REPORT ON
SEISMIC AND ELECTRICAL SURVEYS
MARTIN RIVER AND WILLOWLAKE RIVER AREAS
OF THE MACKENZIE HIGHWAY
NORTH WEST TERRITORIES

for

The Geological Survey of Canada

by

Terraquest Surveys Limited

JANUARY 1975

TABLE OF CONTENTS

1. INTRODUCTION

A contract to carry out geophysical studies of the frost table in two areas along the Mackenzie Highway was awarded to Terraquest Surveys Limited of Toronto by the Geological Survey of Canada in July 1974. The resistivity survey was carried out by Terraquest Surveys Limited who also managed the project. The seismic work was carried out under a sub-contract by J. Fulop and Associates Limited of Toronto.

The two areas, called Martin River and Willowlake River are near Fort Simpson and Wrigley respectively, in the North West Territories.

The field work was carried out during August and September of 1974 and the interpretation and reporting done during the period October 1974 to January 1975, in Toronto.

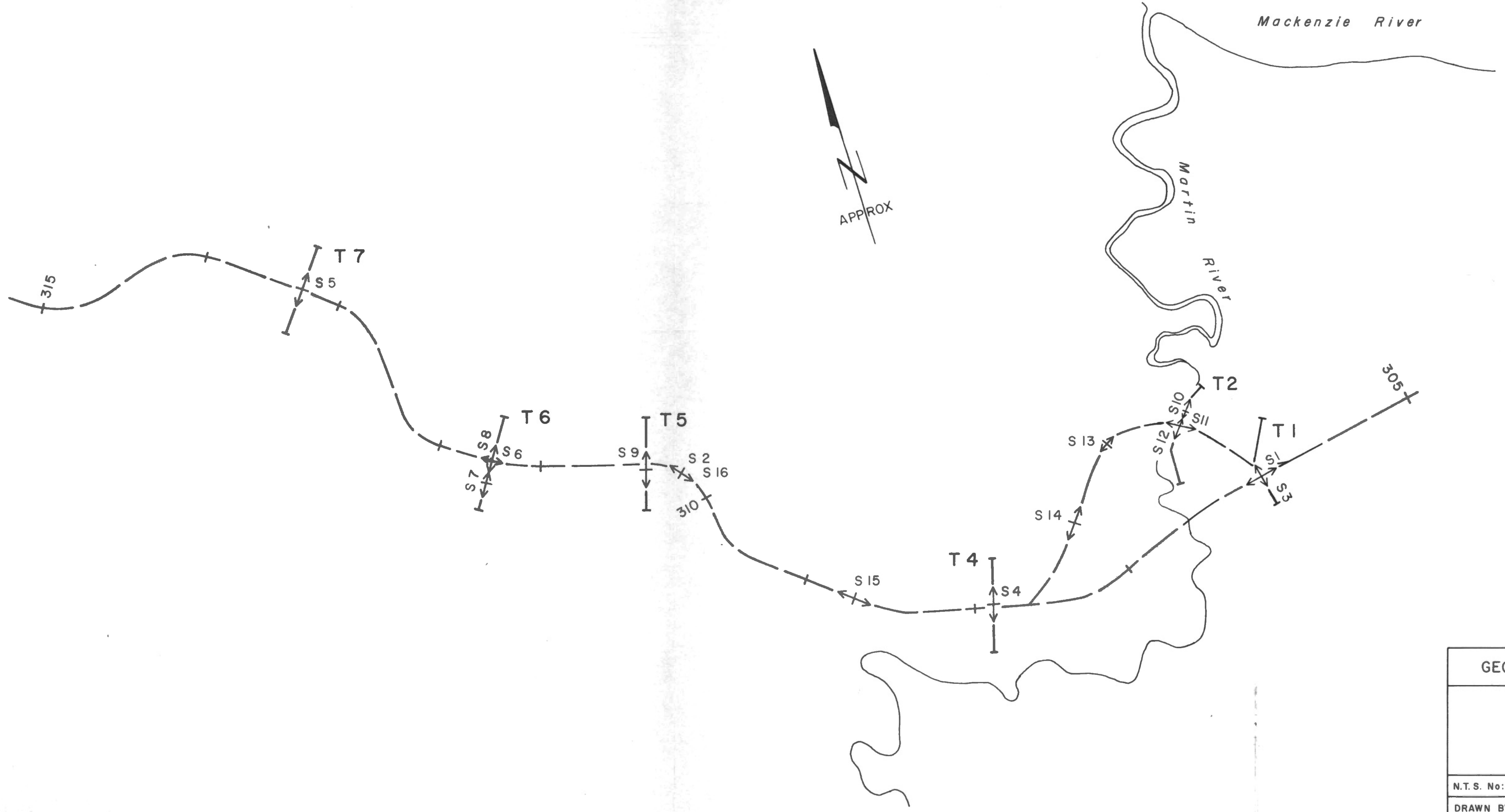
2. STUDY DEFINITION

2.1 Objective

The objectives of this survey were to use geophysical methods to establish the depth from surface, and the thickness where possible, of the permafrost table beneath the highway right-of-way and adjacent undisturbed terrain. Previous studies by the Geological Survey of Canada have established that resistivity and seismic surveys have been successful in delineating the permafrost table and these studies were substantiated by drilling.

2.2 Study Areas

The two study areas are located on the Mackenzie Highway between Fort Simpson and Wrigley. The Martin River area is located between miles 305 and 315, and the Willowlake River area is located between mile 395 and 411. Survey information was gathered both along the centre line of the highway and on lines crossing the highway at right angles called transects. Figures 1 and 2 show these locations at a scale of 3000' per inch.



GEOLOGICAL SURVEY OF CANADA

LOCATION MAP

MARTIN RIVER AREA

N.T.S. No: 95-J	SCALE: 1" = 3000'
DRAWN BY: A.H.	DRAWING No: T29-1
APPROVED:	DATE: November 1974

TERRAQUEST SURVEYS LIMITED
TORONTO, CANADA

GEOLOGICAL SURVEY OF CANADA

LOCATION MAP

WILLOWLAKE RIVER AREA

N.T.S. No: 95 - J	SCALE: 1" = 3000'
DRAWN BY: A. H.	DRAWING No: T 29 - 2
APPROVED:	DATE: November 1974

TERRAQUEST SURVEYS LIMITED
TORONTO, CANADA

3. SURVEY SPECIFICATIONS

3.1 Instrumentation

(a) D. C. Resistivity survey:

Receiver:

Model 1PR-7 Induced Polarization receiver manufactured by Scintrex Limited, Toronto

Maximum sensitivity: 30 microvolts

Accuracy: $\pm$1%

Transmitter:

Model N-250 Induced Polarization Transmitter manufactured by Crone Geophysics Ltd., Mississauga, Ontario

Maximum power available: 250 watts

Maximum current available: 1.5 amps

Cycling time: 2 seconds on, 2 seconds off

Current reading accuracy: ±1%

(b) VLF Resistivity Survey:

Model EM16-R Wave Impedance meter manufactured by Geonics Ltd., Toronto

Transmitter NPG, Jim Creek, Washington, U.S.A.

Frequency: 18.6 kHz

Potential probe separation: 10 meters

(c) Seismic Survey:

Model RS-4 oscillographic seismograph

No. of channels: 12

Geophone separation: 25 feet

3.2 Field Procedures

3.2.1 Mackenzie Highway Centre Line:

The field survey was done with the following procedure:

(a) Picketing:

Each mile of the highway from no. 305 to 314 was picketed at 100 foot intervals. The zero started from beside the tree or post on which the mile number had been fastened by the D.P.W. Pickets were placed on the north side of the road, off the subgrade about 10 feet beyond the ditch. Numbering started over again at zero at each mile post.

(b) Electrical Resistivity Profiling:

The wenner array with an inter-electrode spacing of 100 feet was used and readings were taken at 100 foot intervals.

(c) Radiowave Resistivity:

Readings were taken at each picket with the EM-16R wave impedance meter. The potential electrodes were positioned in line with the direction to the transmitter and were ten meters apart.

(d) Seismic Survey
Refraction spreads were carried out at 300-foot intervals by using a geophone cable with 12 geophone positions spaced at 25-foot intervals. Denotations were placed 25 feet beyond each end of the spread so as to shoot reverse profile. Explosive charges were between a tenth and a half a pound in size and the average depth of burial of the charge was 2 feet.

(e) Centre line detour
During the survey it was learned that the route was to be altered in the vicinity of the Martin River to cross the river at a more favourable point. The geophysical work was done on this detour in the same manner as for the highway except that measurements were taken on the actual centre line since no sub grade had yet been constructed.

3.2.2 Transects

The transects were lines 3,000 feet long, cut at right angles to the highway centre line. The mid point of the transect was established on the east side of the road.

The Selection of the position of the transects was made by the G.S.C.

The geophysical work on the transects was done exactly as for the highway centre line except that the electrode spacing and station interval for the Wenner array was changed from 100 feet to 50.

3.2.3 Resistivity Soundings

Thirty-six depth soundings were carried out at positions selected by Terraquest personnel in the field using guidelines set up by G.S.C.

The Schlumberger electrode array was used and is one in which the electrodes are placed in line, symetrically spaced on either side of the sounding point. The two potential electrodes are placed a distance "a" either side of the sounding point and the current electrodes are placed beyond these at a distance "b" from the sounding point. Starting from small dimensions (a = ½ foot, b = 3 feet) b was increased in approximately logarithmic intervals. a was increased whenever the voltage is reduced to an unreadable level. In practise the electrode intervals were:

for a = ½'

b = 3, 6

for a = 2'

b = 10, 20, 35, 50 and 70 feet

for a = 10'

b = 70, 100, 140 and 200 feet

for a = 20'

b = 200, 300 and 400 feet.

4. SURVEY RESULTS AND INTERPRETATION

4.1 Presentation of Data

(a) Profiles

Each mile of centre line and each transect is presented as a cross section on which the resistivity data is shown in profile and the seismic data is shown as interpreted, subsurface layers. The horizontal scale is 1" = 200 feet. The Wenner array resistivity is plotted logarithmically, one logarithmic interval (decade) per inch. The EM-16R resistivity is also plotted logarithmically, but at 2 cycles per inch. The EM-16R phase angle is plotted at 20 degrees per inch and the neutral 45 degree line is marked as the datum by a heavy line.

The seismic interpretation is shown at a vertical scale of 1" = 20 feet, giving a vertical exaggeration of 1:10. The ground surface for the mile 305-315 centre line and the Willowlake River area transects is accurately plotted from elevation provided by the Dept. of Public Works. Elevation data was not available for the Martin River area transects (nos. 1-7) and these were estimated by eye during the survey. The positions of refractor layers are plotted on the profile along with interval or segment velocities where determined. The layered information interpreted from the resistivity soundings has also shown on the seismic sections. The thickness of each layer, h, is given in feet and the calculated resistivity of each layer is shown in ohm-meters.

The permafrost is shown as a hatched area where it has been interpreted from the geophysical data. The heavy line on the seismic section indicates a hard layer which may either be permafrost or bedrock.

(b) Resistivity Soundings

Apparent resistivity was computed to 3 significant figures in ohm-metres for each expander position. These were plotted on log-log paper (KE467323, 2 x 3 cycles, 1 cycle = 3 1/3 inches) and are shown in section 4.2.3.

The broken lines on the plot are the auxiliary curves used in the Orellana auxiliary curve method.

4.2 Interpretation

4.2.1 Seismic Interpretation Methods

The critical distance method was used for the interpretation of most of the seismic data on this survey. The critical distance is the horizontal distance from the shot point to the point where direct and refracted waves from deeper layers arrive simultaneously. This point is determined on the time distance graph by the intersection of velocity segments. In the case of more than 2 layers, the same method was extended to calculate the depth of each successive layer.

Since each spread was shot from both ends the depths were calculated at two points on each spread using this method. Then the depth points under each geophone were calculated by the modified ray path method. This makes use of the time deviation for each geophone from the straight line velocity segments and the representative seismic velocities that have been determined for that segment.

The Hawkins method was used when velocities of layers overlying the main refractor appeared quite uniform. This is a complex method and is described in the paper by Hawkins in Geophysics, Vol. 26, issue #6.

The time intercept method was applied in instances where the refractor velocities were very well defined.

4.2.2 Resistivity Soundings

Two layer cases were analyzed by fitting the field data to Schlumberger, two-layer curves published by Orellana and Mooney. However, the majority of the expander curves show the presence of a third layer and these were analyzed primarily by the two layer curves supplemented by auxiliary curves again published by Orellana and Mooney. The auxiliary curves enable an interpretation of each section of a multi-layer curve to be made by grouping the upper layers into one fictious layer, which then, with the next layer below it, becomes a two-layer case. Four and five layer cases were also handled with this method. Solutions derived this way were then checked by fitting where possible to a family of three-layer case curves published by Geophysical Prospecting, Vol. 3, supplement #3, September, 1955.

A thorough description of the operation of the auxiliary curve method is to be found in "Electrical Methods in Geophysical Prospecting", by Keller and Frischknecht, Perggamon Press, 1966.

In some cases the values measured at the outermost electrodes positions, usually 300 to 400 feet, decreased more rapidly than theoretically possibly even for a third-layer of infinite conductivity. Inspection of the Wenner profile at these points usually confirms that the electrodes have moved off the high resistivity area beyond the edges of the permafrost lense causing the high resistivity. In this case a three-layer case does not exist and the interpretation rules do not really apply. However, by assuming that ρ_3 is ρ_2 a curve can be fitted to give a minimum h_2 and this has been done for all soundings of this type. In the interpretation notes below this condition is noted by the words "edge effect".

In two or three soundings all values measured for one potential electrode spacing appeared uniformly lower or higher than the rest of the curve. This has been presumed due to an anomalously low (or high) resistivity surface zone near or between the electrodes which has distorted the layered case potential field beyond the normal "noise" limit.

The interpretation was made by fitting curves to where the anomalous points would lie if moved up (or down) to be aligned with the rest of the data. The overlapping readings were useful in establishing the new point positions. In the interpretation discussion this effect is called the anomalous potential effect.

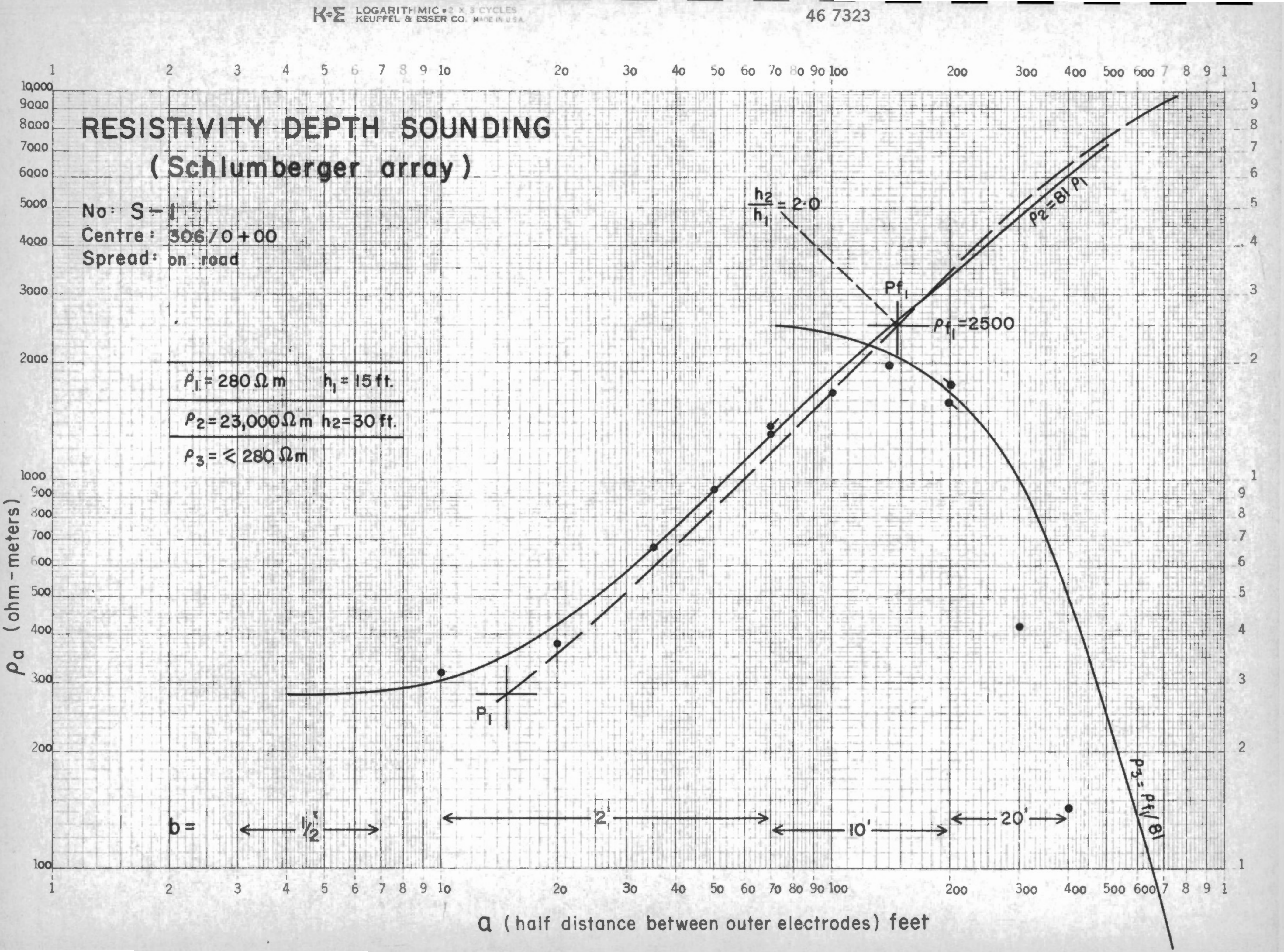
The results of the interpretation are tabulated in Table 1 on the following two pages.

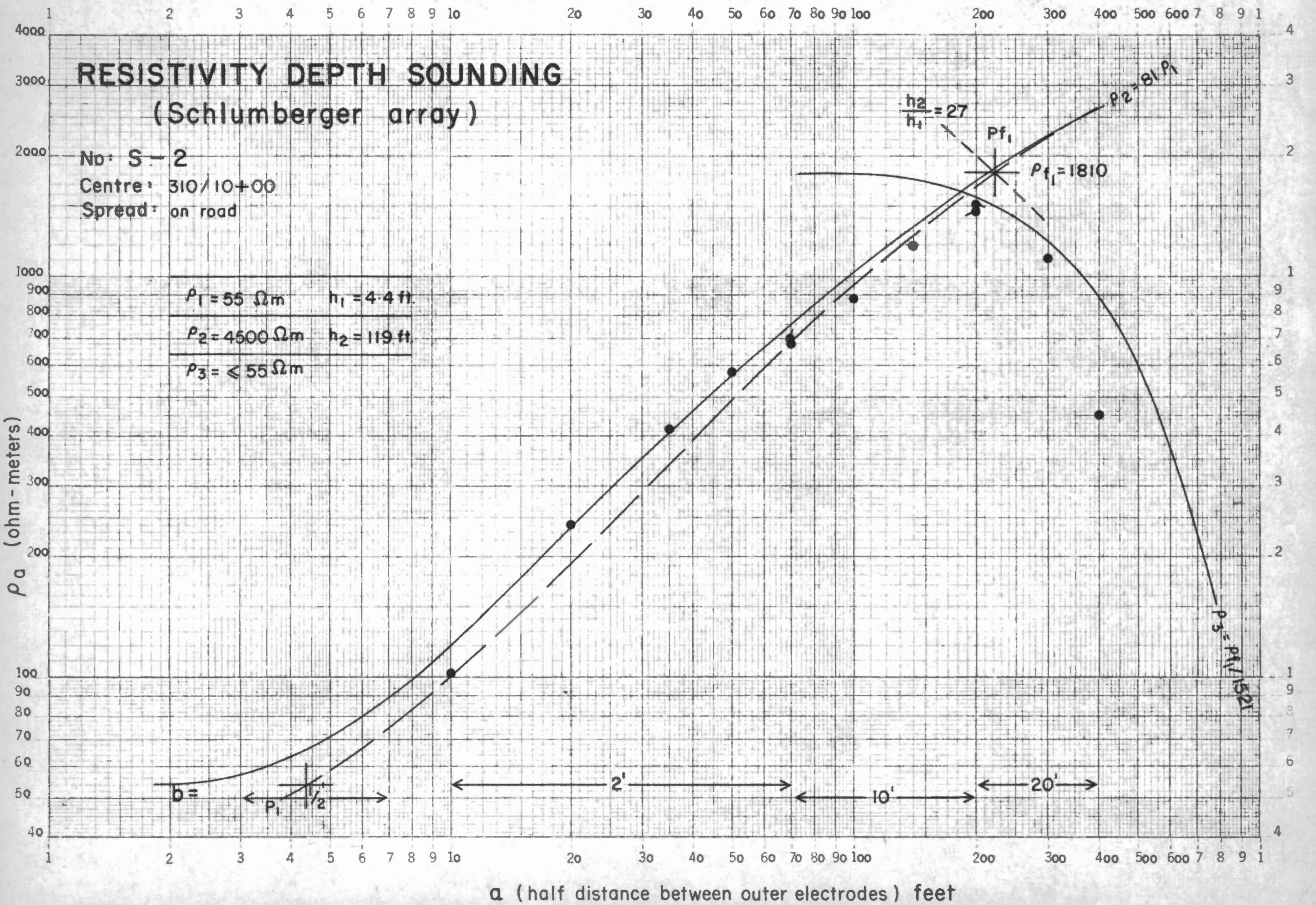
DISCUSSIONS OF INTERPRETATION OF SOUNDING CURVES

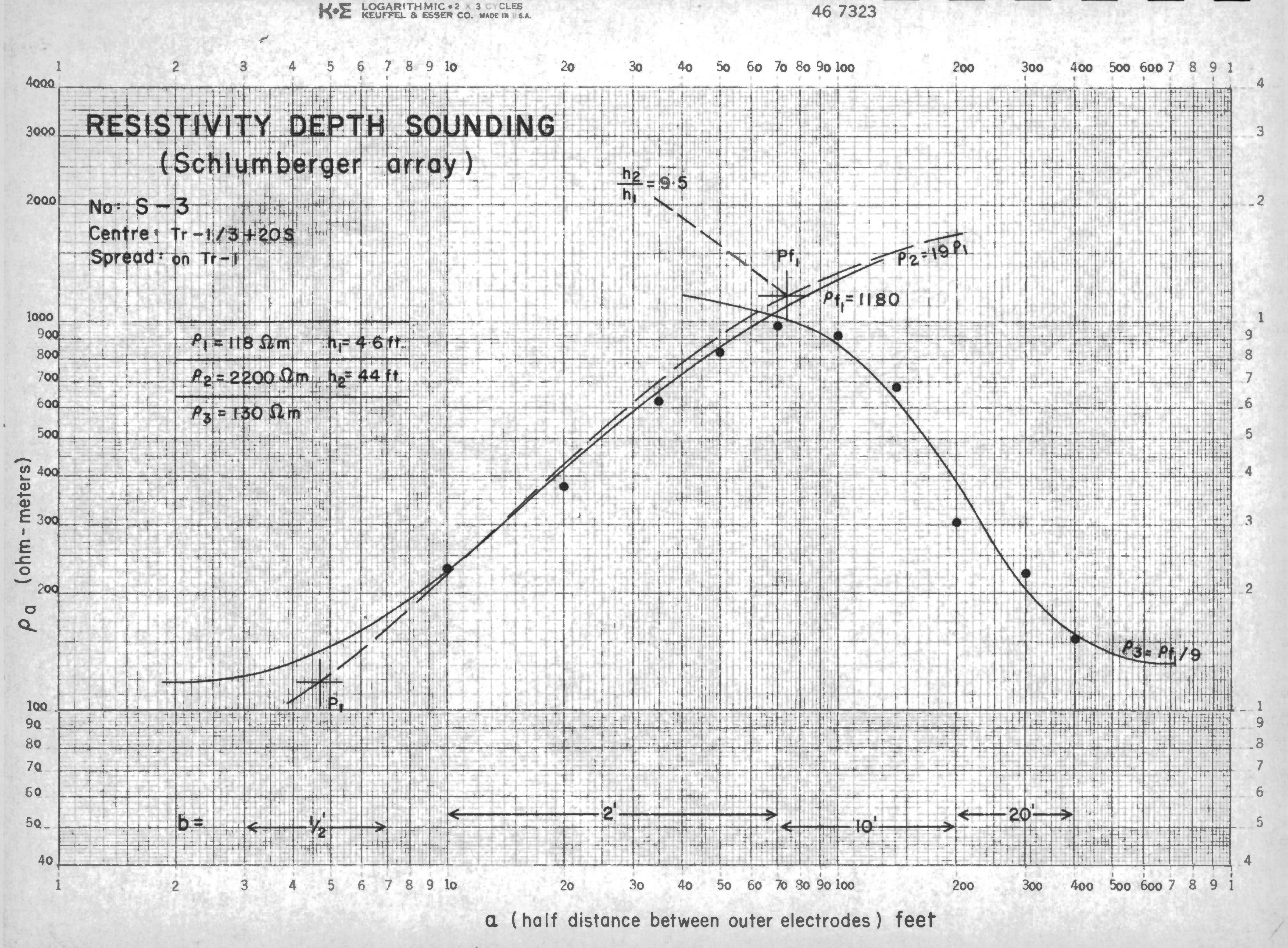
S-1 Edge effects for 300 and 400 feet spacings make h_2 and ρ_3 less accurate. ρ_3 can only be assumed equal to ρ_1 and h_2 is a minimum possible value.

