to the requirements of ASTM Specification E 11, for Wire-Cloth Sieves for Testing Purposes.[3] A full set of sieves includes the following (Note 6):

3-in. (75-mm)
2-in. (50-mm)
$1\frac{1}{2}$-in. (37.5-mm)
1-in. (25.0-mm)
$\frac{3}{4}$-in. (19.0-mm)
$\frac{3}{8}$-in. (9.5-mm)
No. 4 (4.75-mm)
No. 10 (2.00-mm)
No. 20 (850-μm)
No. 40 (425-μm)
No. 60 (250-μm)
No. 140 (106-μm)
No. 200 (75-μm)

NOTE 6—A set of sieves giving uniform spacing of points for the graph, as required in Section 16, may be used if desired. This set consists of the following sieves:

3-in. (75-mm)
$1\frac{1}{2}$-in. (37.5-mm)
$\frac{3}{4}$-in. (19.0-mm)
$\frac{3}{8}$-in. (9.5-mm)
No. 4 (4.75-mm)
No. 8 (2.36-mm)
No. 16 (1.18-mm)
No. 30 (600-μm)
No. 50 (300-μm)
No. 100 (150-μm)
No. 200 (75-μm)

2.7 *Water Bath or Constant-Temperature Room*—A water bath or constant-temperature room for maintaining the soil suspension at a constant temperature during the hydrometer analysis. A satisfactory water tank is an insulated tank that maintains the temperature of the suspension at a convenient constant temperature at or near 68 F (20 C). Such a device is illustrated in Fig. 4. In cases where the work is performed in a room at an automatically controlled constant temperature, the water bath is not necessary.

2.8 *Beaker*—A beaker of 250-ml capacity.

2.9 *Timing Device*—A watch or clock with a second hand.

3. Dispersing Agent

3.1 A solution of sodium hexametaphosphate (sometimes called sodium metaphosphate) shall be used in distilled or demineralized water, at the rate of 40 g of sodium hexametaphosphate/litre of solution (Note 7).

NOTE 7—Solutions of this salt, if acidic, slowly revert or hydrolyze back to the orthophosphate form with a resultant decrease in dispersive action. Solutions should be prepared frequently (at least once a month) or adjusted to pH of 8 or 9 by means of sodium carbonate. Bottles containing solutions should have the date of preparation marked on them.

3.2 All water used shall be either distilled or demineralized water. The water for a hydrometer test shall be brought to the temperature that is expected to prevail during the hydrometer test. For example, if the sedimentation cylinder is to be placed in the water bath, the distilled or demineralized water to be used shall be brought to the temperature of the controlled water bath; or, if the sedimentation cylinder is used in a room with controlled temperature, the water for the test shall be at the temperature of the room. The basic temperature for the hydrometer test is 68 F (20 C). Small variations of temperature do not introduce differences that are of practical significance and do not prevent the use of corrections derived as prescribed.

4. Test Sample

4.1 Prepare the test sample for mechanical analysis as outlined in ASTM Method D 421, Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants.[4] During the preparation procedure the sample is divided into two portions. One portion contains only particles retained on the No. 10 (2.00-mm) sieve while the other portion contains only particles passing the No. 10 sieve. The mass of air-dried soil selected for purpose of tests, as prescribed in Method D 421, shall be sufficient to yield quantities for mechanical analysis as follows:

4.1.1 The size of the portion retained on the No. 10 sieve shall depend on the maximum size of particle, according to the following schedule:

Nominal Diameter of Largest Particles, in (mm)	Approximate Minimum Mass of Portion, g
$\frac{3}{8}$ (9.5)	500
$\frac{3}{4}$ (19.0)	1000

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[3] *Annual Book of ASTM Standards*, Part 41
[4] *Annual Book of ASTM Standards*, Part 19

Nominal Diameter of Largest Particles, in. (mm)	Approximate Minimum Mass of Portion, g
1 (25.4)	2000
1½ (38.1)	3000
2 (50.8)	4000
3 (76.2)	5000

4.1.2 The size of the portion passing the No. 10 sieve shall be approximately 115 g for sandy soils and approximately 65 g for silt and clay soils.

4.2 Provision is made in Section 4 of Method D 421 for the weighing of the air-dry soil selected for purpose of tests, the separation of the soil on the No. 10 sieve by dry-sieving and washing, and the weighing of the washed and dried fraction retained on the No. 10 sieve. From these two masses the percentages retained and passing the No. 10 sieve can be calculated in accordance with 11.1.

NOTE 8—A check on the mass values and the thoroughness of pulverization of the clods may be secured by weighing the portion passing the No. 10 sieve and adding this value to the mass of the washed and oven-dried portion retained on the No. 10 sieve.

SIEVE ANALYSIS OF PORTION RETAINED ON NO. 10 (2.00-mm) SIEVE

5. Procedure

5.1 Separate the portion retained on the No. 10 (2.00-mm) sieve into a series of fractions using the 3-in. (75-mm), 2-in. (50-mm), 1½-in. (37.5-mm), 1-in. (25.0-mm), ¾-in. (19.0-mm), ⅜-in. (9.5-mm), No. 4 (4.75-mm), and No. 10 sieves, or as many as may be needed depending on the sample, or upon the specifications for the material under test.