S-2 The same comments as for S-1 to a lesser degree.

4.2.3 RESISTIVITY SOUNDING CURVES


K+E LOGARITHMIC 2 X 3 CYCLES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 7323
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-1
Centre: 306/0+00
Spread: on road
ρ1 = 280 Ωm   h1 = 15 ft.
ρ2 = 23,000 Ωm   h2 = 30 ft.
ρ3 = ≤ 280 Ωm
h2/h1 = 2·0
Pf1
ρf1 = 2500
ρ2 = 81 ρ1
P1
ρ3 = ρf1/81
b =
1/2'
2'
10'
20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet


RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-2
Centre: 310/10+00
Spread: on road
ρ1 = 55 Ωm h1 = 4.4 ft.
ρ2 = 4500 Ωm h2 = 119 ft.
ρ3 = ≤ 55 Ωm
h2/h1 = 27
Pf1
ρf1 = 1810
ρ2 = 81 ρ1
ρ3 = ρf1/1521
b =
P1
1/2
2'
10'
20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet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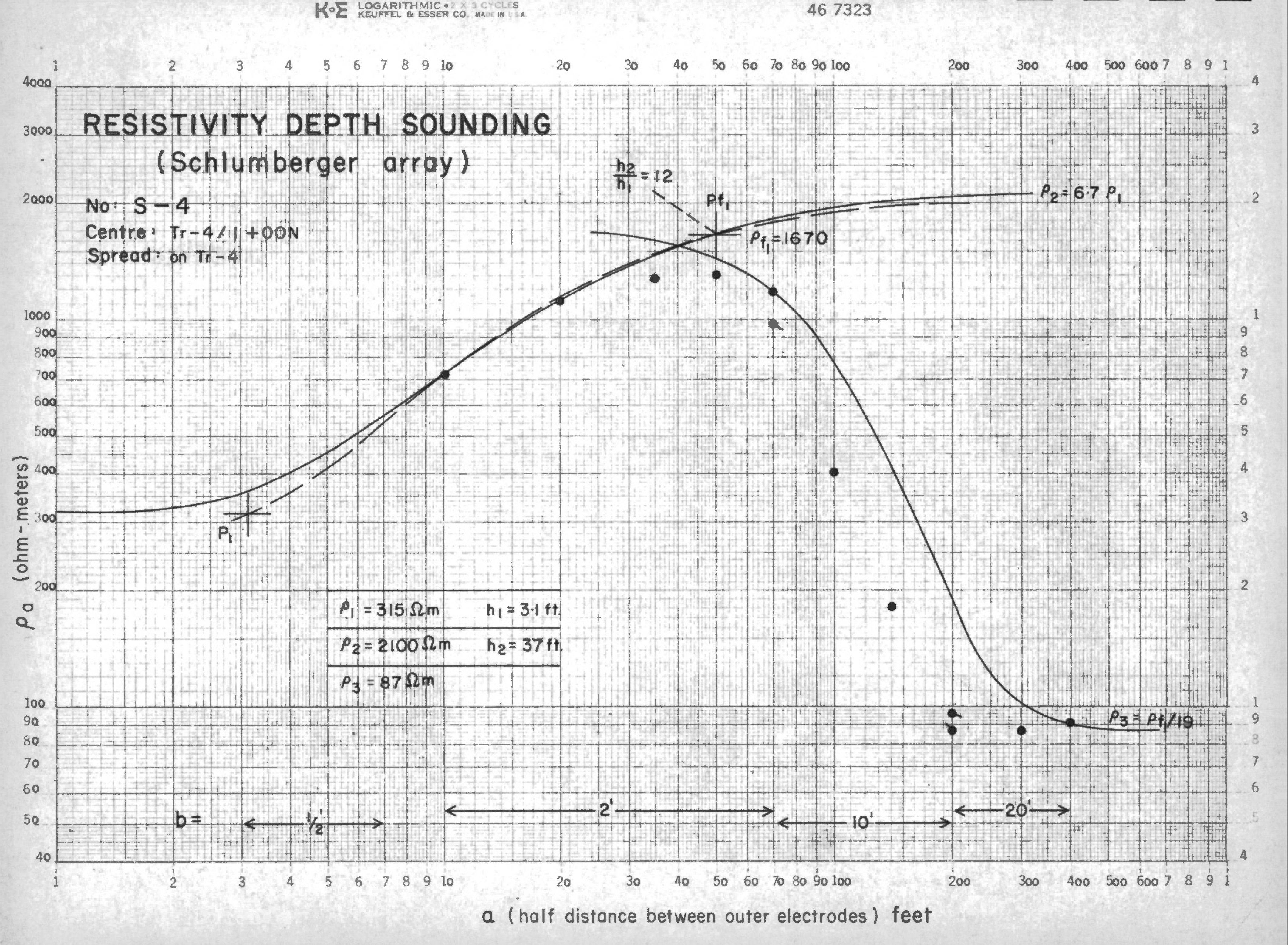
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-3
Centre: Tr-1/3+20S
Spread: on Tr-1
ρ1 = 118 Ωm   h1 = 4.6 ft.
ρ2 = 2200 Ωm   h2 = 44 ft.
ρ3 = 130 Ωm
h2/h1 = 9.5
Pf1
ρf1 = 1180
ρ2 = 19 ρ1
ρ3 = ρf1/9
P1
b =
1/2'
2'
10'
20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet



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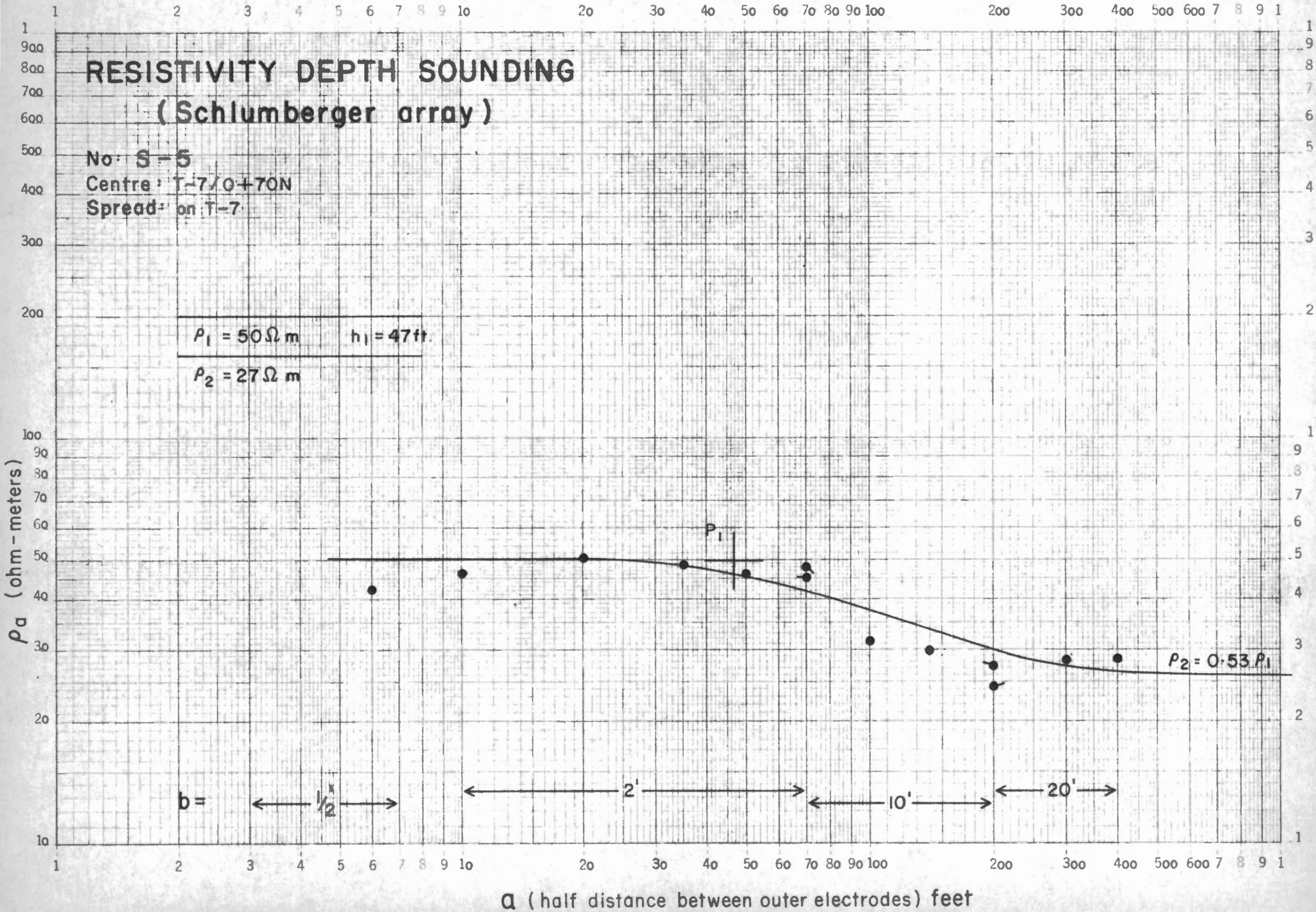
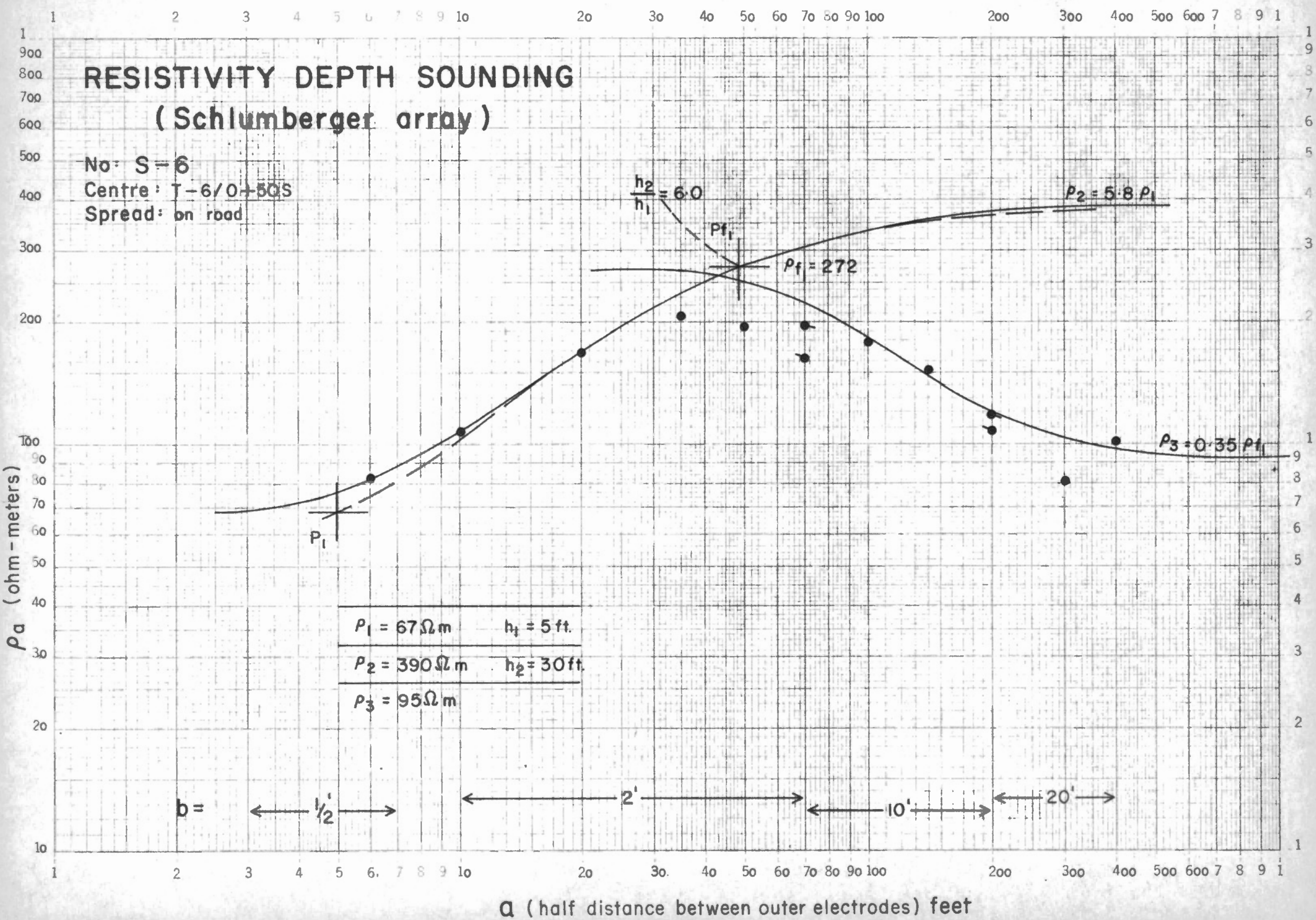
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-4
Centre: Tr-4/1+00N
Spread: on Tr-4
h2/h1 = 12
Pf1
ρ2 = 6.7 ρ1
ρf1 = 1670
P1
ρ1 = 315 Ωm
h1 = 3.1 ft.
ρ2 = 2100 Ωm
h2 = 37 ft.
ρ3 = 87 Ωm
ρ3 = ρf1/19
b =
1/2'
2'
10'
20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet


RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-5
Centre: T-7/0+70N
Spread: on T-7
ρ1 = 50 Ω m
h1 = 47 ft.
ρ2 = 27 Ω m
P1
ρ2 = 0·53 ρ1
b =
½"
2'
10'
20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet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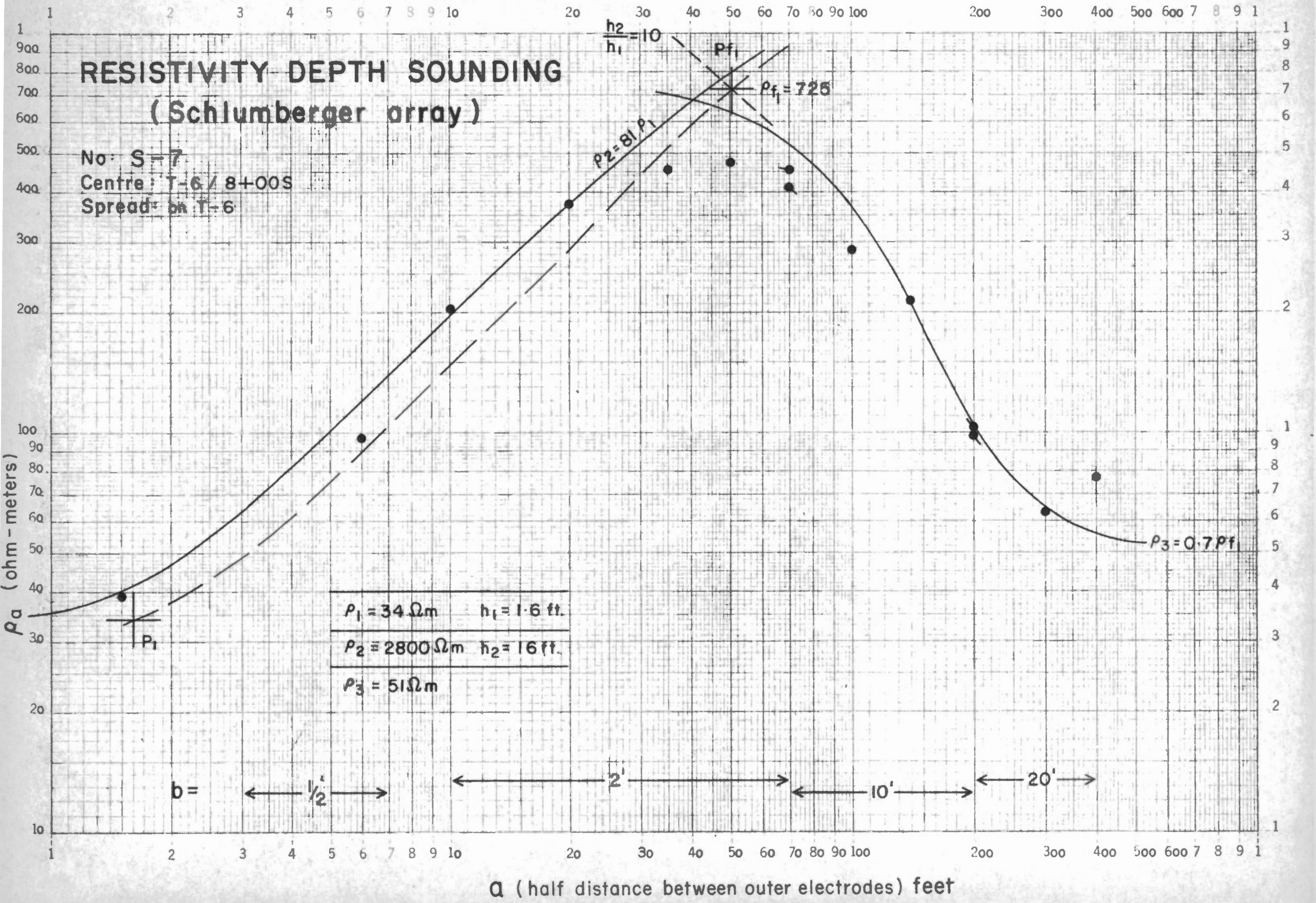
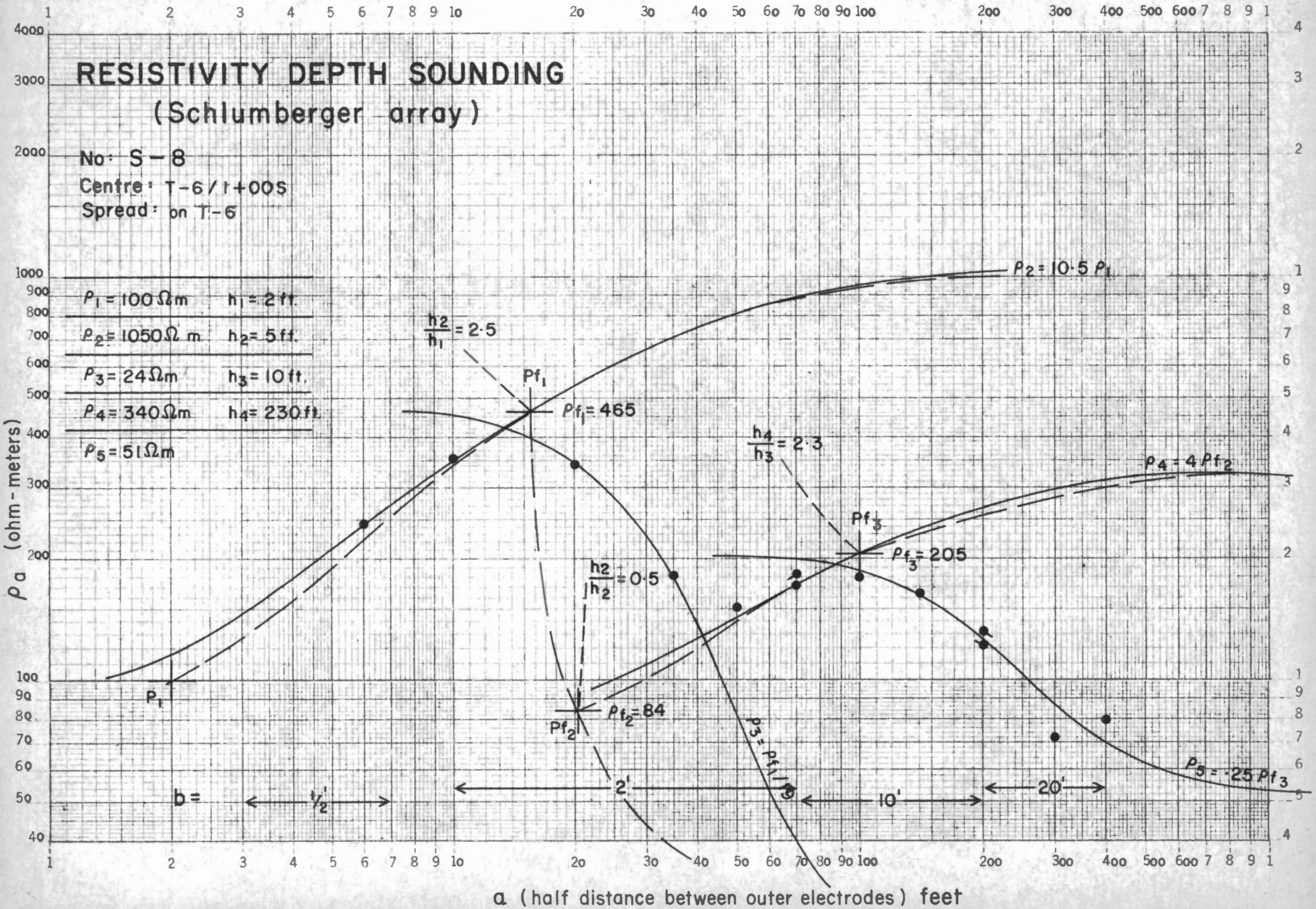
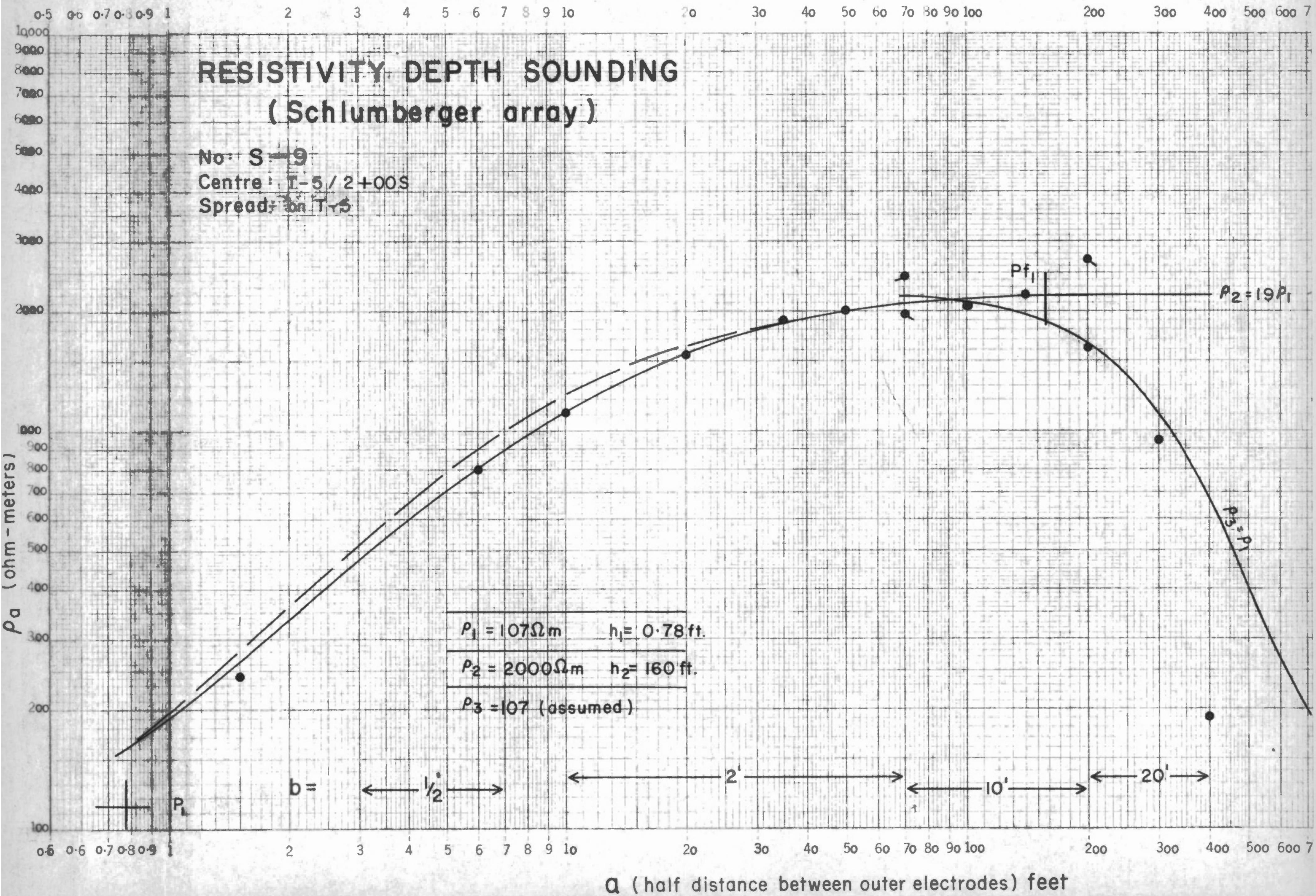
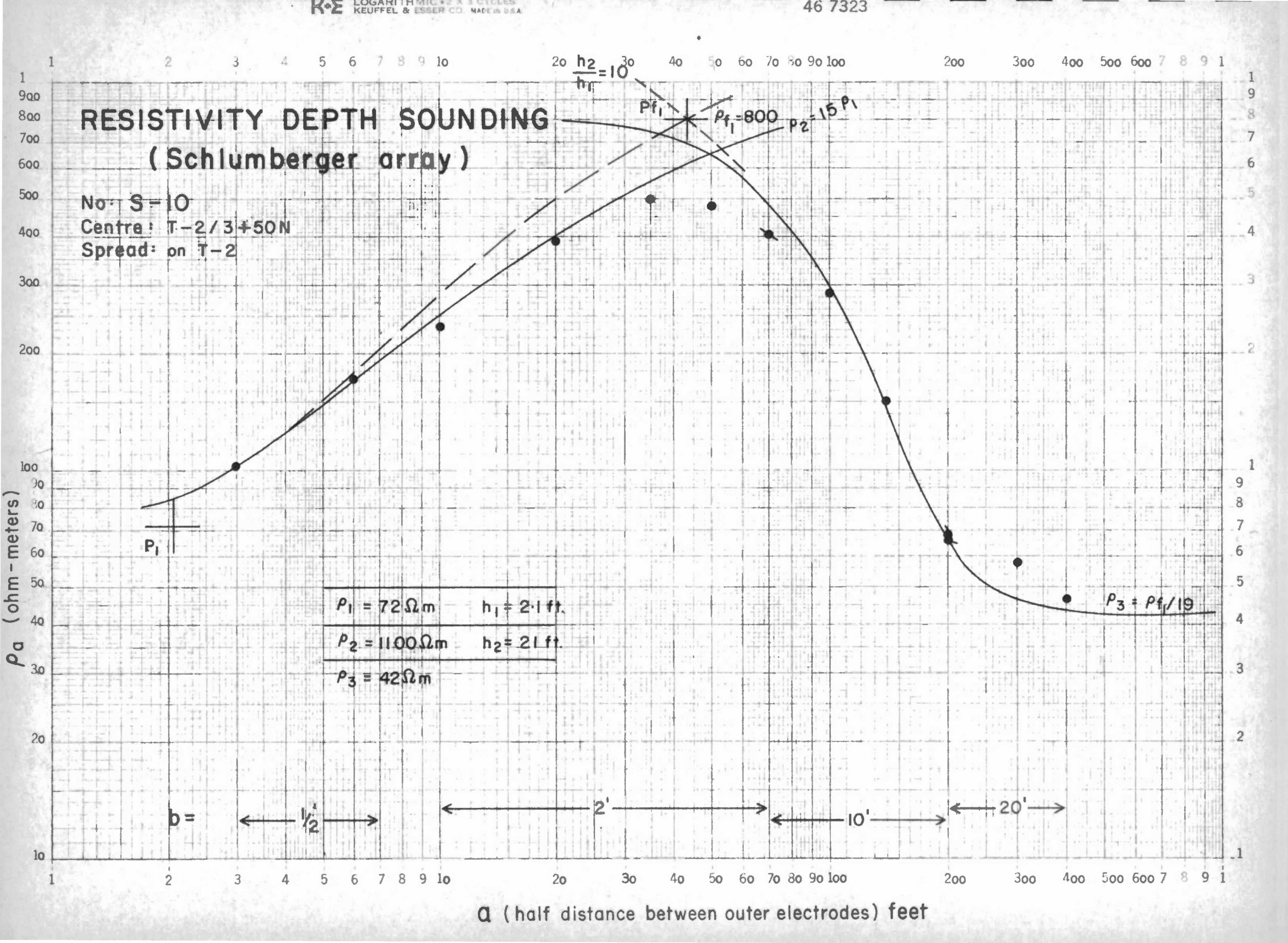
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-6
Centre: T-6/0+50S
Spread: on road
$\frac{h_2}{h_1} = 6.0$
P_{f_1}
$\rho_{f_1} = 272$
$\rho_2 = 5.8\ \rho_1$
$\rho_3 = 0.35\ \rho_{f_1}$
P_1
$\rho_1 = 67\Omega m$ $h_1 = 5$ ft.
$\rho_2 = 390\Omega m$ $h_2 = 30$ ft.
$\rho_3 = 95\Omega m$
b = 1/2' 2' 10' 20'
ρ_a (ohm-meters)
a (half distance between outer electrodes) feet



RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-7
Centre: T-6 / 8+00S
Spread: on T-6
$\frac{h_2}{h_1} = 10$
ρf_1
$\rho_{f_1} = 725$
$\rho_2 = 81\rho_1$
$\rho_3 = 0.7\rho f_1$
P_1
$\rho_1 = 34\,\Omega m$ $h_1 = 1.6$ ft.
$\rho_2 = 2800\,\Omega m$ $h_2 = 16$ ft.
$\rho_3' = 51\,\Omega m$
b = ½' 2' 10' 20'
ρ_a (ohm-meters)
a (half distance between outer electrodes) feet


RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-8
Centre: T-6/1+00S
Spread: on T-6
ρ1 = 100 Ωm h1 = 2 ft.
ρ2 = 1050 Ω m h2 = 5 ft.
ρ3 = 24 Ωm h3 = 10 ft.
ρ4 = 340 Ωm h4 = 230 ft.
ρ5 = 51 Ωm
h2/h1 = 2.5
Pf1
ρf1 = 465
ρ2 = 10.5 ρ1
h4/h3 = 2.3
ρ4 = 4 ρf2
Pf3
ρf3 = 205
h2/h2 = 0.5
Pf2
ρf2 = 84
P1
ρ3 = ρf1/19
ρ5 = .25 ρf3
b = 1/2' 2' 10' 20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet


RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-9
Centre: T-5/2+00S
Spread: on T-5
ρ_1 = 107Ωm h_1 = 0·78 ft.
ρ_2 = 2000Ωm h_2 = 160 ft.
ρ_3 = 107 (assumed)
$\rho_2 = 19\rho_1$
Pf_1
$\rho_3 = \rho_1$
P_1
b = ½' 2' 10' 20'
ρ_a (ohm-meters)
a (half distance between outer electrodes) feet



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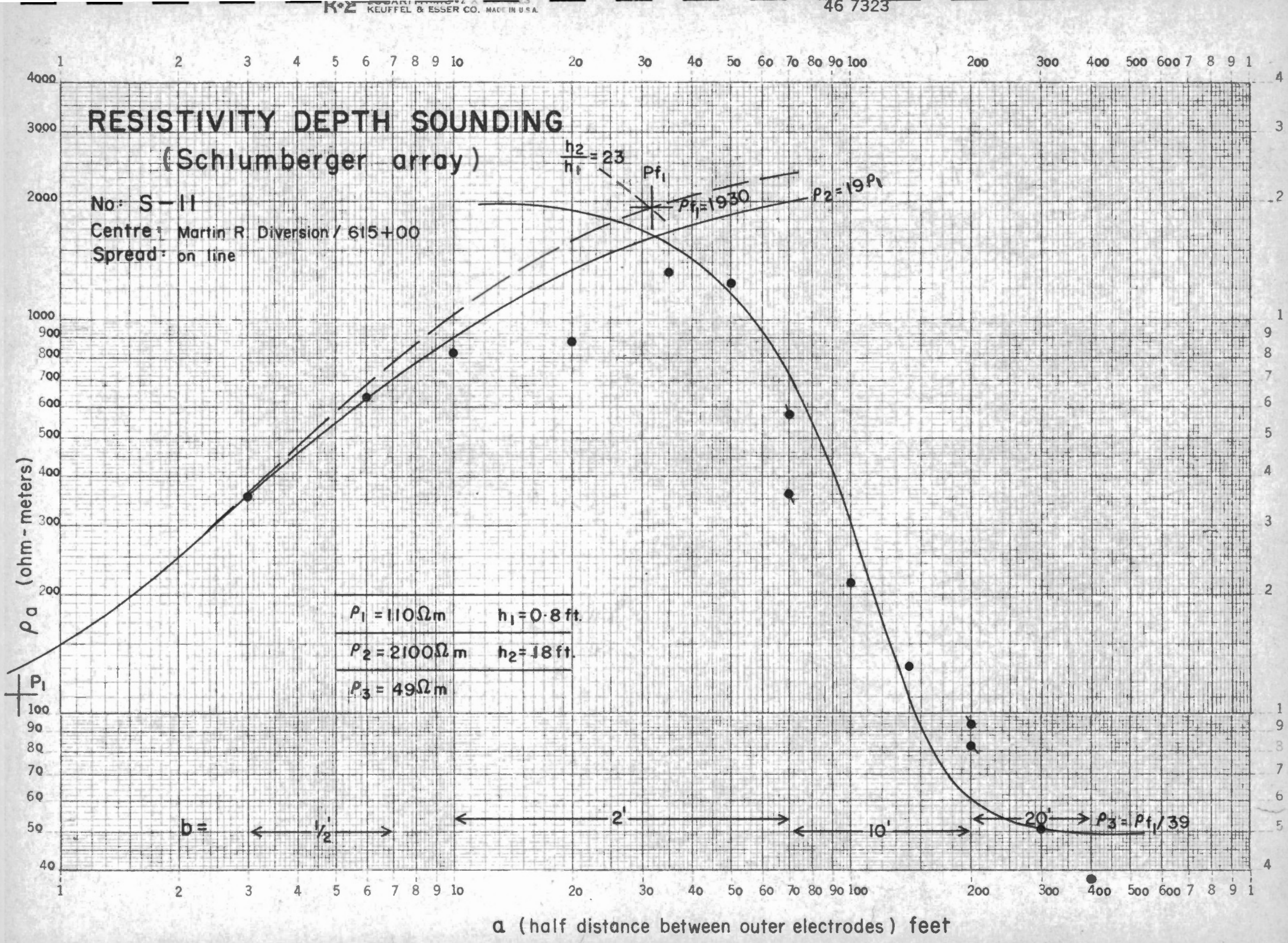
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-10
Centre: T-2/3+50N
Spread: on T-2
$\frac{h_2}{h_1} = 10$
ρf_1
$\rho_{f_1} = 800$
$\rho_2 = 15 \rho_1$
ρ_1
$\rho_3 = \rho f_1 / 19$
$\rho_1 = 72 \Omega m$ $h_1 = 2.1$ ft.
$\rho_2 = 1100 \Omega m$ $h_2 = 21$ ft.
$\rho_3 = 42 \Omega m$
b = ½' 2' 10' 20'
ρ_a (ohm-meters)
a (half distance between outer electrodes) feet



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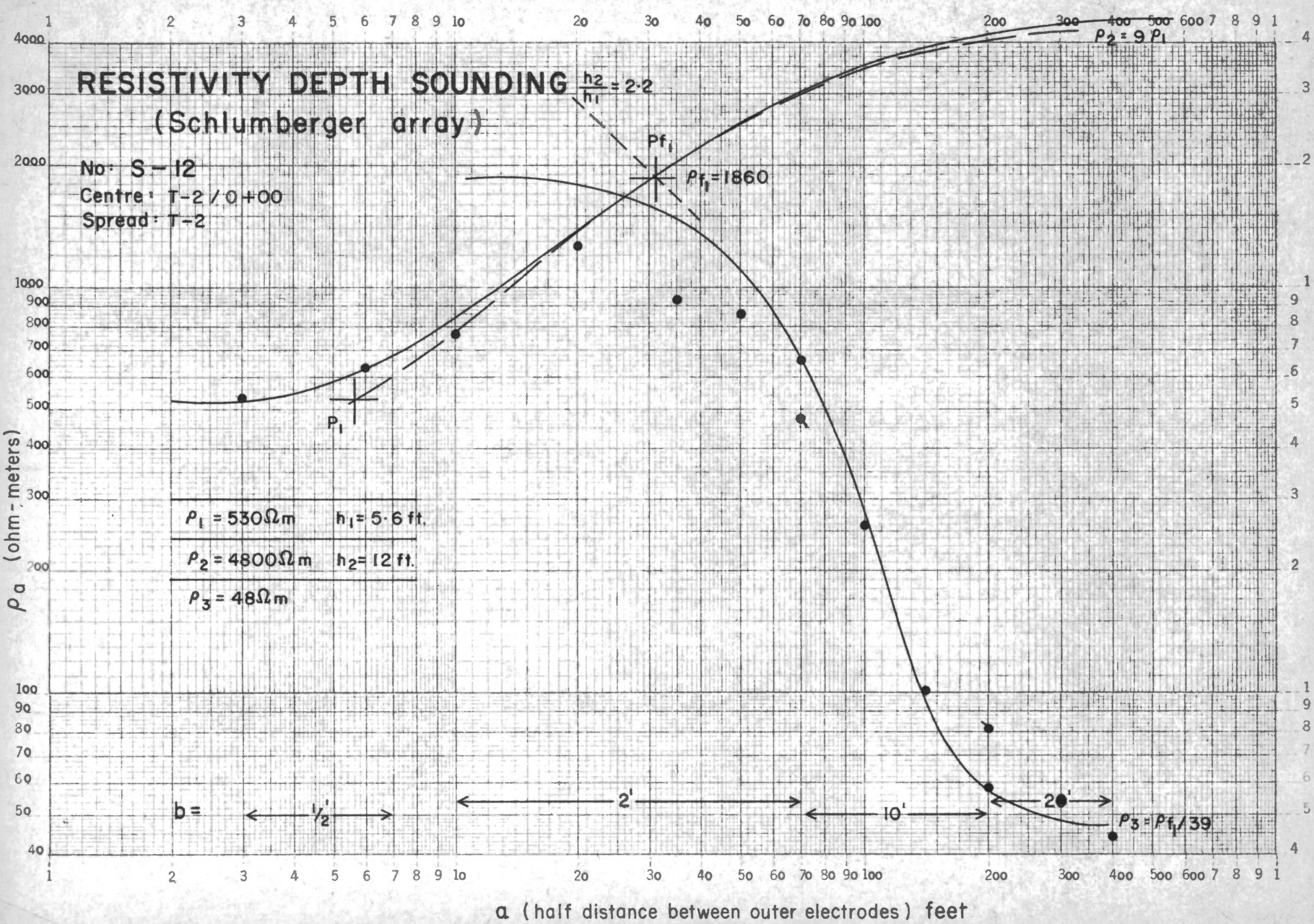
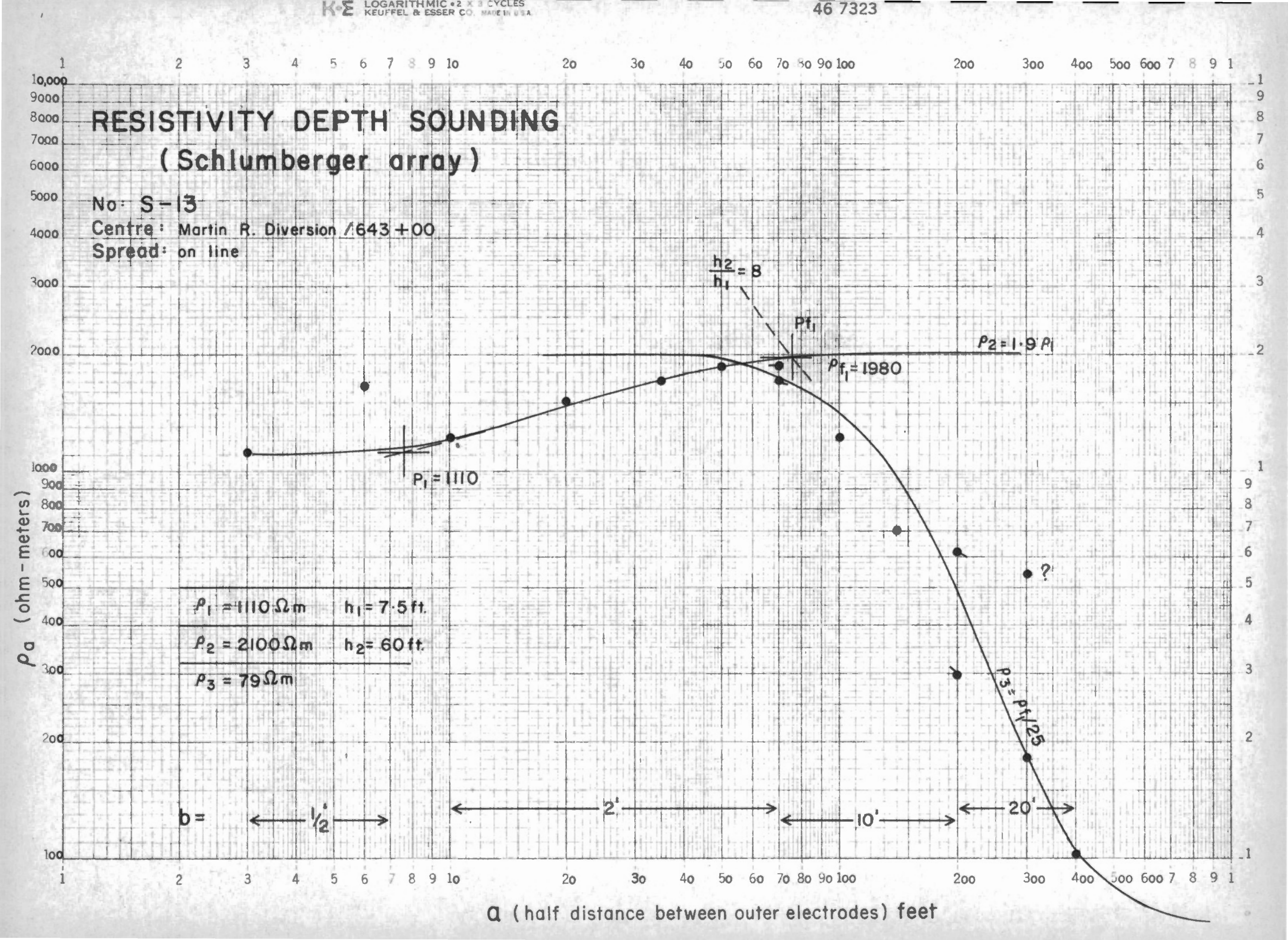
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-11
Centre: Martin R. Diversion / 615+00
Spread: on line
$h_2/h_1 = 23$
P_{f_1}
$\rho_{f_1} = 1930$
$\rho_2 = 19\rho_1$
$\rho_1 = 110\Omega m$ $h_1 = 0.8$ ft.
$\rho_2 = 2100\Omega m$ $h_2 = 18$ ft.
$\rho_3 = 49\Omega m$
P_1
b =
1/2'
2'
10'
20'
$\rho_3 = \rho_{f_1}/39$
ρ_a (ohm-meters)
a (half distance between outer electrodes) feet



RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-12
Centre: T-2 / 0+00
Spread: T-2
h2/h1 = 2·2
Pf1
ρf1 = 1860
ρ2 = 9 ρ1
P1
ρ1 = 530Ωm h1 = 5·6 ft.
ρ2 = 4800Ωm h2 = 12 ft.
ρ3 = 48Ωm
ρa (ohm - meters)
b = ½' 2' 10' 20'
ρ3 = ρf1/39
a (half distance between outer electrodes) feet