5.2 Conduct the sieving operation by means of a lateral and vertical motion of the sieve, accompanied by a jarring action in order to keep the sample moving continuously over the surface of the sieve. In no case turn or manipulate fragments in the sample through the sieve by hand. Continue sieving until not more than 1 mass percent of the residue on a sieve passes that sieve during 1 min of sieving. When mechanical sieving is used, test the thoroughness of sieving by using the hand method of sieving as described above.

5.3 Determine the mass of each fraction on a balance conforming to the requirements of 2.1. At the end of weighing, the sum of the masses retained on all the sieves used should equal closely the original mass of the quantity sieved.

HYDROMETER AND SIEVE ANALYSIS OF PORTION PASSING THE NO. 10 (2.00-mm) SIEVE

6. Determination of Composite Correction for Hydrometer Reading

6.1 Equations for percentages of soil remaining in suspension, as given in 13.3, are based on the use of distilled or demineralized water. A dispersing agent is used in the water, however, and the specific gravity of the resulting liquid is appreciably greater than that of distilled or demineralized water.

6.1.1 Both soil hydrometers are calibrated at 68 F (20 C), and variations in temperature from this standard temperature produce inaccuracies in the actual hydrometer readings. The amount of the inaccuracy increases as the variation from the standard temperature increases.

6.1.2 Hydrometers are graduated by the manufacturer to be read at the bottom of the meniscus formed by the liquid on the stem. Since it is not possible to secure readings of soil suspensions at the bottom of the meniscus, readings must be taken at the top and a correction applied.

6.1.3 The net amount of the corrections for the three items enumerated is designated as the composite correction, and may be determined experimentally.

6.2 For convenience, a graph or table of composite corrections for a series of 1-deg temperature differences for the range of expected test temperatures may be prepared and used as needed. Measurement of the composite corrections may be made at two temperatures spanning the range of expected test temperatures, and corrections for the intermediate temperatures calculated assuming a straight-line relationship between the two observed values.

6.3 Prepare 1000 ml of liquid composed of distilled or demineralized water and dispersing agent in the same proportion as will prevail in the sedimentation (hydrometer) test. Place the liquid in a sedimentation cylinder and the cylinder in the constant-temperature water bath, set for one of the two temperatures to be used. When the temperature of the liquid becomes constant, insert the hydrometer, and, after a short interval to permit the hydrometer to come to the temperature of the liquid, read the hydrometer at the top of the meniscus formed on the stem. For hydrometer 151H the composite correction is the difference between this reading and one; for hydrometer 152H it is the difference between the reading and zero. Bring the liquid and the hydrometer to the other temperature to be used, and secure the composite correction as before.

7. Hygroscopic Moisture

7.1 When the sample is weighed for the hydrometer test, weigh out an auxiliary portion of from 10 to 15 g in a small metal or glass container, dry the sample to a constant mass in an oven at 230 ± 9 F (110 ± 5 C), and weigh again. Record the masses.

8. Dispersion of Soil Sample

8.1 When the soil is mostly of the clay and silt sizes, weigh out a sample of air-dry soil of approximately 50 g. When the soil is mostly sand the sample should be approximately 100 g.

8.2 Place the sample in the 250-ml beaker and cover with 125 ml of sodium hexametaphosphate solution (40 g/litre). Stir until the soil is thoroughly wetted. Allow to soak for at least 16 h.

8.3 At the end of the soaking period, disperse the sample further, using either stirring apparatus A or B. If stirring apparatus A is used, transfer the soil - water slurry from the beaker into the special dispersion cup shown in Fig. 2, washing any residue from the beaker into the cup with distilled or demineralized water (Note 9). Add distilled or demineralized water, if necessary, so that the cup is more than half full. Stir for a period of 1 min.

Note 9—A large size syringe is a convenient device for handling the water in the washing operation. Other devices include the wash-water bottle and a hose with nozzle connected to a pressurized distilled water tank.

8.4 If stirring apparatus B (Fig. 3) is used, remove the cover cap and connect the cup to a compressed air supply by means of a rubber hose. An air gage must be on the line between the cup and the control valve. Open the control valve so that the gage indicates 1 psi (7 kPa) pressure (Note 10). Transfer the soil-water slurry from the beaker to the air-jet dispersion cup by washing with distilled or demineralized water. Add distilled or demineralized water, if necessary, so that the total volume in the cup is 250 ml, but no more.

Note 10—The initial air pressure of 1 psi is required to prevent the soil - water mixture from entering the air-jet chamber when the mixture is transferred to the dispersion cup.

8.5 Place the cover cap on the cup and open the air control valve until the gage pressure is 20 psi (140 kPa). Disperse the soil according to the following schedule:

Plasticity Index	Dispersion Period, min
Under 5	5
6 to 20	10
Over 20	15

Soils containing large percentages of mica need be dispersed for only 1 min. After the dispersion period, reduce the gage pressure to 1 psi preparatory to transfer of soil - water slurry to the sedimentation cylinder.

9. Hydrometer Test

9.1 Immediately after dispersion, transfer the soil - water slurry to the glass sedimentation cylinder, and add distilled or demineralized water until the total volume is 1000 ml.

9.2 Using the palm of the hand over the open end of the cylinder (or a rubber stopper in the open end), turn the cylinder upside down and back for a period of 1 min to complete the agitation of the slurry (Note 11). At the end of 1 min set the cylinder in a convenient location and take hydrometer readings at the following intervals of time (measured from the beginning of sedimentation), or as many as may be needed, depending on the sample or the specification for the material under test: 2, 5, 15, 30, 60, 250, and 1440 min. If the controlled water bath is used, the sedimentation cylinder should be placed in the bath between the 2- and 5-min readings.