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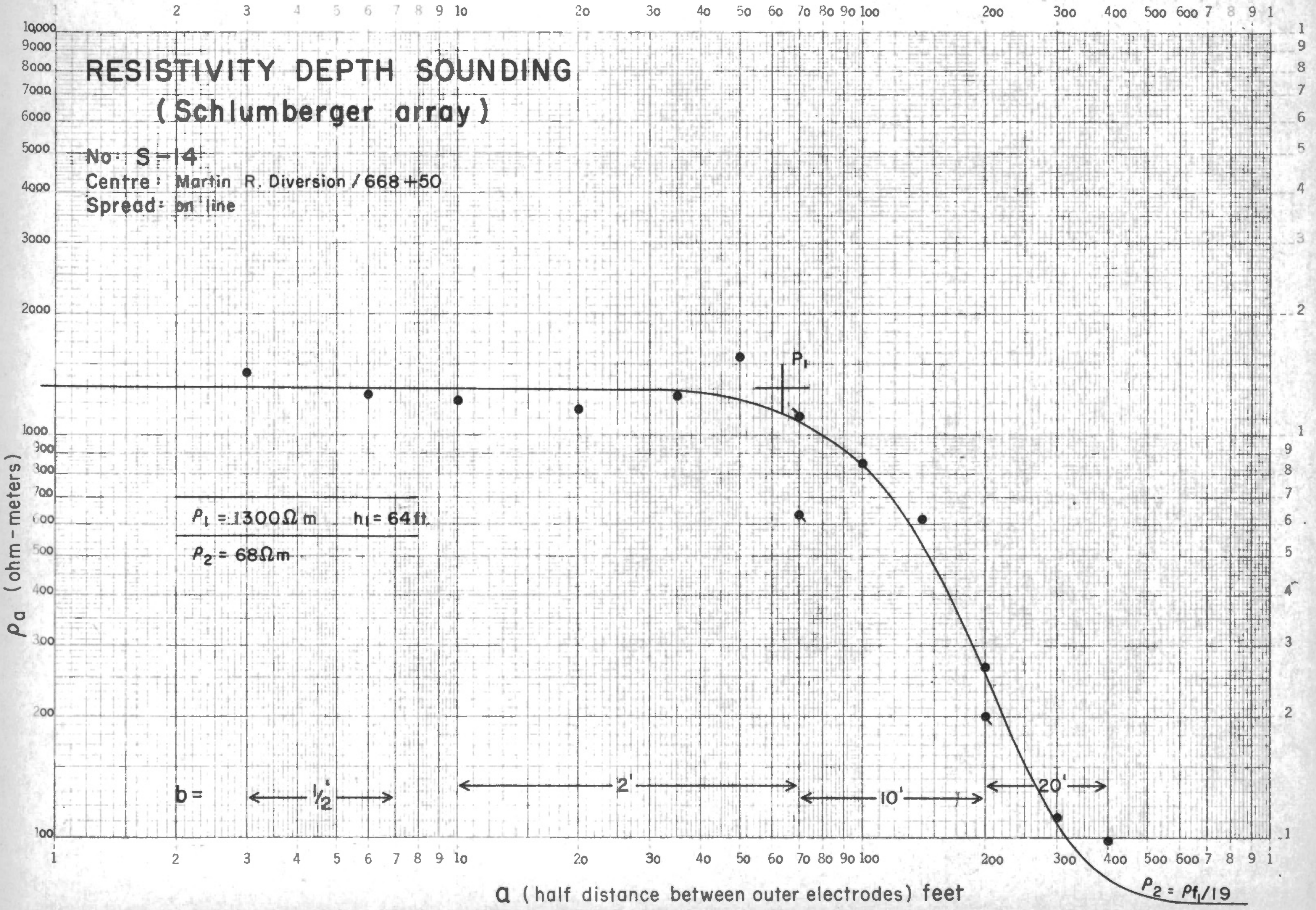
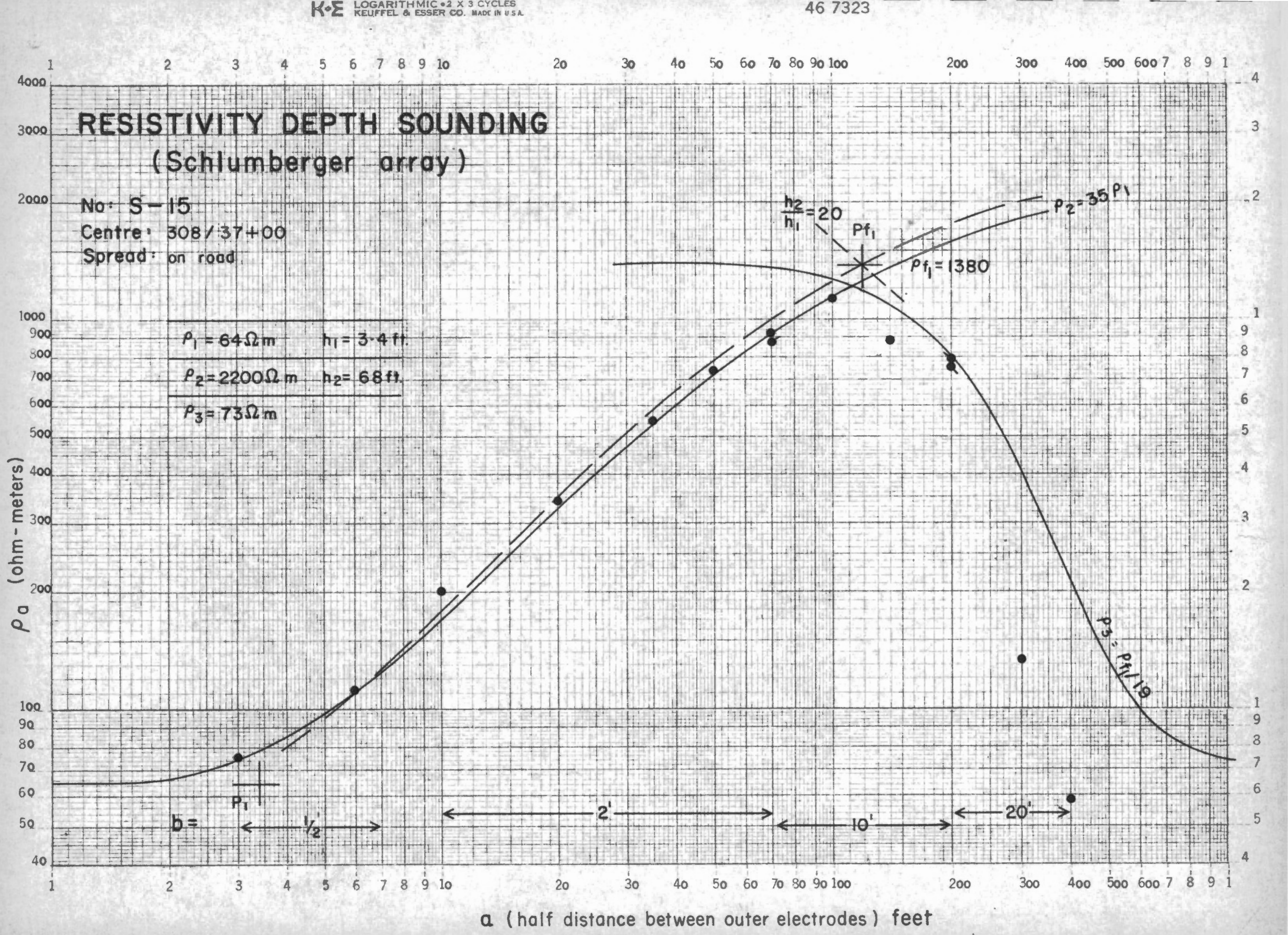
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-13
Centre: Martin R. Diversion /643+00
Spread: on line
h2/h1 = 8
Pf1
ρ2 = 1·9 ρ1
ρf1 = 1980
P1 = 1110
ρ1 = 1110 Ωm h1 = 7·5 ft.
ρ2 = 2100 Ωm h2 = 60 ft.
ρ3 = 79 Ωm
ρ3 = ρf1/25
?
b = 1/2' 2' 10' 20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet



RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-14
Centre: Martin R. Diversion / 668+50
Spread: on line
P1
ρ1 = 1300Ω m
h1 = 64 ft.
ρ2 = 68Ωm
b =
1/2'
2'
10'
20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet
ρ2 = ρ1/19



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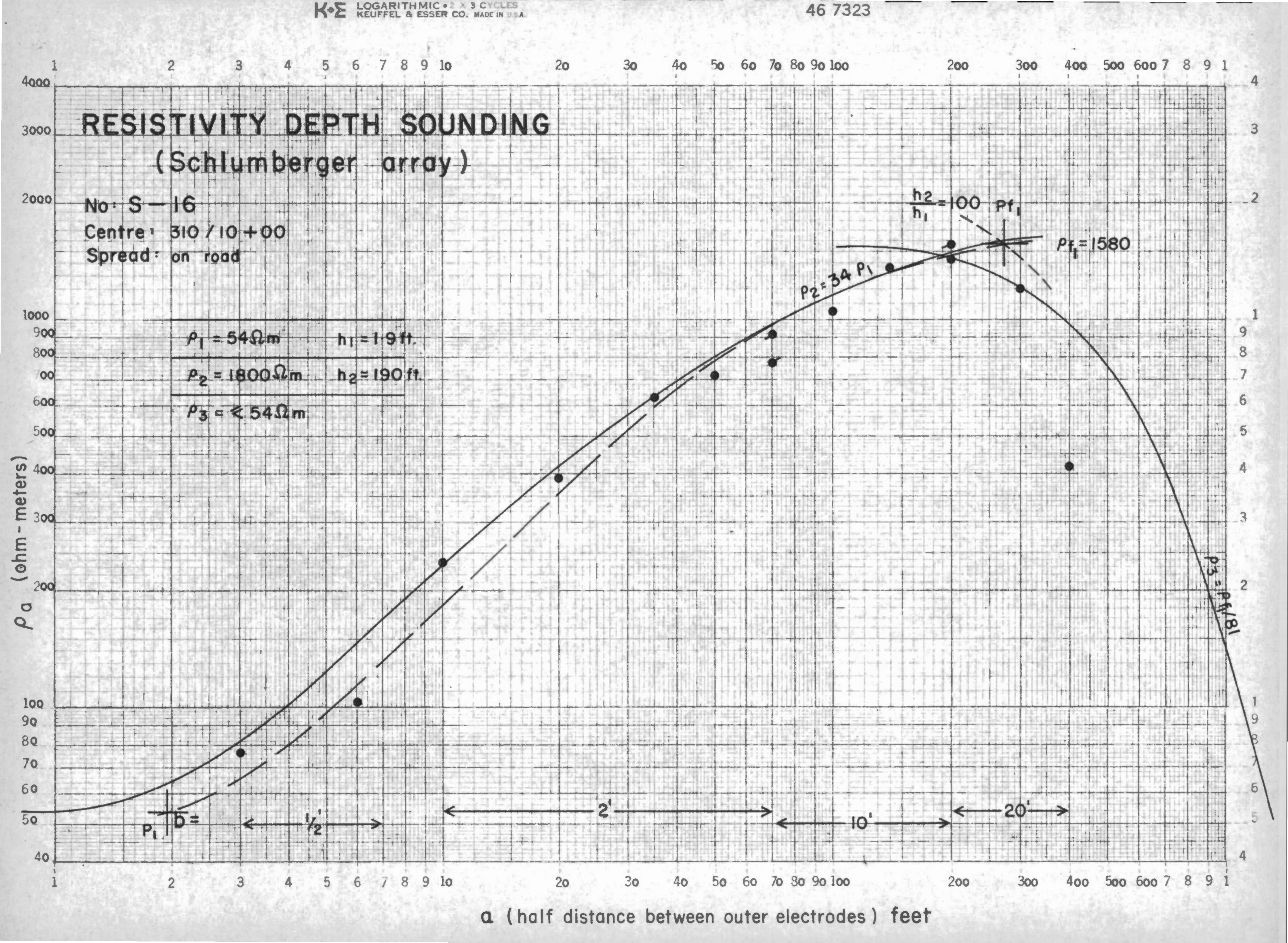
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-15
Centre: 308/37+00
Spread: on road
ρ1 = 64Ω m
h1 = 3·4 ft.
ρ2 = 2200Ω m
h2 = 68 ft.
ρ3 = 73Ω m
h2/h1 = 20
Pf1
ρf1 = 1380
ρ2 = 35 ρ1
ρ3 = ρf1/19
P1
b =
1/2
2'
10'
20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet



K+E LOGARITHMIC • 2 X 3 CYCLES
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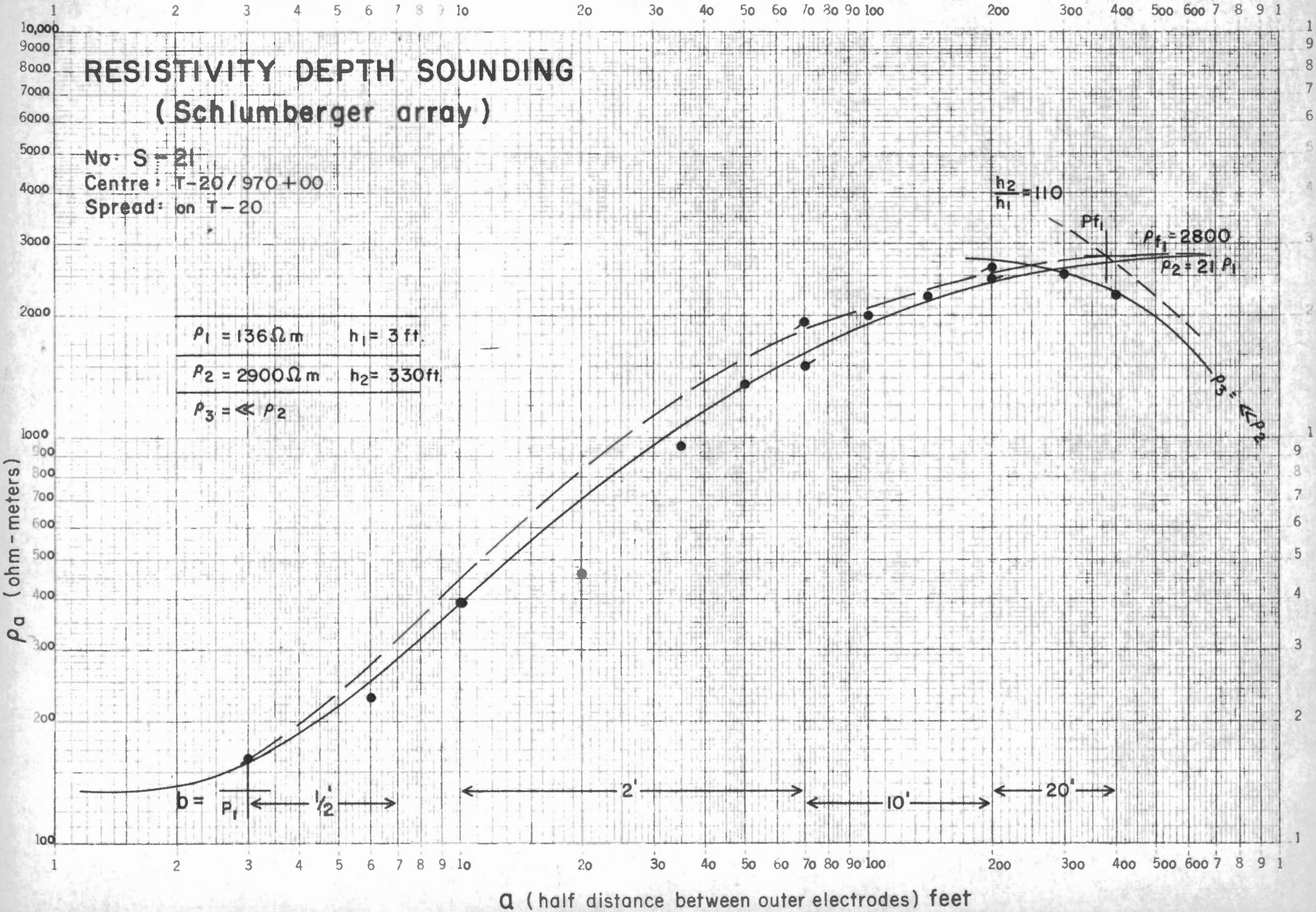
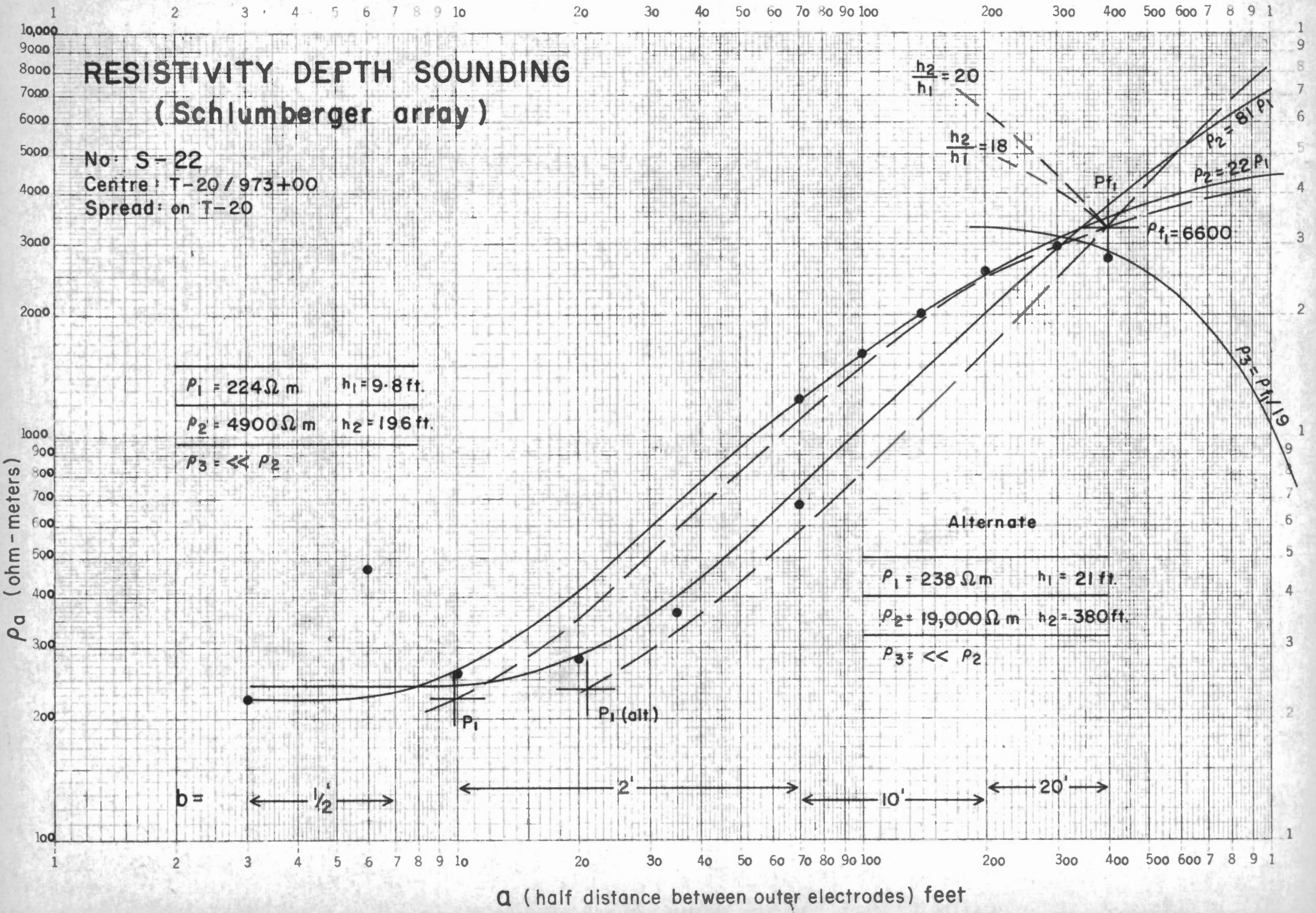
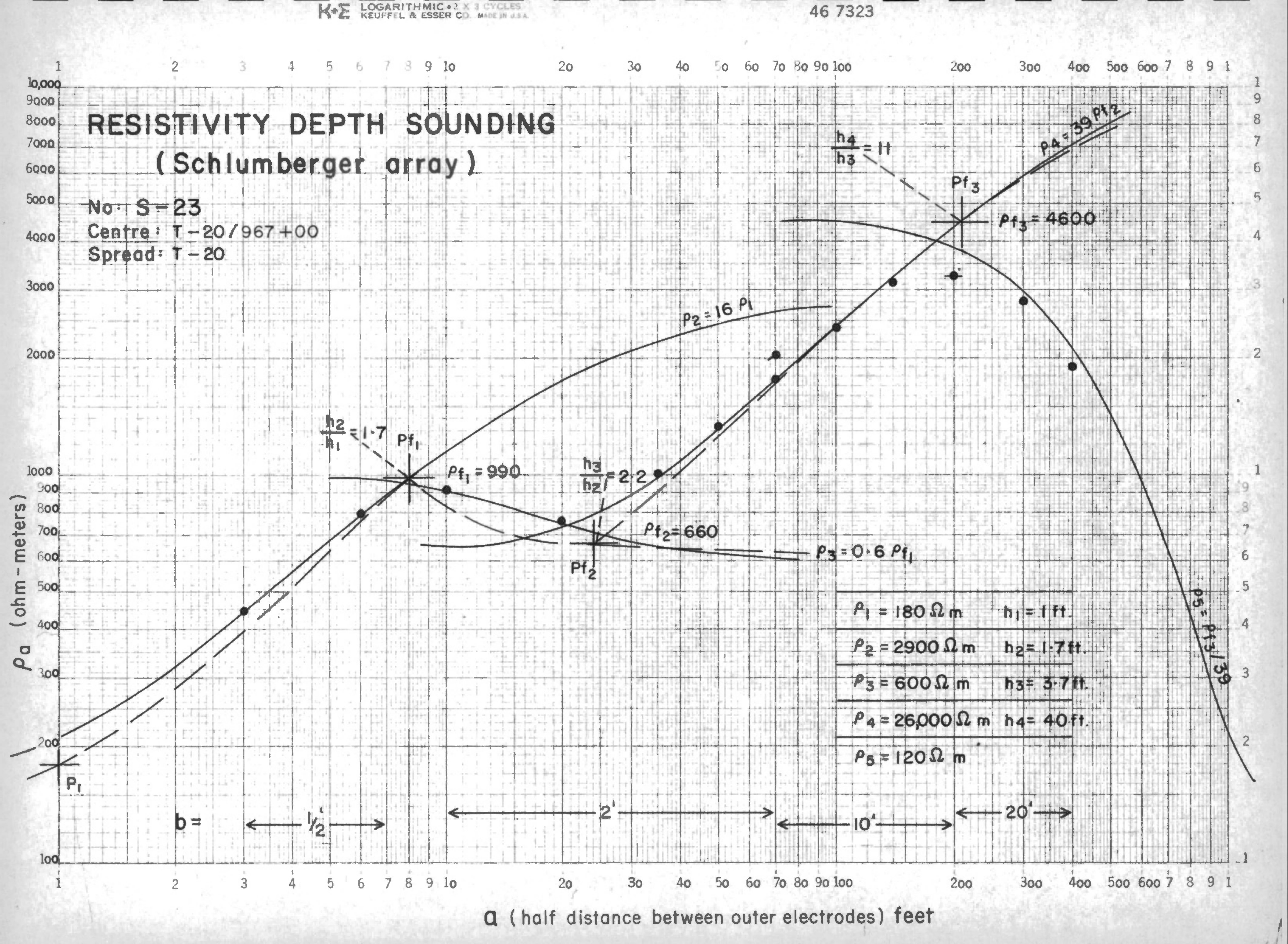
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-16
Centre: 310/10+00
Spread: on road
ρ_1 = 54 Ωm h_1 = 1.9 ft.
ρ_2 = 1800 Ωm h_2 = 190 ft.
ρ_3 = ≤ 54 Ωm
$\frac{h_2}{h_1}$ = 100
P_{f_1}
ρ_{f_1} = 1580
ρ_2 = 34 ρ_1
ρ_3 = ρ_{f_1}/81
P_1
D =
1/2'
2'
10'
20'
ρ_a (ohm-meters)
a (half distance between outer electrodes) feet