Note 11—The number of turns during this minute should be approximately 60, counting the turn upside down and back as two turns. Any soil remaining in the bottom of the cylinder during the first few turns should be loosened by vigorous shaking of the cylinder while it is in the inverted position.

9.3 When it is desired to take a hydrometer reading, carefully insert the hydrometer about

20 to 25 s before the reading is due to approximately the depth it will have when the reading is taken. As soon as the reading is taken, carefully remove the hydrometer and place it with a spinning motion in a graduate of clean distilled or demineralized water.

NOTE 12—It is important to remove the hydrometer immediately after each reading. Readings shall be taken at the top of the meniscus formed by the suspension around the stem, since it is not possible to secure readings at the bottom of the meniscus.

9.4 After each reading, take the temperature of the suspension by inserting the thermometer into the suspension.

10. Sieve Analysis

10.1 After taking the final hydrometer reading, transfer the suspension to a No. 200 (75-μm) sieve and wash with tap water until the wash water is clear. Transfer the material on the No. 200 sieve to a suitable container, dry in an oven at 230 ± 9 F (110 ± 5 C) and make a sieve analysis of the portion retained, using as many sieves as desired, or required for the material, or upon the specification of the material under test.

CALCULATIONS AND REPORT

11. Sieve Analysis Values for the Portion Coarser than the No. 10 (2.00-mm) Sieve

11.1 Calculate the percentage passing the No. 10 sieve by dividing the mass passing the No. 10 sieve by the mass of soil originally split on the No. 10 sieve, and multiplying the result by 100. To obtain the mass passing the No. 10 sieve, subtract the mass retained on the No. 10 sieve from the original mass.

11.2 To secure the total mass of soil passing the No. 4 (4.75-mm) sieve, add to the mass of the material passing the No. 10 sieve the mass of the fraction passing the No. 4 sieve and retained on the No. 10 sieve. To secure the total mass of soil passing the 3/8-in. (9.5-mm) sieve, add to the total mass of soil passing the No. 4 sieve, the mass of the fraction passing the 3/8-in. sieve and retained on the No. 4 sieve. For the remaining sieves, continue the calculations in the same manner.

11.3 To determine the total percentage passing for each sieve, divide the total mass passing (see 11.2) by the total mass of sample and multiply the result by 100.

12. Hygroscopic Moisture Correction Factor

12.1 The hygroscopic moisture correction factor is the ratio between the mass of the oven-dried sample and the air-dry mass before drying. It is a number less than one, except when there is no hygroscopic moisture.

13. Percentages of Soil in Suspension

13.1 Calculate the oven-dry mass of soil used in the hydrometer analysis by multiplying the air-dry mass by the hygroscopic moisture correction factor.

13.2 Calculate the mass of a total sample represented by the mass of soil used in the hydrometer test, by dividing the oven-dry mass used by the percentage passing the No. 10 (2.00-mm) sieve, and multiplying the result by 100. This value is the weight W in the equation for percentage remaining in suspension.

13.3 The percentage of soil remaining in suspension at the level at which the hydrometer is measuring the density of the suspension may be calculated as follows (Note 13):

For hydrometer 151H:

$$P = [(100{,}000/W) \times G/(G - G_1)]\,(R - G_1)$$

NOTE 13—The bracketed portion of the equation for hydrometer 151H is constant for a series of readings and may be calculated first and then multiplied by the portion in the parenthesis.

For hydrometer 152H:

$$P = (Ra/W) \times 100$$

where:

a = correction faction to be applied to the reading of hydrometer 152H. (Values shown on the scale are computed using a specific gravity of 2.65. Correction factors are given in Table 1),

P = percentage of soil remaining in suspension at the level at which the hydrometer measures the density of the suspension,

R = hydrometer reading with composite correction applied (Section 6),

W = oven-dry mass of soil in a total test sample represented by mass of soil dispersed (see 13.2), g,

G = specific gravity of the soil particles, and

G_1 = specific gravity of the liquid in which soil particles are suspended. Use nu-

STANDARD METHOD FOR
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FIGURE
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merical value of one in both instances in the equation. In the first instance any possible variation produces no significant effect, and in the second instance, the composite correction for R is based on a value of one for G_1.

Diameter of Soil Particles

14.1 The diameter of a particle corresponding to the percentage indicated by a given hydrometer reading shall be calculated according to Stokes' law (Note 14), on the basis that a particle of this diameter was at the surface of the suspension at the beginning of sedimentation and had settled to the level at which the hydrometer is measuring the density of the suspension. According to Stokes' law:

$$D = \sqrt{[30n/980(G - G_1)] \times L/T} \quad .$$

where:

D = diameter of particle, mm,

n = coefficient of viscosity of the suspending medium (in this case water) in poises (varies with changes in temperature of the suspending medium),

L = distance from the surface of the suspension to the level at which the density *of the suspension is being measured*, cm. (For a given hydrometer and sedimentation cylinder, values vary according to the hydrometer readings. This distance is known as effective depth (Table 2),

T = interval of time from beginning of sedimentation to the taking of the reading, min,

G = specific gravity of soil particles, and

G_1 = specific gravity (relative density) of suspending medium (value may be used as 1.000 for all practical purposes).