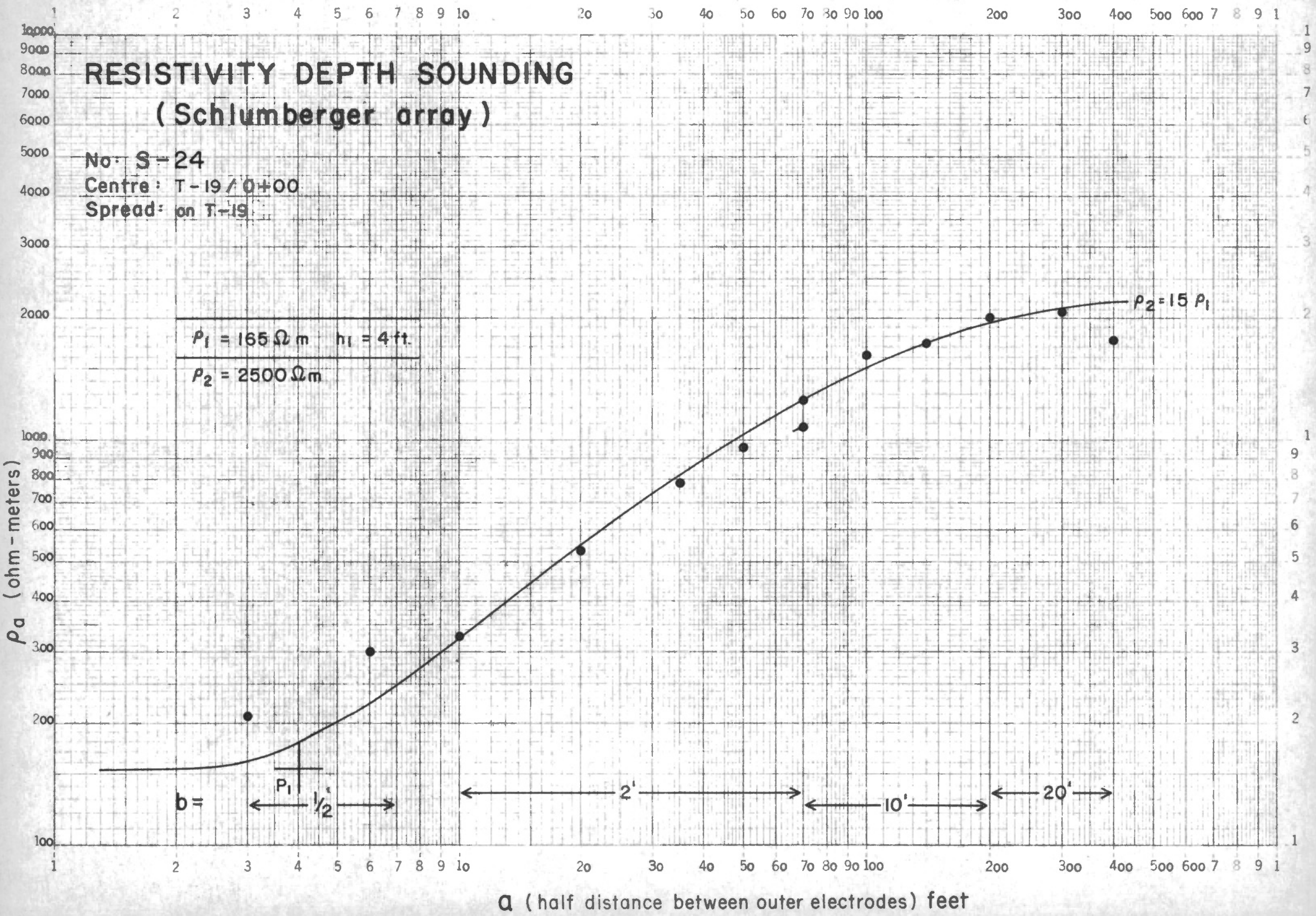


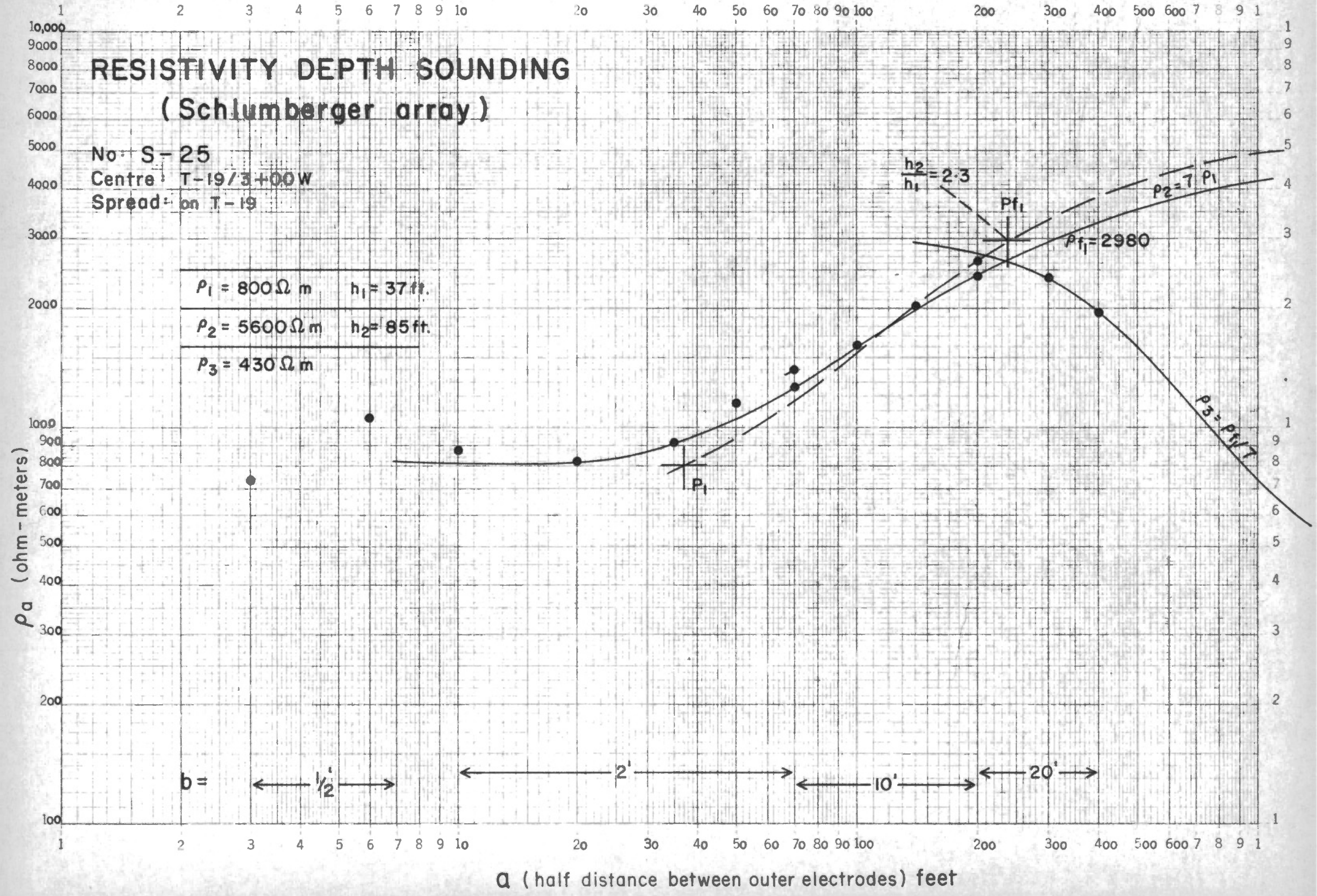
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-21
Centre: T-20/970+00
Spread: on T-20
ρ1 = 136 Ω m   h1 = 3 ft.
ρ2 = 2900 Ω m   h2 = 330 ft.
ρ3 = ≪ ρ2
h2/h1 = 110
Pf1
ρf1 = 2800
ρ2 = 21 ρ1
ρ3 = ≪ ρ2
b = P1
1/2'
2'
10'
20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet



RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-22
Centre: T-20 / 973+00
Spread: on T-20
ρ_1 = 224 Ω m h_1 = 9·8 ft.
ρ_2 = 4900 Ω m h_2 = 196 ft.
ρ_3 = << ρ_2
h_2/h_1 = 20
h_2/h_1 = 18
ρ_2 = 81 ρ_1
ρ_2 = 22 ρ_1
P_{f_1}
ρ_{f_1} = 6600
ρ_3 = ρ_{f_1}/19
Alternate
ρ_1 = 238 Ω m h_1 = 21 ft.
ρ_2 = 19,000 Ω m h_2 = 380 ft.
ρ_3 = << ρ_2
P_1
P_1 (alt)
b = ½' 2' 10' 20'
ρ_a (ohm-meters)
a (half distance between outer electrodes) feet


K+E LOGARITHMIC • 2 X 3 CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 7323
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-23
Centre: T-20/967+00
Spread: T-20
ρ_a (ohm-meters)
a (half distance between outer electrodes) feet
$\frac{h_2}{h_1} = 1.7$
Pf_1
$\rho f_1 = 990$
$\rho_2 = 16\rho_1$
$\frac{h_3}{h_2} = 2.2$
$\rho f_2 = 660$
Pf_2
$\rho_3 = 0.6\rho f_1$
$\frac{h_4}{h_3} = 11$
Pf_3
$\rho f_3 = 4600$
$\rho_4 = 39\rho f_2$
$\rho_5 = \rho f_3/39$
P_1
b = $1/2'$ $2'$ $10'$ $20'$
$\rho_1 = 180\,\Omega m$ $h_1 = 1$ ft.
$\rho_2 = 2900\,\Omega m$ $h_2 = 1.7$ ft.
$\rho_3 = 600\,\Omega m$ $h_3 = 3.7$ ft.
$\rho_4 = 26{,}000\,\Omega m$ $h_4 = 40$ ft.
$\rho_5 = 120\,\Omega m$


RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-24
Centre: T-19/0+00
Spread: on T-19
ρ_1 = 165 Ω m h_1 = 4 ft.
ρ_2 = 2500 Ω m
ρ_2 = 15 ρ_1
P_1
b = 1/2   2'   10'   20'
ρ_a (ohm-meters)
a (half distance between outer electrodes) feet
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
1 2 3 4 5 6 7 8 9 10 20 30 40 50 60 70 80 90 100 200 300 400 500 600 7 8 9 1



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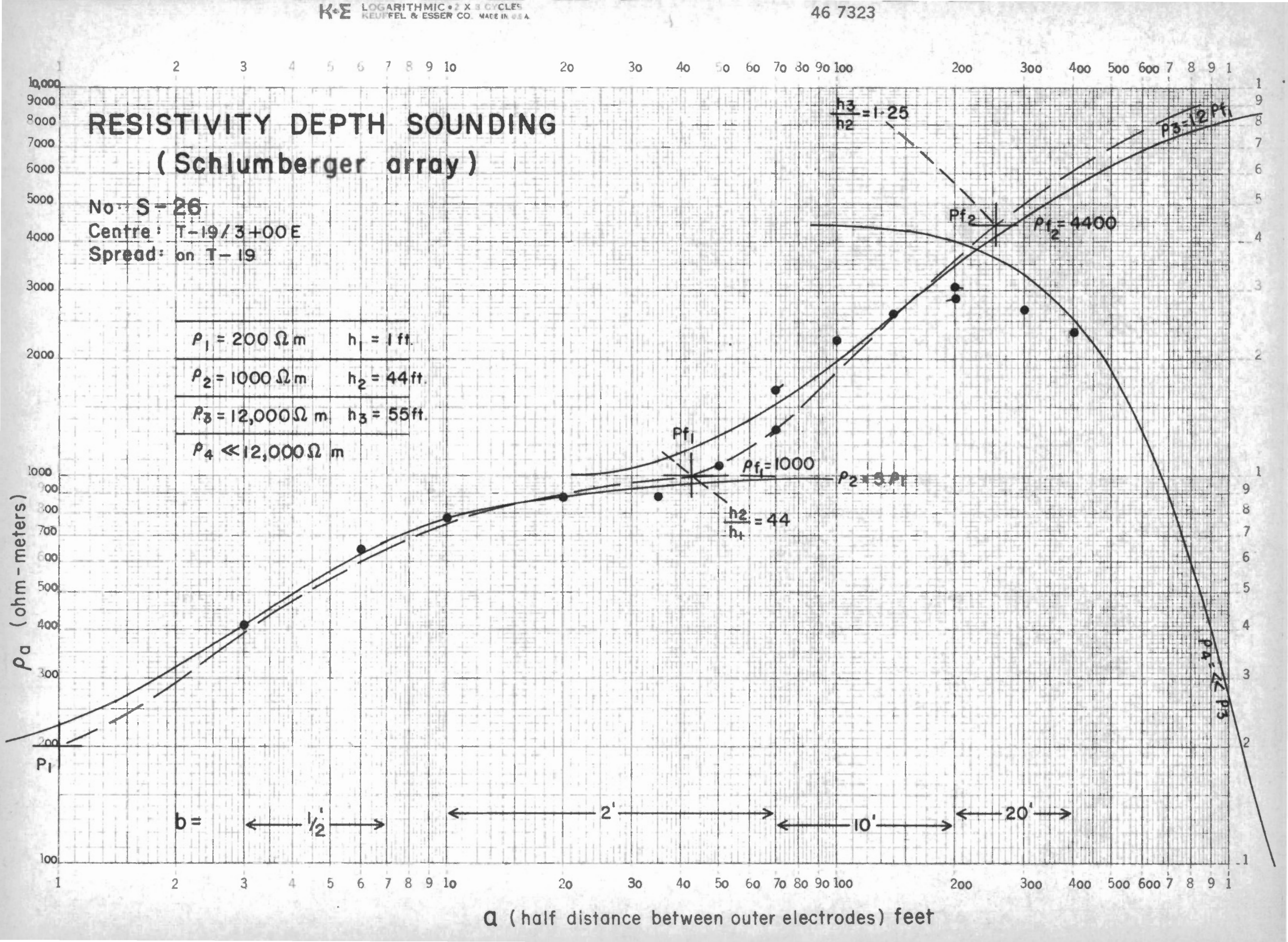
46 7323
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-25
Centre: T-19/3+00W
Spread: on T-19
ρ1 = 800 Ω m   h1 = 37 ft.
ρ2 = 5600 Ω m   h2 = 85 ft.
ρ3 = 430 Ω m
h2/h1 = 2·3
Pf1
ρf1 = 2980
ρ2 = 7 ρ1
ρ3 = ρf1/7
P1
b =
1/2'
2'
10'
20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet



K+E LOGARITHMIC 2 X 3 CYCLES KEUFFEL & ESSER CO. MADE IN U.S.A.
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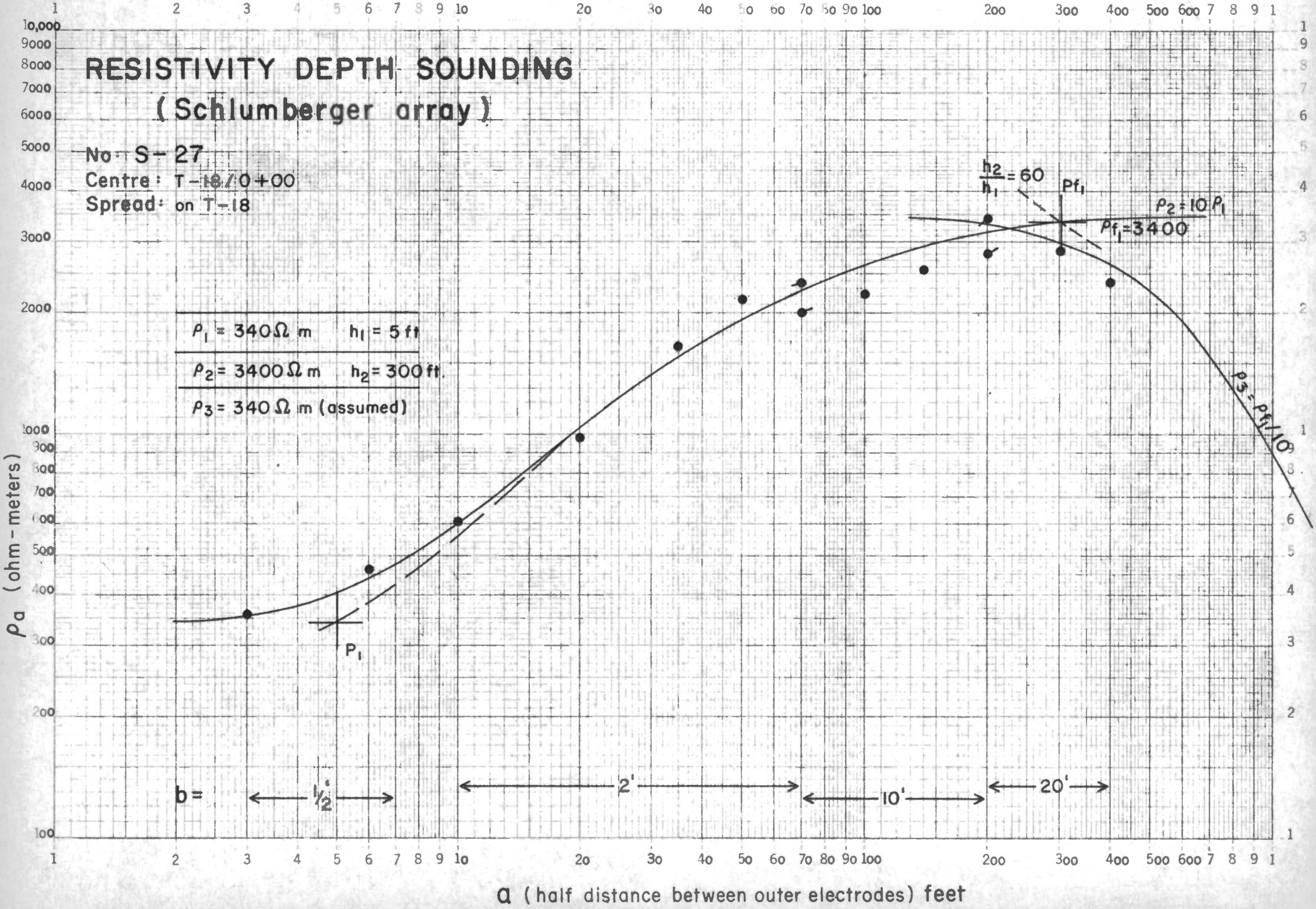
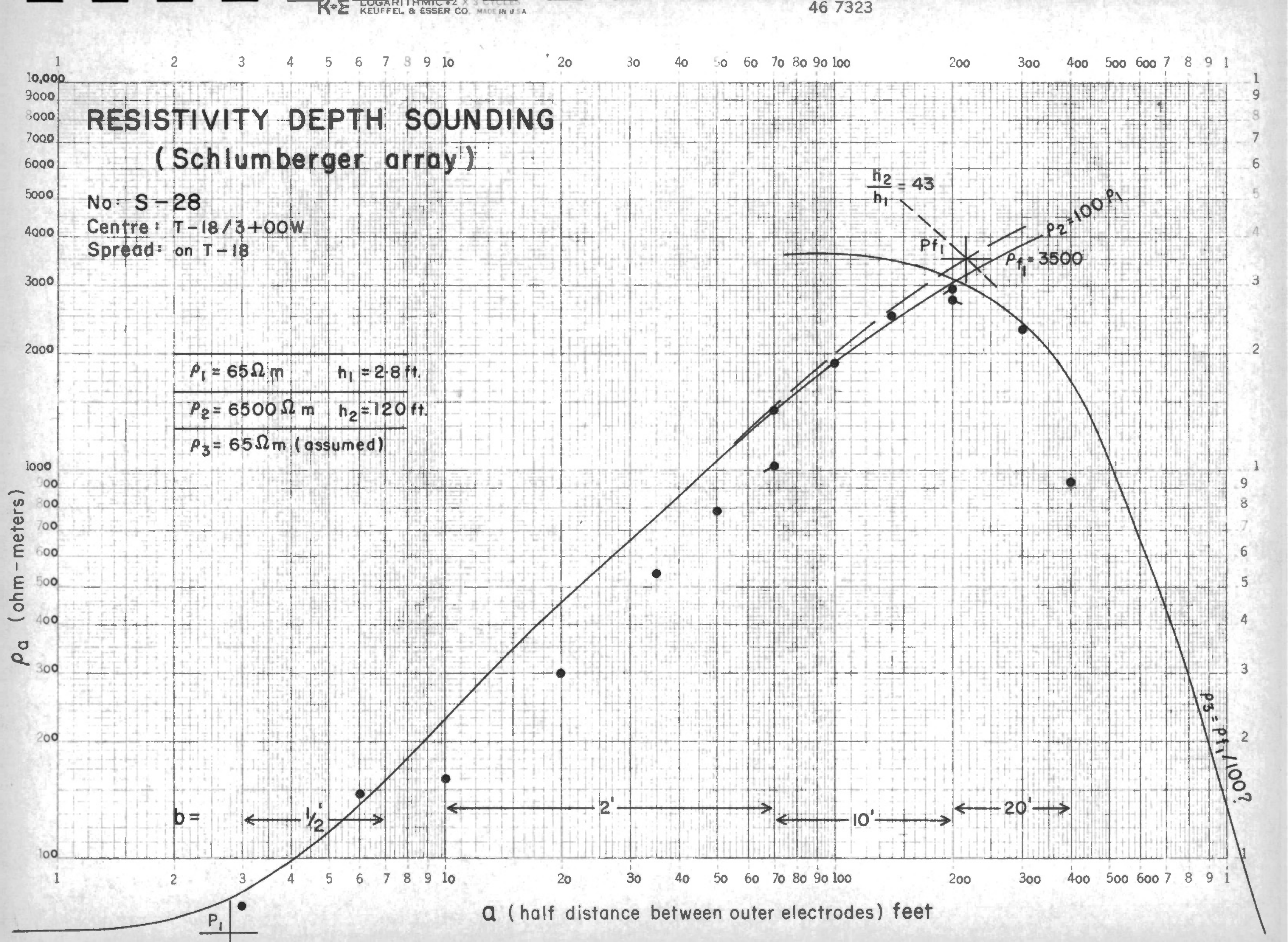
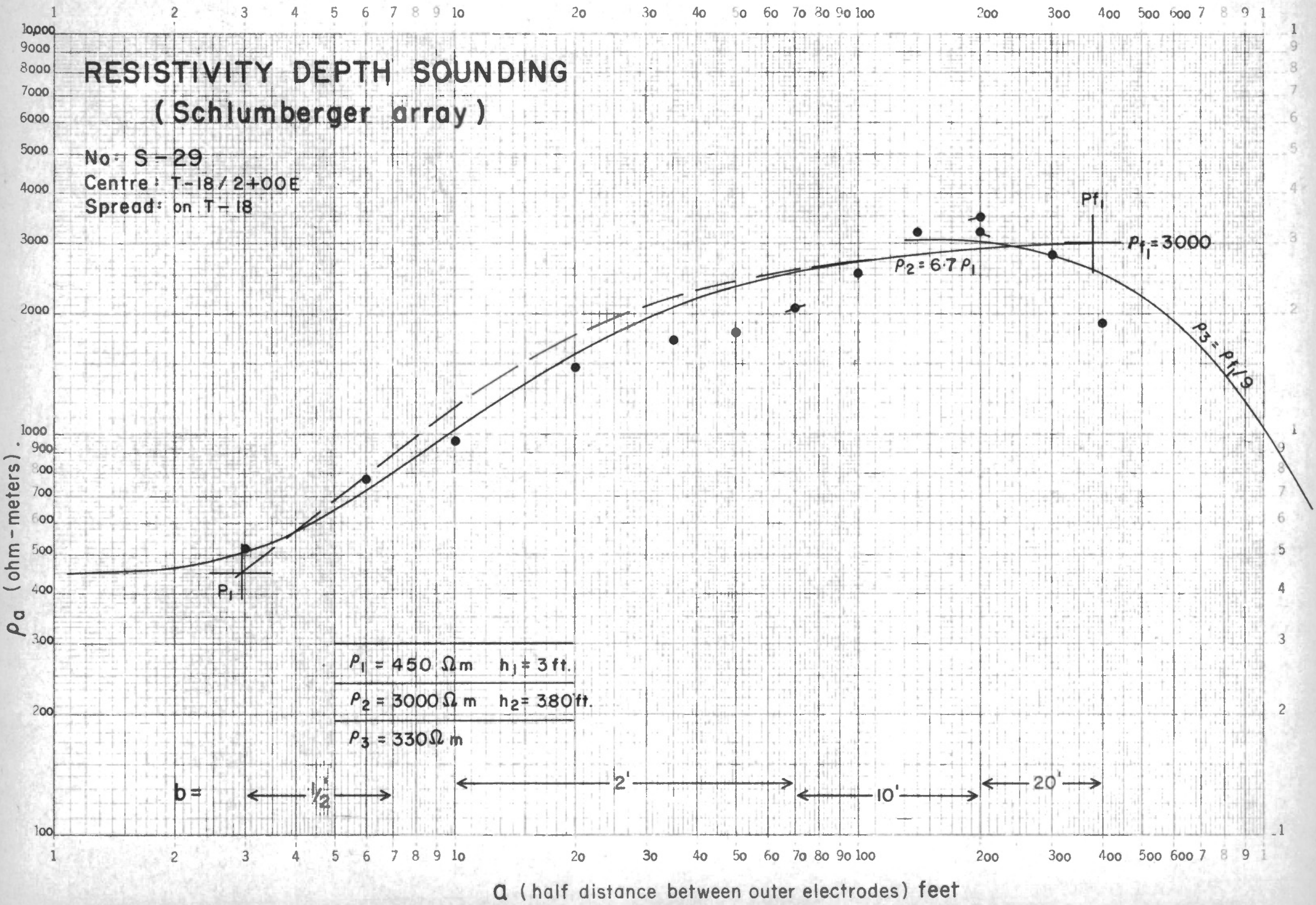
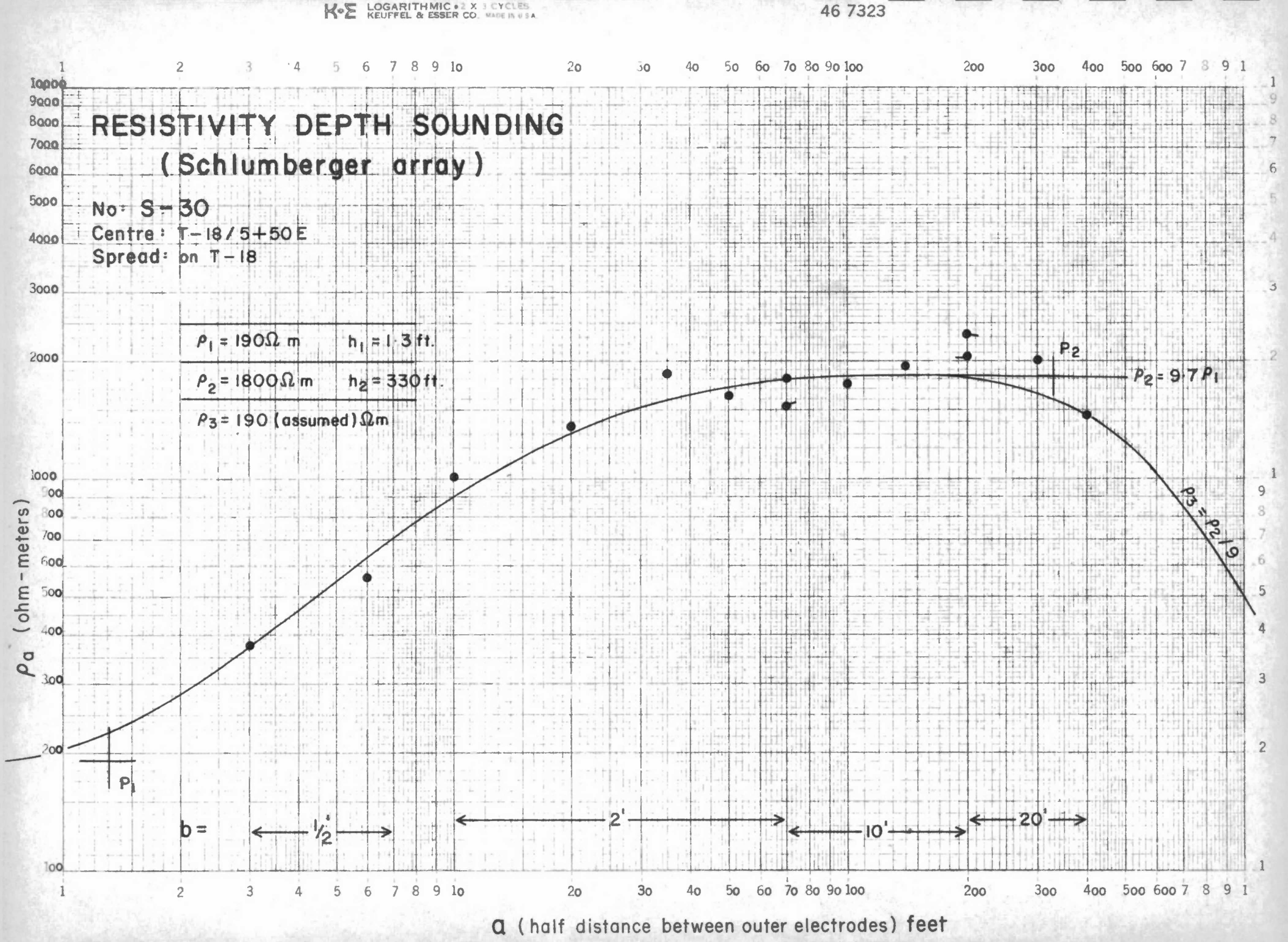
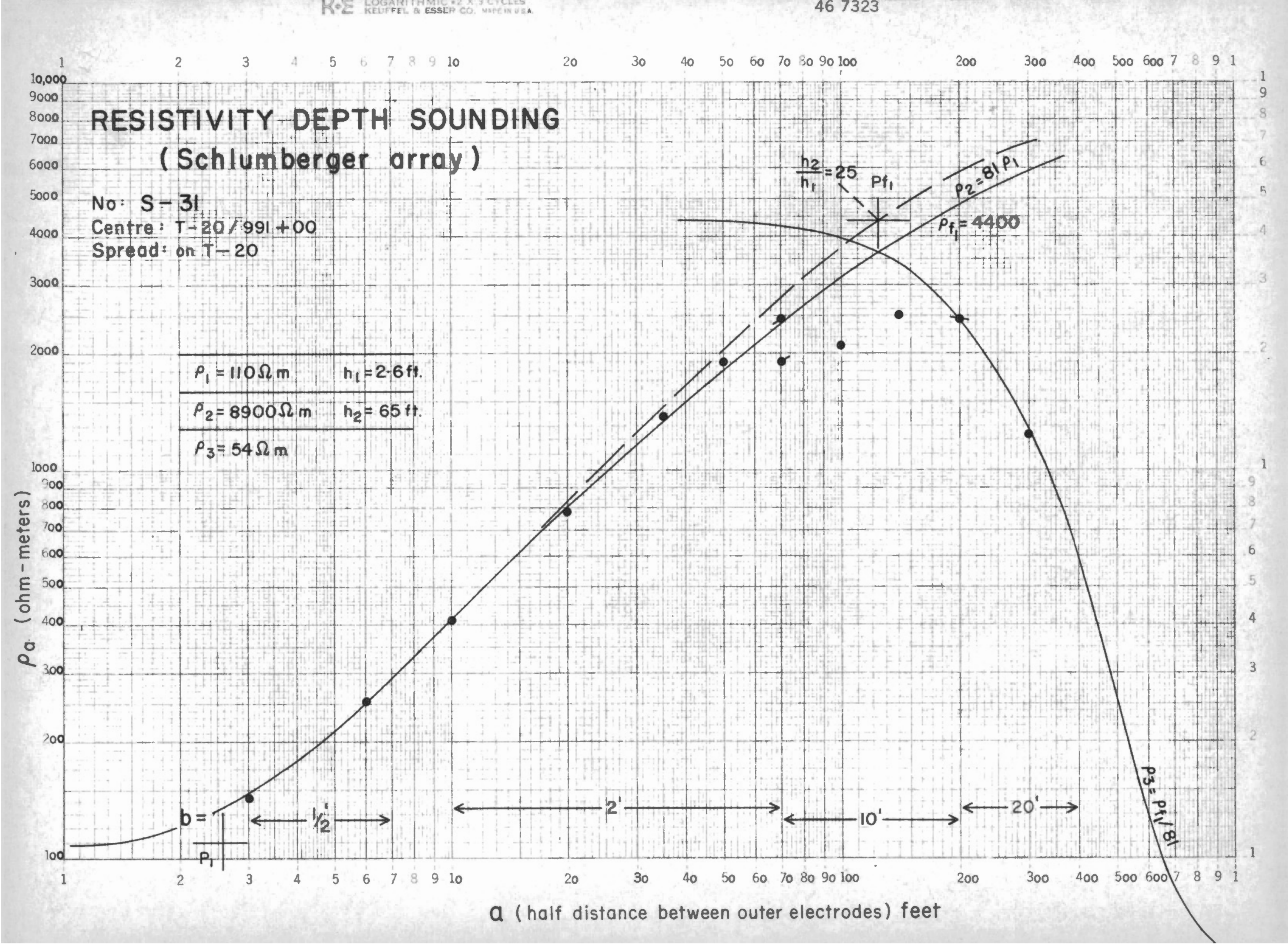
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-26
Centre: T-19/3+00E
Spread: on T-19
ρ1 = 200 Ω m   h1 = 1 ft.
ρ2 = 1000 Ω m   h2 = 44 ft.
ρ3 = 12,000 Ω m   h3 = 55 ft.
ρ4 ≪ 12,000 Ω m
h3/h2 = 1·25
ρ3 = 12 ρf1
Pf2
ρf2 = 4400
Pf1
ρf1 = 1000
ρ2 = 5 ρ1
h2/h1 = 44
ρ4 ≪ ρ3
P1
b =
1/2'
2'
10'
20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet


RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-27
Centre: T-18/0+00
Spread: on T-18
ρ_1 = 340 Ω m h_1 = 5 ft
ρ_2 = 3400 Ω m h_2 = 300 ft.
ρ_3 = 340 Ω m (assumed)
$\frac{h_2}{h_1}$ = 60
Pf_1
$\rho_2 = 10\,\rho_1$
ρf_1 = 3400
$\rho_3 = \rho f_1/10$
P_1
b = 1/2' 2' 10' 20'
ρ_a (ohm-meters)
a (half distance between outer electrodes) feet


K+E LOGARITHMIC #2 X 3 CYCLES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 7323
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-28
Centre: T-18/3+00W
Spread: on T-18
ρ_1 = 65 Ω m h_1 = 2.8 ft.
ρ_2 = 6500 Ω m h_2 = 120 ft.
ρ_3 = 65 Ω m (assumed)
$\frac{h_2}{h_1}$ = 43
ρ_2 = 100 ρ_1
P_{f_1}
ρ_{f_1} = 3500
ρ_3 = ρ_{f_1}/100?
b = ½' 2' 10' 20'
P_1
ρ_a (ohm-meters)
a (half distance between outer electrodes) feet


RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-29
Centre: T-18/2+00E
Spread: on T-18
Pf1
ρf1 = 3000
ρ2 = 6.7 ρ1
ρ3 = ρf1/9
P1
ρ1 = 450 Ωm h1 = 3 ft.
ρ2 = 3000 Ωm h2 = 380 ft.
ρ3 = 330 Ωm
b = ½ 2' 10' 20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet


K+E LOGARITHMIC 2 X 3 CYCLES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 7323
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-30
Centre: T-18/5+50E
Spread: on T-18
ρ1 = 190Ω m   h1 = 1·3 ft.
ρ2 = 1800Ω m   h2 = 330 ft.
ρ3 = 190 (assumed) Ωm
P2
ρ2 = 9·7 ρ1
ρ3 = ρ2/9
P1
b =
1/2'
2'
10'
20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet



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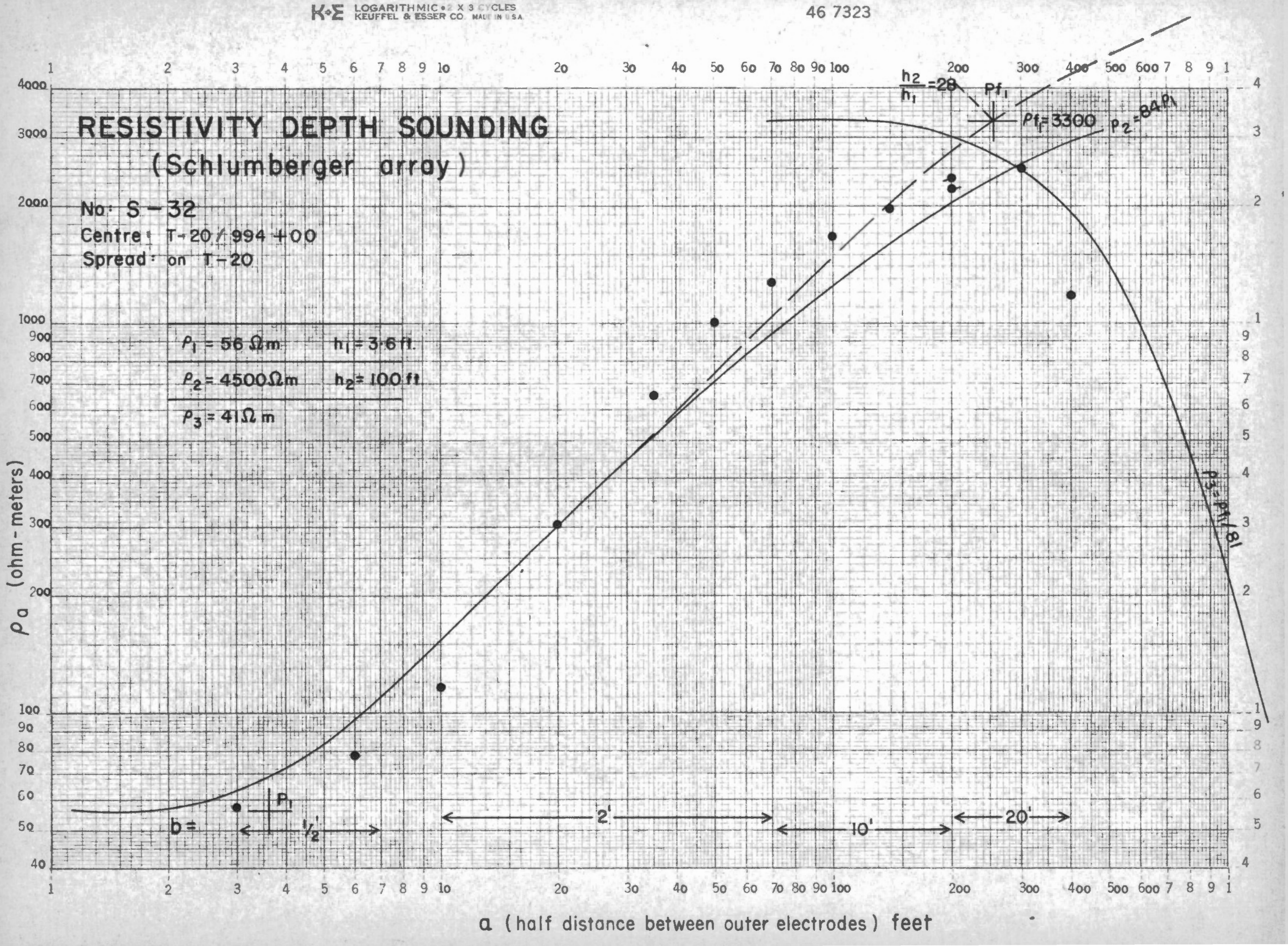
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-31
Centre: T-20/991+00
Spread: on T-20
$\rho_1 = 110\,\Omega m$ $h_1 = 2.6$ ft.
$\rho_2 = 8900\,\Omega m$ $h_2 = 65$ ft.
$\rho_3 = 54\,\Omega m$
$\frac{h_2}{h_1} = 25$
Pf_1
$\rho_2 = 81\,\rho_1$
$\rho_{f_1} = 4400$
$\rho_3 = \rho_{f_1}/81$
b =
P_1
1/2'
2'
10'
20'
ρ_a (ohm-meters)
a (half distance between outer electrodes) feet



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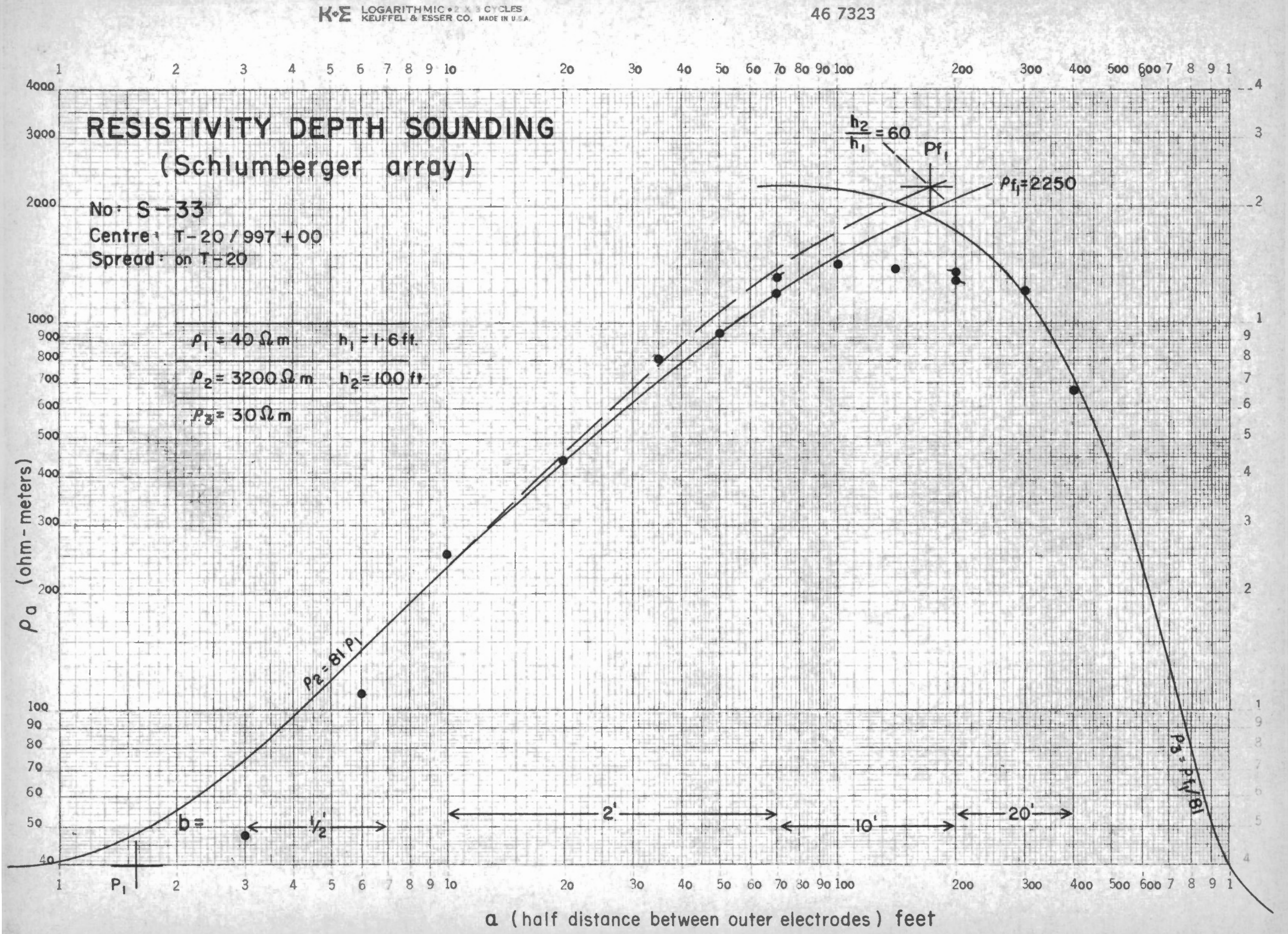
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-32
Centre: T-20/994+00
Spread: on T-20
ρ1 = 56 Ωm
h1 = 3·6 ft.
ρ2 = 4500 Ωm
h2 = 100 ft
ρ3 = 41 Ω m
h2/h1 = 28
ρf1
ρf1 = 3300
ρ2 = 84ρ1
ρ3 = ρf1/81
ρ1
b =
1/2'
2'
10'
20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet



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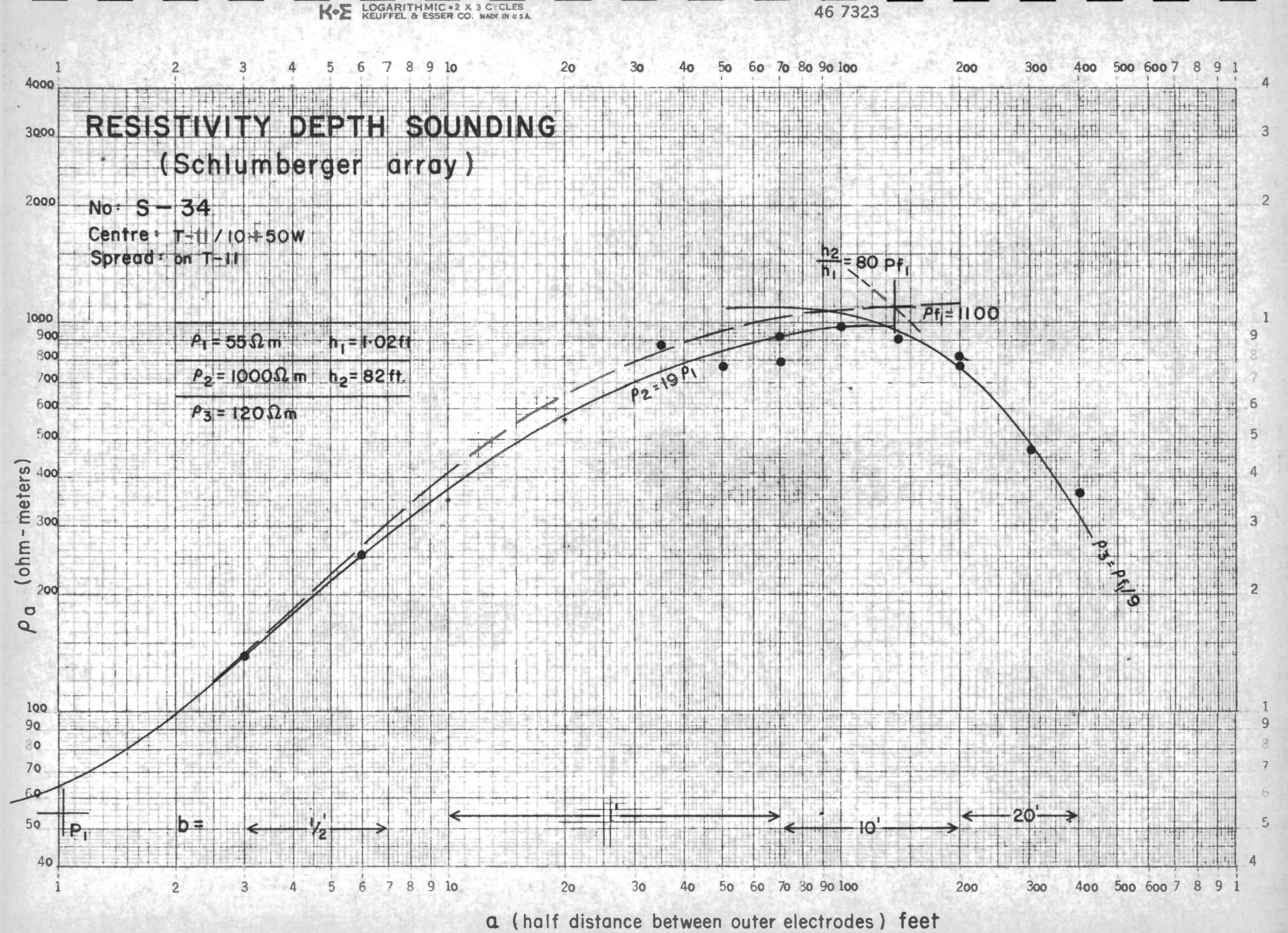
46 7323
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-33
Centre: T-20 / 997 + 00
Spread: on T-20
ρ1 = 40 Ωm   h1 = 1·6 ft.
ρ2 = 3200 Ωm   h2 = 100 ft
ρ3 = 30 Ωm
h2/h1 = 60
Pf1
ρf1 = 2250
ρ2 = 81 ρ1
ρ3 = ρf1/81
b =
1/2'
2'
10'
20'
P1
ρa (ohm-meters)
a (half distance between outer electrodes) feet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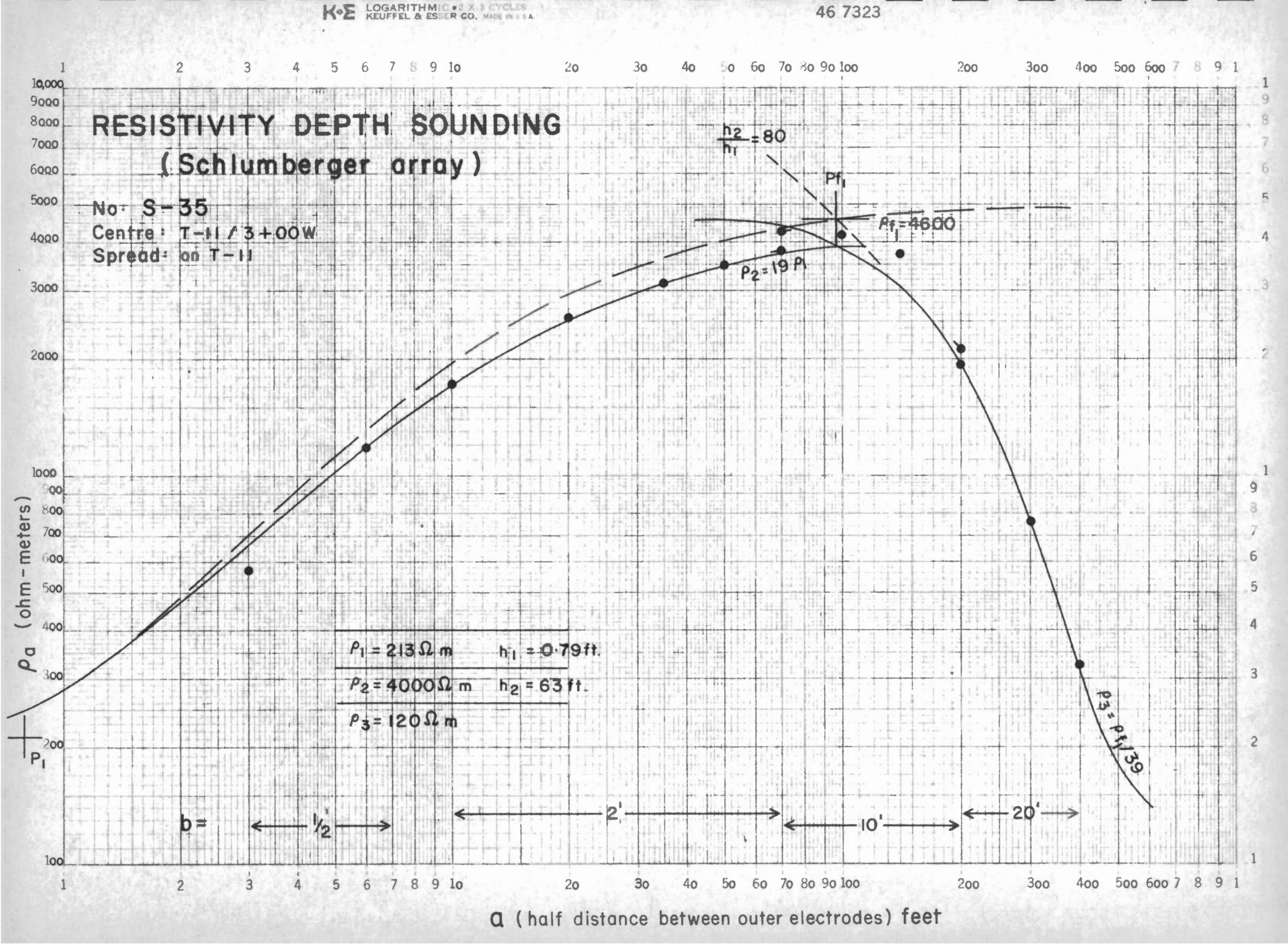
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 7323
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S – 34
Centre: T-11/10+50W
Spread: on T-11
ρ_1 = 55 Ω m h_1 = 1·02 ft
ρ_2 = 1000 Ω m h_2 = 82 ft.
ρ_3 = 120 Ω m
$\frac{h_2}{h_1}$ = 80 P_{f_1}
ρ_{f_1} = 1100
ρ_2 = 19 ρ_1
ρ_3 = ρ_{f_1}/9
P_1
b = ½' 1' 10' 20'
ρ_a (ohm-meters)
a (half distance between outer electrodes) feet