NOTE 14—Since Stokes' law considers the terminal velocity of a single sphere falling in an infinity of liquid, the sizes calculated represent the diameter of spheres that would fall at the same rate as the soil particles.

14.2 For convenience in calculations the above equation may be written as follows:

$$D = K\sqrt{L/T}$$

where:

K = constant depending on the temperature of the suspension and the specific gravity of the soil particles. Values of K for a range of temperatures and specific gravities are given in Table 3. The value of K does not change for a series of readings constituting a test, while values of L and T do vary.

14.3 Values of D may be computed with sufficient accuracy, using an ordinary 10-in. slide rule.

NOTE 15—The value of L is divided by T using the A- and B-scales, the square root being indicated on the D-scale. Without ascertaining the value of the square root it may be multiplied by K, using either the C- or CI-scale.

15. Sieve Analysis Values for Portion Finer than No. 10 (2.00-mm) Sieve

15.1 Calculation of percentages passing the various sieves used in sieving the portion of the sample from the hydrometer test involves several steps. The first step is to calculate the mass of the fraction that would have been retained on the No. 10 sieve had it not been removed. This mass is equal to the total percentage retained on the No. 10 sieve (100 minus total percentage passing) times the mass of the total sample represented by the mass of soil used (as calculated in 13.2), and the result divided by 100.

15.2 Calculate next the total mass passing the No. 200 sieve. Add together the fractional masses retained on all the sieves, including the No. 10 sieve, and subtract this sum from the mass of the total sample (as calculated in 13.2).

15.3 Calculate next the total masses passing each of the other sieves, in a manner similar to that given in 11.2.

15.4 Calculate last the total percentages passing by dividing the total mass passing (as calculated in 15.3) by the total mass of sample (as calculated in 13.2), and multiply the result by 100.

16. Graph

16.1 When the hydrometer analysis is performed, a graph of the test results shall be made, plotting the diameters of the particles on a logarithmic scale as the abscissa and the percentages smaller than the corresponding diameters to an arithmetic scale as the ordinate. When the hydrometer analysis is not made on a portion of the soil, the preparation of the graph is optional, since values may be secured directly from tabulated data.

17. Report

17.1 The report shall include the following:

17.1.1 Maximum size of particles,

17.1.2 Percentage passing (or retained on) each sieve, which may be tabulated or presented by plotting on a graph (Note 16),

17.1.3 Description of sand and gravel particles:

17.1.3.1 Shape—rounded or angular,

17.1.3.2 Hardness—hard and durable, soft, or weathered and friable,

17.1.4 Specific gravity, if unusually high or low,

17.1.5 Any difficulty in dispersing the fraction passing the No. 10 (2.00-mm) sieve, indicating any change in type and amount of dispersing agent, and

17.1.6 The dispersion device used and the *length of the dispersion period.*

NOTE 16—This tabulation of graph represents the gradation of the sample tested. If particles larger than those contained in the sample were removed before testing, the report shall so state giving the amount and maximum size.

17.2 For materials tested for compliance with definite specifications, the fractions called for in such specifications shall be reported. The fractions smaller than the No. 10 sieve shall be read from the graph.

17.3 For materials for which compliance with definite specifications is not indicated and when the soil is composed almost entirely of particles passing the No. 4 (4.75-mm) sieve, the results read from the graph may be reported as follows:

(*1*) Gravel, passing 3-in. and retained on No. 4 sieve	......percent
(*2*) Sand, passing No. 4 sieve and retained on No. 200 sieve	......percent
(*a*) Coarse sand, passing No. 4 sieve and retained on No. 10 sieve	......percent
(*b*) Medium sand, passing No. 10 sieve and retained on No. 40 sieve	......percent
(*c*) Fine sand, passing No. 40 sieve and retained on No. 200 sieve	......percent
(*3*) Silt size, 0.074 to 0.005 mm	......percent
(*4*) Clay size, smaller than 0.005 mm	......percent
Colloids, smaller than 0.001 mm	......percent

17.4 For materials for which compliance with definite specifications is not indicated and when the soil contains material retained on the No. 4 sieve sufficient to require a sieve analysis on that portion, the results may be reported as follows (Note 17):

SIEVE ANALYSIS

Sieve Size	Percentage Passing
3-in.	....
2-in.	....
1½-in.	....
1-in.	....
¾-in.	....
⅜-in.	....
No. 4 (4.75-mm)	....
No. 10 (2.00-mm)	....
No. 40 (425-µm)	....
No. 200 (75-µm)	....

HYDROMETER ANALYSIS

0.074 mm	....
0.005 mm	....
0.001 mm	....

NOTE 17—No. 8 (2.36-mm) and No. 50 (300-µm) sieves may be substituted for No. 10 and No. 40 sieves.

TABLE 1 Values of Correction Factor, *a*, for Different Specific Gravities of Soil Particles[a]

Specific Gravity	Correction Factor[a]
2.95	0.94
2.90	0.95
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.03
2.45	1.05

[a] For use in equation for percentage of soil remaining in suspension when using Hydrometer 152H.