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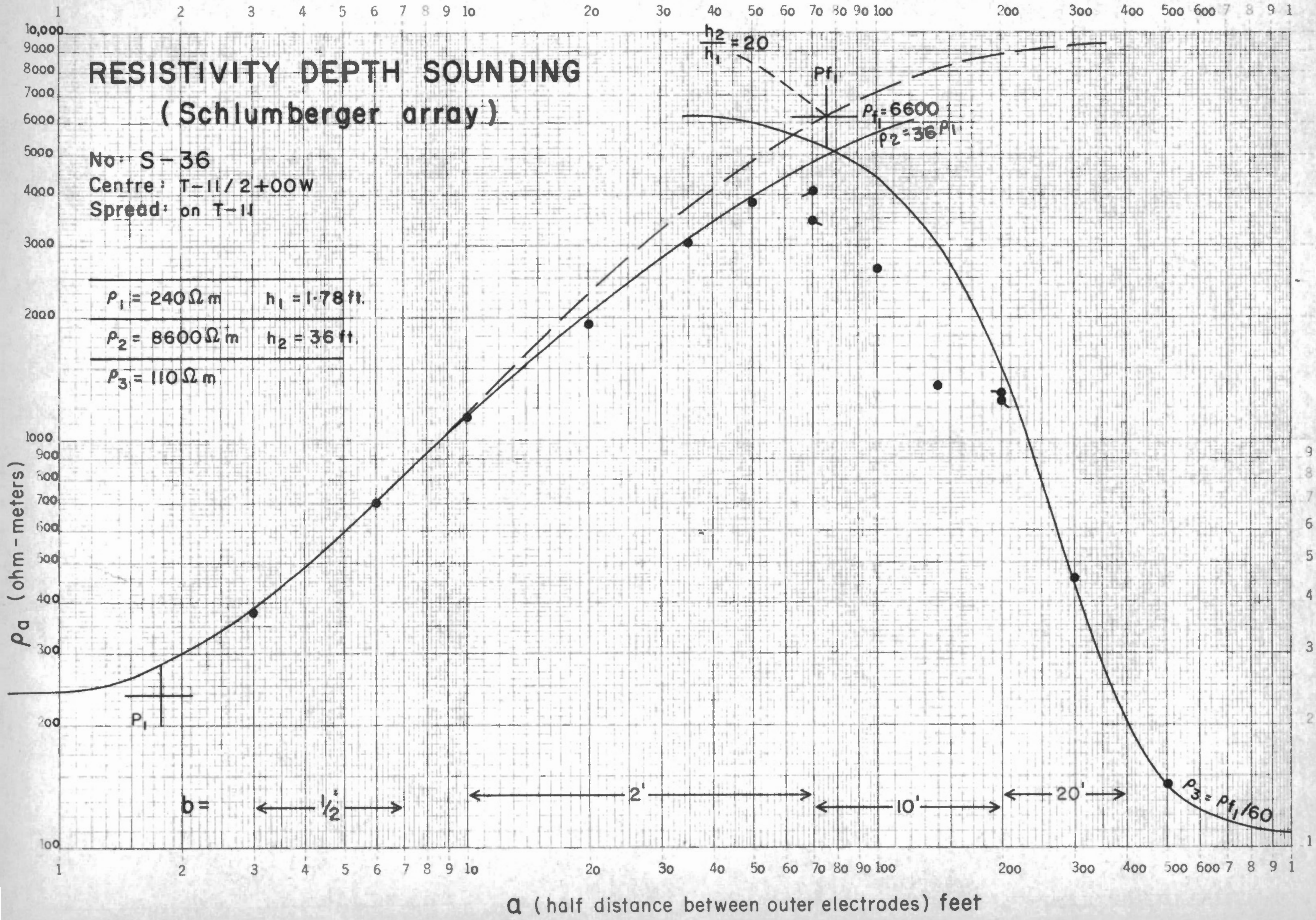
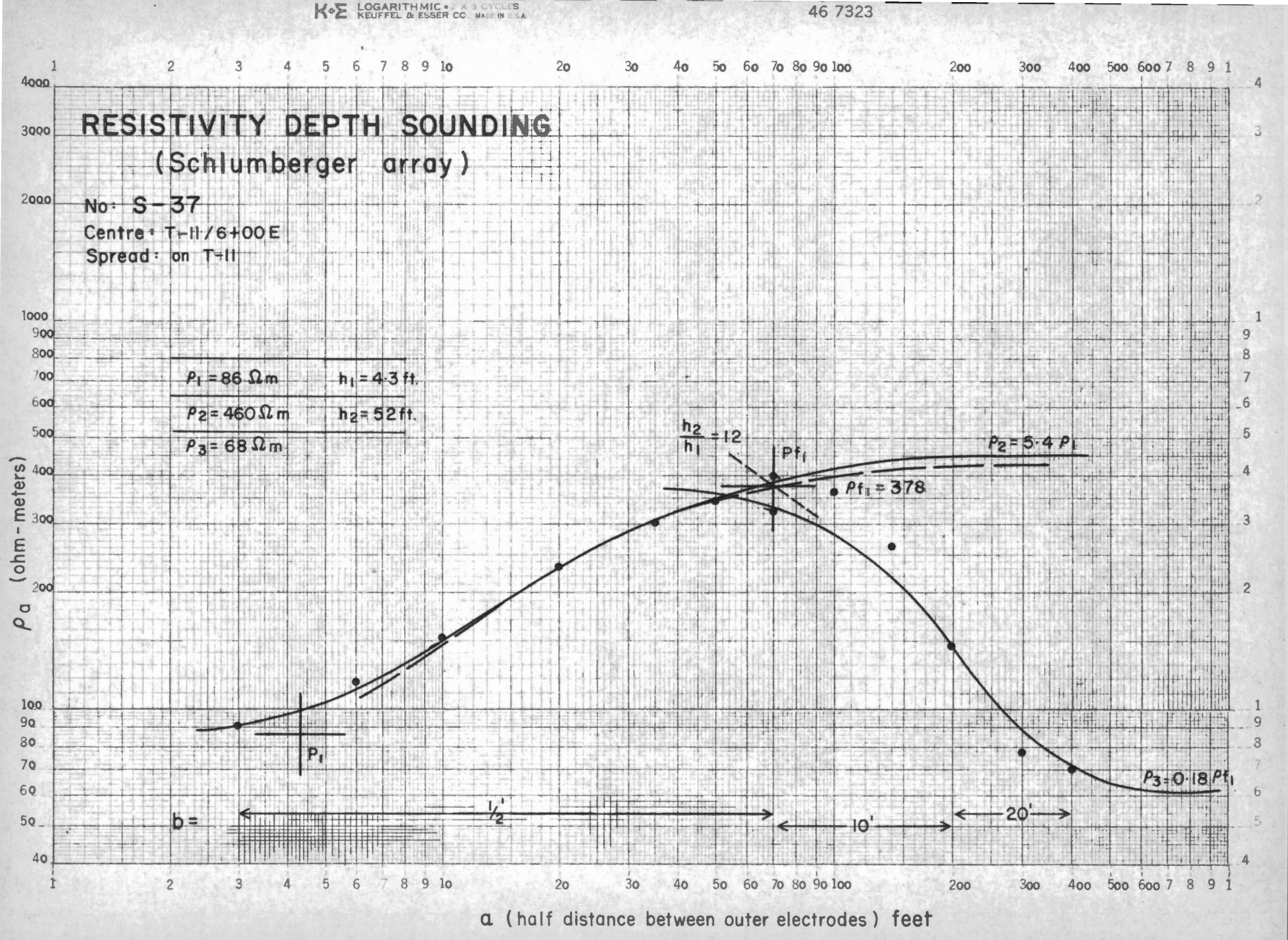
46 7323
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-35
Centre: T-11 / 3+00W
Spread: on T-11
h2/h1 = 80
Pf1
ρf1 = 4600
ρ2 = 19 ρ1
ρ1 = 213 Ω m
h1 = 0·79 ft.
ρ2 = 4000 Ω m
h2 = 63 ft.
ρ3 = 120 Ω m
ρ3 = ρf1/39
P1
b =
1/2'
2'
10'
20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet



RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-36
Centre: T-11/2+00W
Spread: on T-11
ρ_1 = 240 Ω m h_1 = 1·78 ft.
ρ_2 = 8600 Ω m h_2 = 36 ft.
ρ_3 = 110 Ω m
h_2/h_1 = 20
Pf_1
ρ_{f_1} = 6600
$\rho_2 = 36\rho_1$
P_1
$\rho_3 = \rho_{f_1}/60$
b = ½' 2' 10' 20'
ρ_a (ohm-meters)
a (half distance between outer electrodes) feet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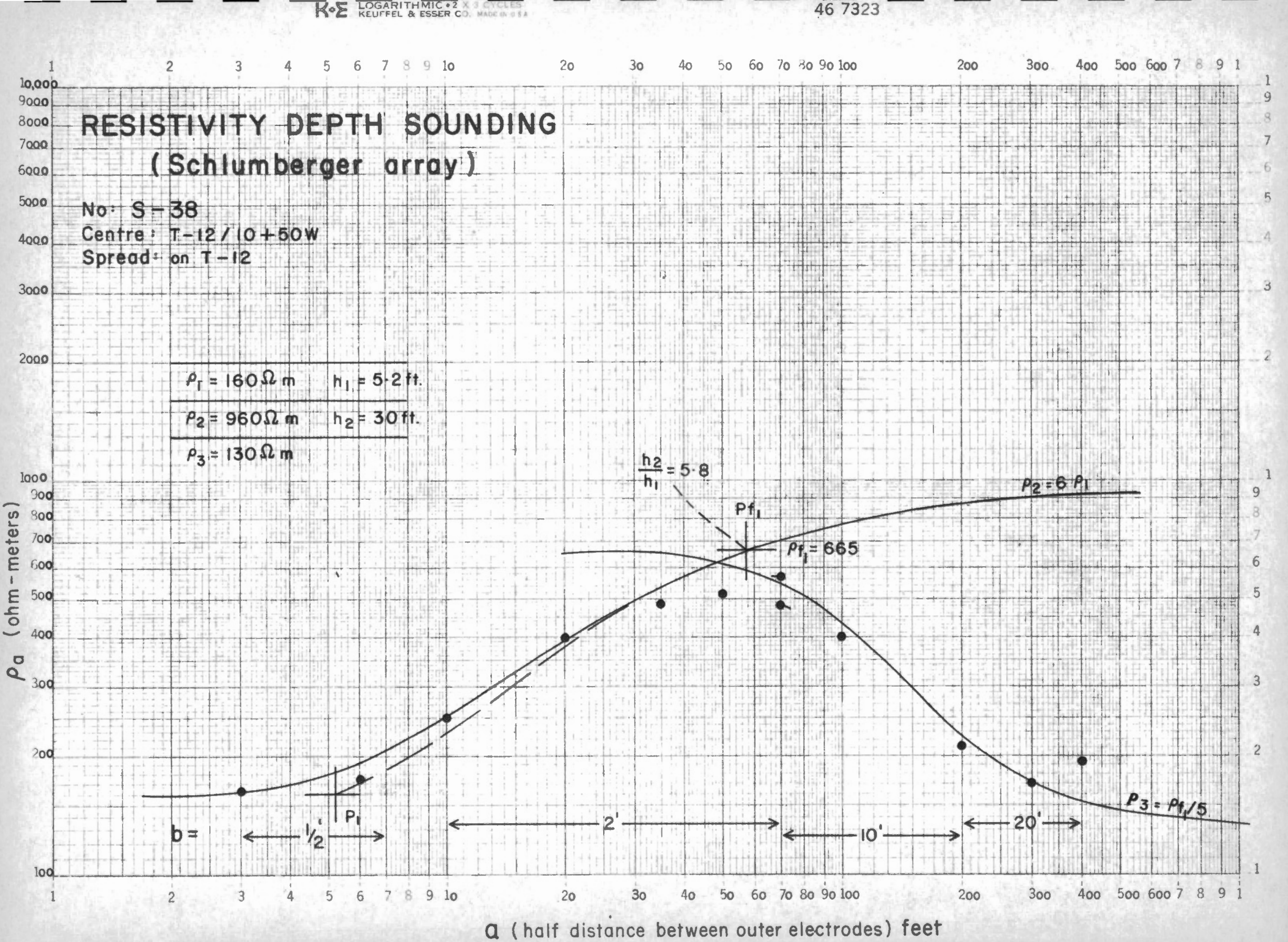
46 7323
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-37
Centre: T-11/6+00E
Spread: on T-11
ρ1 = 86 Ωm h1 = 4.3 ft.
ρ2 = 460 Ωm h2 = 52 ft.
ρ3 = 68 Ωm
h2/h1 = 12
Pf1
ρf1 = 378
ρ2 = 5.4 ρ1
ρ1
ρ3 = 0.18 ρf1
b =
1/2'
10'
20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet



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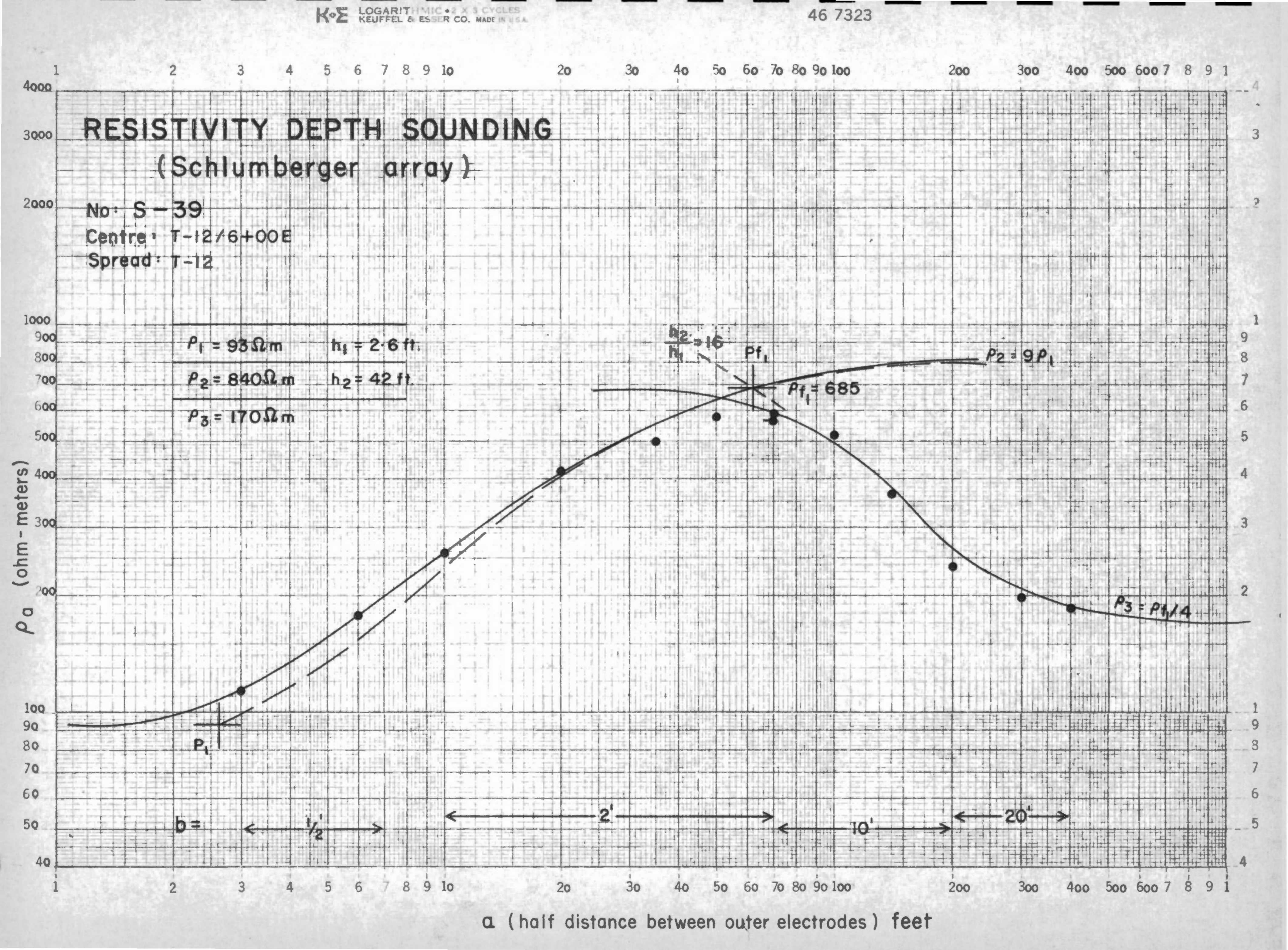
46 7323
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-38
Centre: T-12 / 10+50W
Spread: on T-12
ρ1 = 160 Ω m
h1 = 5·2 ft.
ρ2 = 960 Ω m
h2 = 30 ft.
ρ3 = 130 Ω m
h2/h1 = 5·8
Pf1
ρf1 = 665
ρ2 = 6 ρ1
ρ3 = ρf1/5
P1
b =
1/2
2'
10'
20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet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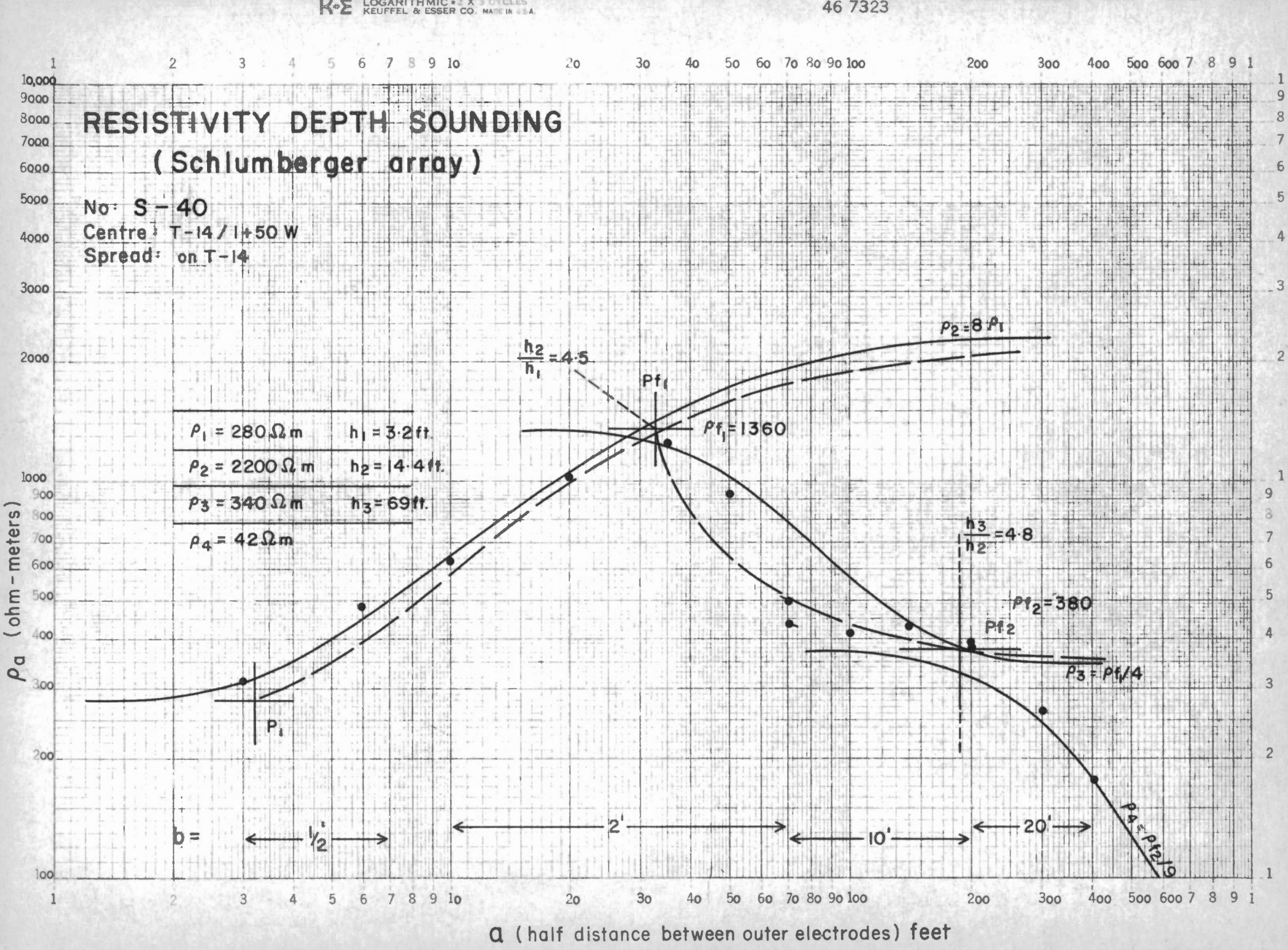
46 7323
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-39
Centre: T-12/6+00E
Spread: T-12
ρ1 = 93Ωm h1 = 2·6 ft.
ρ2 = 840Ωm h2 = 42 ft.
ρ3 = 170Ωm
h2/h1 = 16
Pf1
ρf1 = 685
ρ2 = 9ρ1
ρ3 = ρf1/4
P1
b = 1/2' 2' 10' 20'
ρa (ohm-meters)
a (half distance between outer electrodes) feet