TABLE 2 Values of Effective Depth Based on Hydrometer and Sedimentation Cylinder of Specified Sizes[a]

Hydrometer 151H		Hydrometer 152H			
Actual Hydrometer Reading	Effective Depth, *L*, cm	Actual Hydrometer Reading	Effective Depth, *L*, cm	Actual Hydrometer Reading	Effective Depth, *L*, cm
1.000	16.3	0	16.3	31	11.2
1.001	16.0	1	16.1	32	11.1
1.002	15.8	2	16.0	33	10.9
1.003	15.5	3	15.8	34	10.7
1.004	15.2	4	15.6	35	10.6
1.005	15.0	5	15.5		
1.006	14.7	6	15.3	36	10.4
1.007	14.4	7	15.2	37	10.2
1.008	14.2	8	15.0	38	10.1
1.009	13.9	9	14.8	39	9.9
1.010	13.7	10	14.7	40	9.7
1.011	13.4	11	14.5	41	9.6
1.012	13.1	12	14.3	42	9.4
1.013	12.9	13	14.2	43	9.2
1.014	12.6	14	14.0	44	9.1
1.015	12.3	15	13.8	45	8.9
1.016	12.1	16	13.7	46	8.8
1.017	11.8	17	13.5	47	8.6
1.018	11.5	18	13.3	48	8.4
1.019	11.3	19	13.2	49	8.3
1.020	11.0	20	13.0	50	8.1
1.021	10.7	21	12.9	51	7.9
1.022	10.5	22	12.7	52	7.8
1.023	10.2	23	12.5	53	7.6
1.024	10.0	24	12.4	54	7.4
1.025	9.7	25	12.2	55	7.3
1.026	9.4	26	12.0	56	7.1
1.027	9.2	27	11.9	57	7.0
1.028	8.9	28	11.7	58	6.8
1.029	8.6	29	11.5	59	6.6
1.030	8.4	30	11.4	60	6.5
1.031	8.1				
1.032	7.8				
1.033	7.6				
1.034	7.3				
1.035	7.0				
1.036	6.8				
1.037	6.5				
1.038	6.2				

[a] Values of effective depth are calculated from the equation:

$$L = L_1 + \frac{1}{2}[L_2 - (V_B/A)]$$

where:

L = effective depth, cm,

L_1 = distance along the stem of the hydrometer from the top of the bulb to the mark for a hydrometer reading, cm,

L_2 = overall length of the hydrometer bulb, cm,

V_B = volume of hydrometer bulb, cm³, and

A = cross-sectional area of sedimentation cylinder, cm²

Values used in calculating the values in Table 2 are as follows:

For both hydrometers, 151H and 152H

L_2 = 14.0 cm

V_B = 67.0 cm³

A = 27.8 cm²

For hydrometer 151H:

L_1 = 10.5 cm for a reading of 1.000

= 2.3 cm for a reading of 1.031

For hydrometer 152H:

L_1 = 10.5 cm for a reading of 0 g/litre

= 2.3 cm for a reading of 50 g/litre

STANDARD METHOD FOR
PARTICLE-SIZE ANALYSIS OF SOILS

MX SITING INVESTIGATION
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FIGURE
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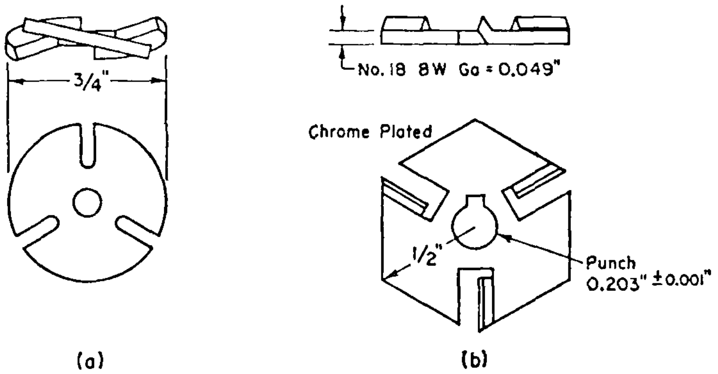
TABLE 3 Values of *K* for Use in Equation for Computing Diameter of Particle in Hydrometer Analysis

Temperature, deg C	Specific Gravity of Soil Particles								
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.01510	0.01505	0.01481	0.01457	0.01435	0.01414	0.01394	0.01374	0.01356
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356	0.01338
18	0.01492	0.01467	0.01443	0.01421	0.01399	0.01378	0.01359	0.01339	0.01321
19	0.01474	0.01449	0.01425	0.01403	0.01382	0.01361	0.01342	0.01323	0.01305
20	0.01456	0.01431	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307	0.01289
21	0.01438	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291	0.01273
22	0.01421	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276	0.01258
23	0.01404	0.01381	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261	0.01243
24	0.01388	0.01365	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246	0.01229
25	0.01372	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232	0.01215
26	0.01357	0.01334	0.01312	0.01291	0.01272	0.01253	0.01235	0.01218	0.01201
27	0.01342	0.01319	0.01297	0.01277	0.01258	0.01239	0.01221	0.01204	0.01188
28	0.01327	0.01304	0.01283	0.01264	0.01244	0.01225	0.01208	0.01191	0.01175
29	0.01312	0.01290	0.01269	0.01249	0.01230	0.01212	0.01195	0.01178	0.01162
30	0.01298	0.01276	0.01256	0.01236	0.01217	0.01199	0.01182	0.01165	0.01149



Metric Equivalents

in	0.001	0.049	0.203	½	¾
mm	0.03	1.24	5.16	12.7	19.0

FIG. 1 Detail of Stirring Paddles.

STANDARD METHOD FOR
PARTICLE-SIZE ANALYSIS OF SOILS

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FIGURE
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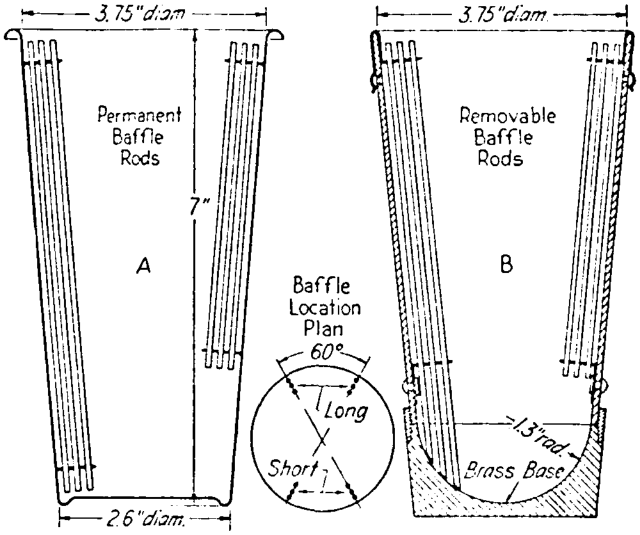

Metric Equivalents

in.	1.3	2.6	3.75
mm	33	66	95.2

FIG. 2 Dispersion Cups of Apparatus A.

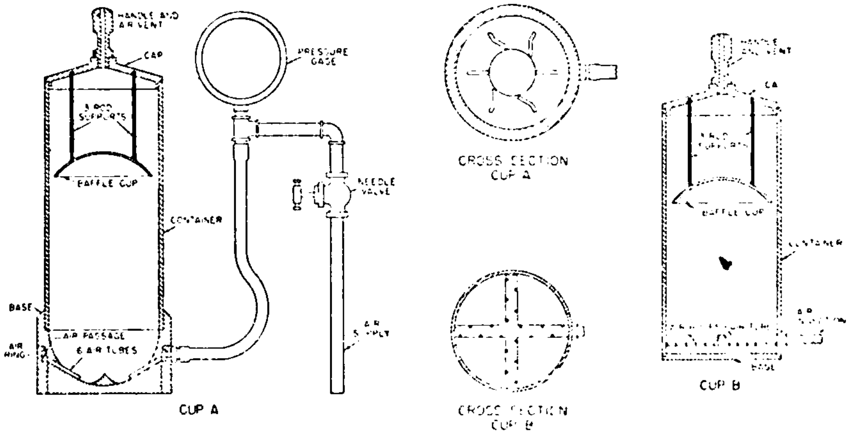

FIG. 3 Air-Jet Dispersion Cups of Apparatus B.

STANDARD METHOD FOR
PARTICLE-SIZE ANALYSIS OF SOILS

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FIGURE
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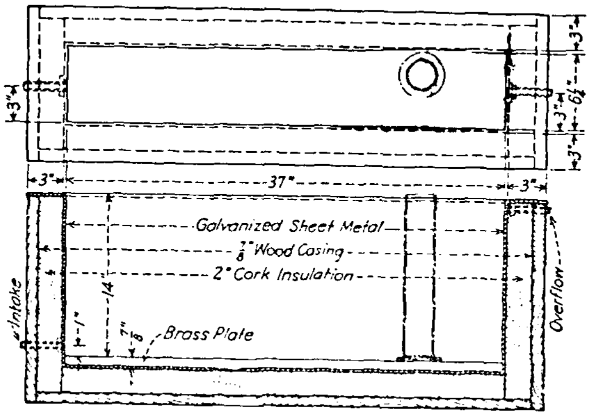

Metric Equivalents

in.	⅞	1	3	6¼	14	37
mm	22.2	25.4	76.2	158.2	356	940

FIG. 4 Insulated Water Bath.

STANDARD METHOD FOR
PARTICLE-SIZE ANALYSIS OF SOILS

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FIGURE
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PARTICLE-SIZE ANALYSIS OF SOILS

SHEET ___ OF ___

FUGRO TEST PROCEDURE 130
ASTM D 422-63 (REVISED 1972)

PROJECT [illegible]
PROJECT NO. [illegible]
CLIENT [illegible]
CLIENT PROJECT NO ____
BORING NO. SAMPLE LOCATION [illegible]
TESTED BY [illegible]
DATE [illegible]
SAMPLE NO. [illegible]
COMPUTED BY Cal Engineering
DATE [illegible]
SAMPLE DEPTH ELEV. 7.0 - 8.0
CHECKED BY
DATE 8-13-79

BEFORE SIEVE ANALYSIS

WT. OF DRY SOIL + CONTAINER gm 202.5
WT. OF CONTAINER NO 295 gm 58.2
WT. OF DRY SOIL gm 144.3

AFTER WET SIEVE

WT. OF DRY SOIL + CONTAINER gm 160.1
WT. OF CONTAINER NO. 295 gm 58.2
WT. OF DRY SOIL RETAINED ON #200 SIEVE gm 101.9

SIEVE SET NO ____

U.S. SIEVE SIZE	TOTAL RETAINED ON EACH SIEVE			WT. OF DRY SOIL PASSING	PERCENT FINER THAN
	CUMULATIVE WT. DRY SOIL + CONTAINER	WT. OF CONTAINER	CUMULATIVE WT DRY SOIL RETAINED		
6"					
3"					
1½"					
3/4"					
3/8"					
4			0	144.3	100.0
10			0.7	143.6	99.5
20			8.3	136.0	94.2
40			21.6	122.7	85.0
60			39.8	104.5	72.4
100			65.1	79.2	54.8
200			101.6	42.7	29.4
PAN					

REMARKS SM - [illegible]

FUGRO

REV 1 6-76 L-004

TYPICAL TEST DATA SHEET
PARTICLE-SIZE ANALYSIS OF SOIL

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FIGURE
D-16

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APPENDIX E

VOLUMETRIC HEAT CAPACITY

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APPENDIX E - VOLUMETRIC HEAT CAPACITY

LIST OF FIGURES

PLATES

E1.0 METHODOLOGY

The volumetric heat capacity of a soil-water system can be calculated if the specific heat and amounts of each soil and water constituent are known. Since the specific heat of water is known, the procedure to determine the specific heat of soil is presented in this appendix.

The methodology utilized to determine the specific heat of soil constituents is similar to that presented by Taylor and Jackson (1965). Calculations required to compute volumetric heat capacity of the soil using specific heats of soil and water constituents are also included in this appendix.

E2.0 TEST APPARATUS

The test apparatus used in determination of specific heat of soils consisted of the following:

1. Calorimeter - A 1-pint thermos jar with an insulated cap placed in an insulated box;
2. Accessory Vessel - A 1-pint thermos jar with an insulated cap placed in an insulated box;
3. Thermometers sensitive to 0.02°C;
4. Glass Stirrer;
5. Balance - a balance sensitive to 0.01g; and
6. Stop Watch.

E3.0 CALIBRATION

The heat capacity of the calorimeter over the test temperature range was determined before performing a set of specific heat tests on soil samples. The procedure was as follows.

1. A known amount of water was added initially to the calorimeter and its temperature was measured.
2. An additional known amount of water at a higher known temperature from the accessory vessel was added to the calorimeter.
3. An interval of 5 to 10 minutes of time was allowed for thermal equilibrium to be established inside the calorimeter.
4. The final temperature of the water in the calorimeter was then measured.
5. The heat capacity of the calorimeter was calculated using the following formula:

$$C_c = M_{wa}\, c_\omega \frac{\Delta T_a}{\Delta T_c} - M_{wc}\, c_\omega \text{ (Taylor and Jackson, 1965) .... [1]}$$

where

C_c = heat capacity of calorimeter, cal/^oC;
M_{wc} = mass of water initially in calorimeter, g;
M_{wa} = mass of water added to calorimeter, g;
ΔT_a = temperature drop for water added, ^oC;
ΔT_c = temperature rise of water initially in the calorimeter, ^oC; and
c_ω = specific heat of water at mean temperature of determination cal/g-^oC

E4.0 TEST PROCEDURE

Following is the test procedure used in determining the specific heat of soil particles:

1. A known weight of dry soil (representative sample) was added to calorimeter.
2. A known weight of water was added to the calorimeter to form a dilute suspension.

3. The suspension was stirred until thermal equilibrium was established. The initial temperature of the suspension was measured to the nearest 0.02°C.
4. From the accessory vessel, a known weight of water (which is at a higher temperature than the soil-water suspension in the calorimeter) was added to the calorimeter so that the final temperature of the soil-water suspension was between 1° to 5°C higher than the initial temperature of the suspension in the calorimeter.
5. The final temperature of the soil-water suspension was measured to the nearest 0.02°C after thermal equilibrium was achieved.

Photographs of the test procedure and test setup are presented in Plate E-1.

E5.0 CALCULATIONS

The heat capacity of the calorimeter was computed as explained in Section E3.0. A typical test data sheet is shown in Figure E-1. The average specific heat of the soil sample was determined using the following formula:

$$c_s = c_\omega (M_{wa}/M_s)(\Delta T_a/\Delta T_c) - (M_{wc}\, c_\omega + C_c)/M_s$$ (Taylor and Jackson, 1965) .... [2]

where

c_s = average specific heat of the soil sample, cal/g-°C;
M_s = mass of soil, g; and
other symbols are as explained in Section E3.0.

A typical test data sheet showing the results of a specific heat test is presented in Figure E-2.

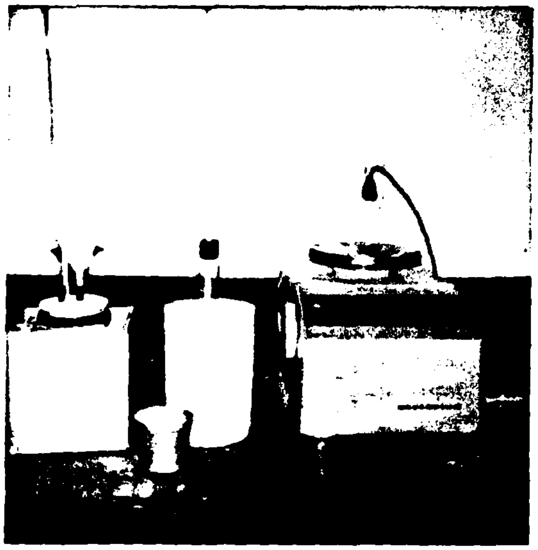

PHOTO 1 - TEST APPARATUS

PHOTO 2 - ADDING A KNOWN AMOUNT OF SOIL TO THE CALORIMETER

PHOTO 3 - ADDING WATER TO FORM A DILUTE SOIL-WATER SUSPENSION

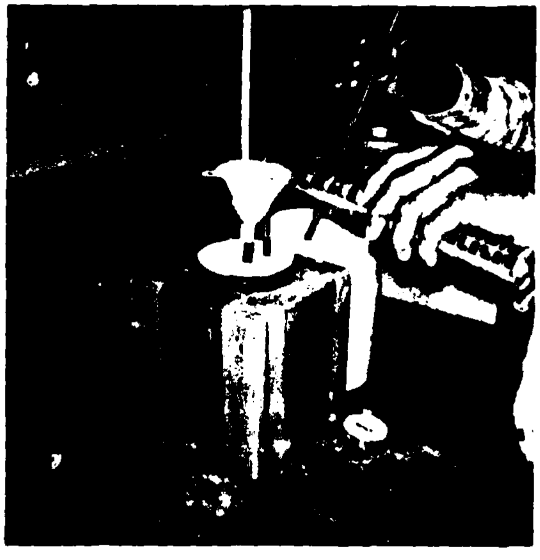

PHOTO 4 - ADDING WATER AT A HIGHER TEMPERATURE TO THE SOIL-WATER SUSPENSION IN THE CALORIMETER

SPECIFIC HEAT TEST SETUP

DETERMINATION OF HEAT CAPACITY OF SPECIFIC HEAT APPARATUS

PROJECT NAME Trial #1 TESTED BY D.K. DATE 9-16-79

PROJECT NUMBER 78-280-RL CHECKED BY ______ DATE ______

FLASK NUMBER #1

$$C_c = M_{wa} c_w \cdot \Delta T_a / \Delta T_c - M_{wc} c_w$$

45.01 C_c - HEAT CAPACITY OF APPARATUS (Cal/°C)

142.90 M_{wc} - MASS OF WATER INITIALLY (gm)

.99883 c_w - SPECIFIC HEAT OF WATER AT THE MEAN TEMPERATURE OF THE DETERMINATION (Cal/gm °C)

5406 M_{wa} - MASS OF WATER ADDED TO CALORIMETER (gm)

24.54 T_{11} (°C) - TEMPERATURE OF WATER IN FLASK INITIALLY

30.26 T_{1a} (°C) - TEMPERATURE OF WATER ADDED

25.82 T_s (°C) - TEMPERATURE OF RESULTING SOLUTION

4.44 $\Delta T_a = T_{1a} - T_s$ (°C)

1.28 $\Delta T_c = T_s - T_{11}$ (°C)

C_c = -(14290 x .99883) + (5406 x .99883) (4.44 / 1.28)

- 142.73 + 187.74

C_c = 45.01 (Cal/°C)

T = 610.40 gm

T + Mwa = 753.30 "

= 807.36

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TYPICAL COMPUTATIONS
HEAT CAPACITY OF APPARATUS

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FIGURE E-1

FUGRO NATIONAL, INC.

SPECIFIC HEAT DETERMINATION OF SOIL

PROJECT NAME A.F. THERMAL TESTED BY P.L DATE 9-16-79
PROJECT NUMBER 78-280-82 COMPUTED BY P.L DATE 9-16-79
BORING NUMBER RR-B-6, D-14 CHECKED BY ____ DATE ____
DEPTH (FEET) 65.7′-66.4′ FLASK NUMBER ____
SOIL DESCRIPTION SM

C_c = 45.01 (Cal °C) HEAT CAPACITY OF APPARATUS

$$C_s = c_w (M_{wa}\ M_s)\ (\Delta T_a \,'\Delta T_c) - (M_{wc}\, c_w + C_c)\, M_s$$

WHERE

·99883 c_w - SPECIFIC HEAT OF WATER (Cal gm °C)

23.43 T_{if} (°C) - TEMPERATURE OF WATER IN FLASK INITIALLY

30.64 T_{ia} (°C) - TEMPERATURE OF WATER ADDED

24.92 T_s (°C) - TEMPERATURE OF RESULTING SOLUTION

5.72 $\Delta T_a = T_{ia} - T_s$ (°C)

1.49 $\Delta T_c = T_s - T_{if}$ (°C)

51.24 M_{wa} - MASS OF WATER ADDED TO CALORIMETER (gm)

50.00 M_s - MASS OF SOIL (gm)

142.52 M_{wc} - MASS OF WATER INITIALLY IN CALORIMETER (gm)

C_s ·99883 (51.24 / 50.00) (5.72 / 1.49) -

3.930 - 3.747 (142.52 x ·99883 + 45.01) / 50.00

C_s ·183 (Cal/gm C)

$T = 610.52$ gm

$T + M_s + M_{wc} = 803.04$ ″

$T + M_s + M_{wc} + M_{wa} = 854.28$ ″

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TYPICAL COMPUTATIONS
SPECIFIC HEAT DETERMINATION OF SOIL

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FIGURE
E-2

FUGRO NATIONAL, INC.

The volumetric heat capacity of the in situ soil was calculated using the following relationship:

$C_v = \gamma(c_s + w)$ (Jumikis, 1966) .... [3]

where

C_v = volumetric heat capacity, cal/cm^3-°C;

γ = dry unit weight of soil, g/cm^3;

c_s = specific heat of soil constituent, cal/g-°C; and

w = moisture content of soil sample.