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46 7323
RESISTIVITY DEPTH SOUNDING
(Schlumberger array)
No: S-40
Centre: T-14 / 1+50 W
Spread: on T-14
ρ_1 = 280 Ω m h_1 = 3·2 ft.
ρ_2 = 2200 Ω m h_2 = 14·4 ft.
ρ_3 = 340 Ω m h_3 = 69 ft.
ρ_4 = 42 Ω m
$\frac{h_2}{h_1}$ = 4·5
$P f_1$
ρf_1 = 1360
$\rho_2 = 8\rho_1$
$\frac{h_3}{h_2}$ = 4·8
ρf_2 = 380
$P f_2$
$\rho_3 = \rho f_1/4$
$\rho_4 = \rho f_2/9$
P_1
b = ← 1/2 → ← 2' → ← 10' → ← 20' →
ρ_a (ohm-meters)
a (half distance between outer electrodes) feet

TABLE I

INTERPRETATION OF RESISTIVITY SOUNDINGS

Sounding	Location	Layer thicknesses (feet) h_1	h_2	Layer resistivities (ohm-meters) ρ_1	ρ_2	ρ_3
S-1	306, 0+00	15	30	280	23,000	⩽280
S-2	310, 10+00	4.4	119	55	4,500	⩽55
S-3	T-1, 3+20S	4.6	44	118	2,000	130
S-4	T-4, 1+00M	3.1	37	315	2,100	87
S-5	T-7, 0+70N	47	-	50	27	-
S-6	T-6, 0+50S	5.0	30	67	390	95
S-7	T-6, 8+00S	1.6	16	34	2,800	51
S-8	T-6, 1+00S	2.0	5.0	100	1,050	25
		h_3 10	h_4 230	ρ_4= 340	ρ_5 = 51	
S-9	T-5, 2+00S	0.58	160	107	2,000	107
S-10	T-2, 3+50N	2.1	21	72	1,100	42
S-11	C.L. 615+00	0.8	18	110	2,100	49
S-12	T-2, 0+00	5.6	12	530	4,800	48
S-13	C.L. 643+00	7.5	60	1,110	2,100	79
S-14	C.L. 668+50	64	-	1,300	68	-
S-15	308, 37+00	3.4	68	64	2,200	73
S-16	310, 10+00 (south side of road)	1.9	190	54	1,800	⩽54
S-21	T-20, 970+00	3	330	136	2,900	$\ll \rho_2$
S-22	T-20, 973+00	9.8	196	224	4,900	$\ll \rho_2$
S-23	T-20, 967+00	1	1.7	180	2,900	600
		h_3 = 3.7	h_4 = 40	ρ_4=26,000	ρ_5 = 120	
S-24	T-19, 0+00	4	-	165	2,500	-
S-25	T-19, 3+00W	37	85	800	5,600	430
S-26	T-19, 3+00E	1	44	200	1,000	12,000
		h_3= 55		$\rho_4 \ll$12,000		
S-27	T-18, 0+00	5	300	340	3,400	340?
S-28	T-18, 3+00W	2.8	120	65	6,500	65?
S-29	T-18, 2+00E	3.0	380	450	3,000	330
S-30	T-18, 5+50E	1.3	330	190	1,800	190?

TABLE I

- 2 -

Sounding	Location	Layer thicknesses (feet)		Layer resistivities (ohm-meters)		
S-31	T-20, 991+00	2.6	65	110	8,900	54
S-32	T-20, 994+00	3.6	100	56	4,500	41
S-33	T-20, 997+00	1.6	80-110	40	3,200	30
S-34	T-11, 10_50W	1.02	82	55	1,000	120
S-35	T-11, 3+00W	0.79	63	213	4,000	120
S-36	T-11, 2+00W	1.78	36	240	8,600	110
S-37	T-11, 6+00E	4.3	52	86	460	68
S-38	T-12, 10+50W	5.2	30	160	960	130
S-39	T-12, 6+00E	2.6	42	93	840	170
S-40	T-14, 1+50W	3.2	18	280	2,200	160?

S-3 Good fit.

S-4 Small anomalous potential effect for b of 10 feet. Curve fit considered fair to good.

S-5 Some scatter but reasonably good two-layer fit. No indication of permafrost.

S-6 Reasonably good fit.

S-7 Good fit.

S-8 The point density is not adequate for five layers and accuracy of the interpreted values is quite low.

S-9 Edge effects make ρ_2 a minimum value.

S-10 Good fit.

S-11 Fair fit in scattered points.

S-12 Fair to good fit.

S-13 For a = 300 feet the recorded value lies above the general trend. If corrected by a factor of three, on the assumption that the wrong instrument scale factor was written down for this reading, the points fits the general trend very closely and a good fit of the interpretation curves can be achieved.

S-14 Good fit to two-layer case.

S-15 Edge effects for a = 300 and 400 feet.

S-16 Probable edge effect for a = 400 feet.

S-21 Third-layer not well defined, h_2 a minimum value.

S-22 Anomalous potential effect may be present for the b = 2 feet readings and two alternate interpretations are possible. In either case the third layer is barely visible and h_2 is certainly a minimum, if present at all.

S-23 A very complex curve and point density is not really adequate for proper definition of all layers.

S-24 Good fit, two layers

S-25 For this fit the values for a = 3 feet and 6 feet were assumed scattered and ρ_1 was chosen as 800 ohm-metres. The rest of the fit is good except that ρ_3 is uncertain owing to too few points at that end.

S-26 Fair fit.

S-27 Good fit for upper layers. ρ_3 is assumed = ρ_1 and h_2 is a minimum value.

S-28 Edge effect, h_2 minimum and ρ_3 assumed = ρ_1

S-29 Fair fit. h_2 is minimum.

S-30 Some scatter but essentially a good fit. h_2 is minimum.

S-31 Good fit for first two layers.

S-32 The points form a smooth curve but are too steep for even the maximum resistivity contrast ($\rho_2 = \infty$). This indicates a smooth departure from a layered case, possibly a bowl shaped interface between the first and second layers.

The best fit was obtained using the maximum contrast curve ($\rho_2 = 81 \rho_1$) which should give correct depth averaged along the surface. The a = 400 feet value may be an edge effect and so h_2 is a minimum value.

S-33 Like S-32 the early part of the curve is steeper than the maximum resistivity contrast so curvey made to fit later points.

S-34 Good fit.

S-35 Good fit.

S-36 Fair to good fit.

S-37 Good fit.

S-38 Excellent fit except for possible edge effect for a = 400 feet.

S-39 Excellent fit.

S-40 Fair fit to four-layer case.

4.2.4 Profiles

Mile 305/0-8

A short segment of high velocity material is seen centred at 6 + 00 and is interpreted as an unfrozen bedrock since the resistivity profile remains comparatively smooth and below 100 ohm-metres.

Mile 305-8 to 41

Medium velocity and a uniform resistivity profile varying between 100 and 300 ohm-metres are interpreted as dry layers of granular material with no permafrost present.

305-41 to 306-3

A high velocity layer is present in this section ranging from 8,500 to 12,500 feet per second in velocity. The apparent resistivity shows a slight increase compared to the dry material to the south. The high velocity layer is interpreted as bedrock which is probably frozen as indicated by the three-layer interpretation of Sounders S-1 and S-3.

Mile 306

There is fair correlation between resistivity and velocity for

1,000 feet on either side of the Martin River indicating permafrost in this stretch. Velocities alone indicate thin lenses of permafrost at 42 + 00. A number of layers of low velocity and low resistivity material lie from 5 + 00 to 12 + 00 which are interpreted as dry granular loose sand.

306/50 to 307/42

A smooth resistivity profile varying slowly from 100 to 300 ohm-metres and several layers of low velocity material indicate layers of a dry unfrozen granular material, probably sand.

307/43 to 307/49

Permafrost clearly indicated by velocities and resistivities. Sounder S-4 indicates a thickness of 37 feet and a depth to top of 3.1 feet.

The EM-16 phase angle is above the 45 degree neutral datum for these first three miles indicating a high resistivity layer overlying a low resistivity layer. This is contrary to what the sounders show but may possibly be explained as a few inches of dry surface material overlying a thin perched water table of low resistivity.

In mile 308 four zones of permafrost are indicated by both resistivity and velocities. S-15 at 308/37 shows it to be 3.4 feet deep and 68 feet thick. From 308/12 to 20, between to frozen zones the apparent resistivity decreases to a uniform 40-50 ohm-metres which is probably the value most typical of unfrozen clay in this area.

For the rest of the highway centre line to mile 315 the profiles show stretches of uniformly low resistivity and water-table velocities, broken by permafrost sections well defined by both velocities and sudden increases in ρ_a.

From 313/16 to 315 short stretches of a low velocity layer are seen projecting down into the medium velocity surface. They have no resistivity expression but may be pockets of soft dry sand.

The Martin River centre line diversion shows a series of short high velocity sections from 580 to 606. The velocity is in the bedrock range, 9,500 - 12,000 feet per second but the broken up nature of the surfaces suggest permafrost lenses rather than a uniform bedrock surface. The apparent resistivity supports this interpretation, ranging from 100 to 800 ohm-metres.

At 612-616 a high velocity layer (10,000 ft/sec) coincides with the third resistivity layer interpreted from S-11 and S-12 which has a ρ_3 of 48 to 49 ohm-metres. This is far too low for permafrost but could possibly be a hard shale bedrock. The middle layer is the high resistivity layer and would be interpreted as permafrost except that it is not supported by the low velocities above the bedrock. A drill hole is recommended at 615.

Permafrost or bedrock is interpreted at three places in the stretch 622 - 636.

No permafrost is indicated by velocities for the rest of the centre line diversion. However, high resistivities exist for most of the line and drill holes are recommended at S-13 and S-14 to identify the near surface high resistivity layers.

Transect 1

This transect is centred on the Martin River diversion and crosses the present road at 3 + 20 south. High but variable ρ_a (500 - 1,500 ohm-metres) and discontinuous sections of a high velocity subsurface suggest the presence of permafrost lenses from 0 + 00 to 7S. S-1 and S-3 support this, showing a high resistivity layer up to 44 feet thick. A pocket of medium-low velocity material is interpreted as dry sand at 13 south. High velocity material at the north end is believed to be bedrock.

Transect 2

Two sounders, S-10 and S-12, indicate a permafrost layer 12 to 21 feet thick and are supported by high velocities in this area. However, even higher velocities from 4N to 15N may indicate bedrock, which may or may not be frozen. Short segments of high velocity material are seen from 12S to 14S but may be a low resistivity bedrock since there is no resistivity expression.

Transect 3 was not surveyed.

Transect 4

Good correlation between apparent resistivity and high velocity sections indicates three sections of permafrost. Sounder S-4 at 1N indicates a 37 foot thickness of permafrost, having an apparent resistivity of 2,100 ohm-metres. A zone of low velocity material at the south end may be dry granular material.

Transect 5

All of this line is underlain by permafrost as shown by apparent resistivity profiles and high velocity areas that support each other. Sounder S-9 supports this interpretation at 2S but did not find the lower surface of the permafrost. A depression of the permafrost surface is seen lying under the road at the centre of the transect. This is to be expected where the insulating organic cover is scraped off to provide a firm base for the road subgrade. A sharp depression between 4S and 7S into the high velocity material contains medium velocity material and shows a low resistivity expression in the Wenner profile. This is interpreted as an unfrozen layer of clay and occurs farther south at 14S as well. One of these areas is recommended for confirmation by drilling.

Transect 6

Permafrost is seen for a short section from 1S to 2N and from 6N to 16N, indicated both by velocity and resistivity. The sounders S-6 and S-8 show complex results with true resistivities no higher than 390 ohm-metres (S-6) but these are believed distorted by the absence of a true layered case at this particular location. A broad smooth resistivity high of 400 to 500 ohm-metres stretching from 58 to 12S overlies only medium velocities and permafrost is not expected here. Sounder S-7 indicates 16 feet of high resistivity material which in this case is interpreted as coarse dry granular material, possibly gravel. A drill hole at 8S would be useful to confirm this interpretation.

Transect 7

Two very prominent apparent resistivity highs lie towards each end of this transect. There is very little seismic expression of either one of them, although short high velocity segments appear scattered through the time distance curves in these general areas. It is possible that a mass of permafrost lenses exists which are barely detectable by the seismic waves but together form a noticeable change in bulk resistivity. The EM-16 data from 7S to 12S indicates a low resistivity layer lying under a dry surface layer and this hardly supports the interpretation. To add to the uncertainty of the interpretation on this transect, a depression in the medium velocity layer occurs at the centre underneath the road subgrade much the same as in Transect 5 which would suggest that the medium velocity layer of 5,000 feet per second may be frozen. Three drill holes are recommended on this transect. To attempt to answer these questions, located at 9S, 0 + 00, and 10N.

Transects 8, 9 and 10 were not surveyed.

Willowlake River Area

Transect 11

The entire west half of this transect is underlain by high velocity material ranging from 9,000 to 12,000 feet per second. The apparent resistivity varies between 500 and 2,000 ohm-metres but decreases noticeably at the eastern boundary of this section, 2 + OOE. Three sounders indicate from 36 to 82 feet of high resistivity material ranging from 1,000 to 8,600 ohm-metres, which overlies a third layer of low resistivity (120 ohm-metres). This middle layer is confidently interpreted as permafrost. East of 2 + OOE the resistivity decreases to less than 500 ohm-metres and the velocity changes to a range between 6,500 and 7,500 feet per second. Sounder S-37 shows a second layer of only 590 ohm-metres. This would suggest a different kind of permafrost or at least a different material which is partially or completely frozen. Drilling is recommended to identify these two types of material preferably at 6 + OOE and at 3 + OOW.

Transect 12

Permafrost is interpreted as underlying the entire transect to within 5 feet of surface except from 1W to 8W where its upper surface appears to move downwards and is covered by a medium velocity material, possibly dry sand. This would appear to be similar material to the east portion of Transect 11 since the sounder

S-39 showed the middle layer to have a resistivity of only 840 ohm-metres. A drill hole is recommended at S-39 and S-38.

Transect 13

This transect lies on the side of a steep hill where bedrock outcrops were observed. A high velocity layer ranging from 7,500 to 13,000 feet per second underlies the entire line and this is believed to be the bedrock surface which may or may not be frozen. The apparent resistivity ranges from 200 to 500 ohm-metres over most of the line and would suggest that the bedrock is not frozen in this stretch. At the west end it increases to over 1,000 ohm-metres which may indicate some permafrost at this end.

Transect 14

A high velocity layer and a high apparent resistivity section go hand in hand to indicate permafrost from 6W to 12E . Expander S-40 confirms this interpretation, showing a thickness of 18 feet of a 2,200 ohm-meter material. This is one of the few profiles in which the EM-16 information supports this interpretation, where from 4W to 4E a high resistivity layer is indicated lying over a lower resistivity layer.

Transect 15

A high velocity layer underlies almost all of this line but has absolutely no resistivity expression except at the last few stations at the east end. This high velocity layer is interpreted as an unfrozen bedrock of low resistivity, possibly shale.

Transect 16

A high velocity and high resistivity layer extend from the eastern end to about 5W on this transect and is interpreted as permafrost. At the west end of the line a thick layer of low velocity and low resistivity material may be dry granular material.

Transect 17

This line is underlain by an unusually high velocity and resistivity material which is interpreted as a hard bedrock, probably limestone. The EM-16 phase angle is well below 45 degrees indicating a conductive surface layer overlying a resistive sub layer. Whether or not the bedrock is frozen cannot be determined from this data.

Transect 18

Four resistivities sounders give good resistivity control on this line. They were done in a stretch of the profile which showed a uniform resistivity level of 2,000 - 3,000 ohm-metres. All four expanders detected a subsurface layer of between 3,000 and 6,500 ohm-metres which coincide with a high velocity surface underlying the entire line. Depression in the apparent resistivity profile at the west end coincide with depressions in this high velocity surface. It is believed that the entire line, like Transect 17, is underlain by bedrock which may or may not be frozen. Valleys in the bedrock contain a medium to high velocity material, (2E to 4E and 8E to 10E) which may be frozen unconsolidated material.

Transect 19

This line is similar to 18 and is believed underlain entirely by bedrock, frozen or unfrozen. Valleys in the bedrock appear to be filled with a medium to high velocity material which may be frozen. Drilling is recommended at 2W, 5W, and 10W to test this conclusion.

Transect 20

A bedrock having a velocity of 10 to 15,000 feet per second and a resistivity of between 2,900 and 8,900 ohm-metres is interpreted as underlying all of this line. Unlike Transect 17 the EM-16 phase angle lies above the neutral 45 degree position and indicates a conductive layer under a dry surface layer. Drilling is recommended at S22 and S32 to help identify the materials.

5. SUMMARY AND CONCLUSIONS

1. Permafrost is characterized by a sharp rise in apparent resistivity above the uniform profile of 40 to 60 ohm-metres, together with subsurface velocity of 7,500 to 9,000 feet per second. The best example of this expression is in Mile 309.

2. If dry granular material is present at surface, permafrost is more difficult to detect by measuring resistivity. Seismic velocities appear to be more diagnostic in this case, e.g. Mile 305.

3. If bedrock is present in which the velocity of sound is greater than 7,500 feet per second and whose apparent resistivity is greater than 1 or 2,000 ohm-metres it will not be able to tell whether or not it is frozen. If its resistivity is less than 500 ohm-metres it may well be unfrozen.

4. Transect 7 provides some exceptions to these rules and it is recommended that 3 holes be drilled to identify materials and resolve these differences.

6. RECOMMENDATIONS

1. A number of drill holes are recommended to test the interpretation of the geophysical results and are listed in Appendix B. This list should be considered a minimum since they are recommended for places where the interpretation was ambiguous.

2. Multispaced profiling should be considered instead of the single spacing used on this project. By using the dipole-dipole array two or more separations can be measured at very little extra cost and the data would help resolve the problem of trying to detect thin, near-surface permafrost layers at the same time as deeper layers.

3. Refraction seismic work should include small interval spreads so as to properly assess the near-surface velocities and accurately obtain depth to permafrost when under 10 feet or so. A 25-foot geophone interval as used in this survey makes it impossible to determine an accurate depth to the first refractor if it is less than 10 feet, unless the surface layer velocity is assumed.

Respectfully submitted,

TERRAQUEST SURVEYS LIMITED

Roger K. Watson, B.A.Sc., P.Eng.
Consulting Geophysicist

APPENDIX A

PERSONNEL AND DATES

Prime Contractor and Resistivity Surveys:	Terraquest Surveys Limited
Project Consultant:	Norman R. Paterson
Project Manager and Field Supervision:	Roger K. Watson
Party Chief and Principal Operator:	Chris H. Broadbent
Instrument Operators and Helpers:	D. Done
	R. Reid
	D. Passfield
Cook and line cutters.	
Seismic Survey:	J. Fulop and Associates Limited
Party Chief and Operator:	J. Fulop
Operator:	W. Jensen
Helper:	D. Done

Main Dates

Mobilization to Fort Simpson:	August 1 - 5, 1974
Martin River Area Camp Set-Up:	August 6 to 8, 1974
Survey Work:	August 9 - September 4, 1974
Move to Willowlake River:	September 5, 1974
Survey Work:	September 6 - 16, 1974
Demobilization, Fort Simpson:	September 17, 1974

Camp Location and Transport

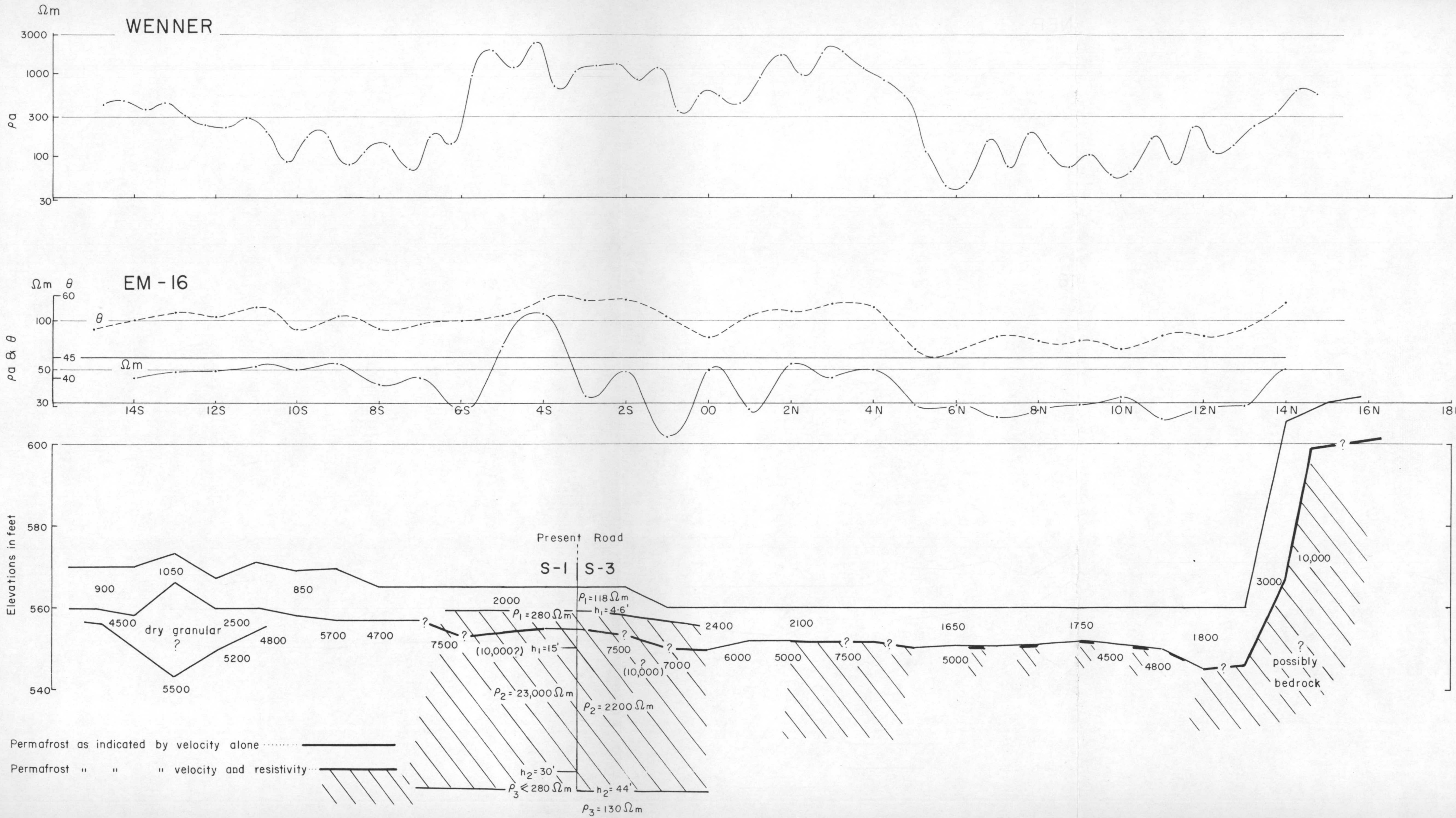
For the first part of the project a field camp was used, located at Mile 304½ on the Mackenzie Highway. The survey was accessible by 4-wheel drive truck, except the revised centre line which was accessible by foot only.

The survey crews were accommodated in the Department of Public Works Camp, near the river between Two Mountains for the second part of the project. Transportation was by helicopter and truck. The helicopter was a Bell G3B chartered from Totum Air Limited, Fort Simpson.

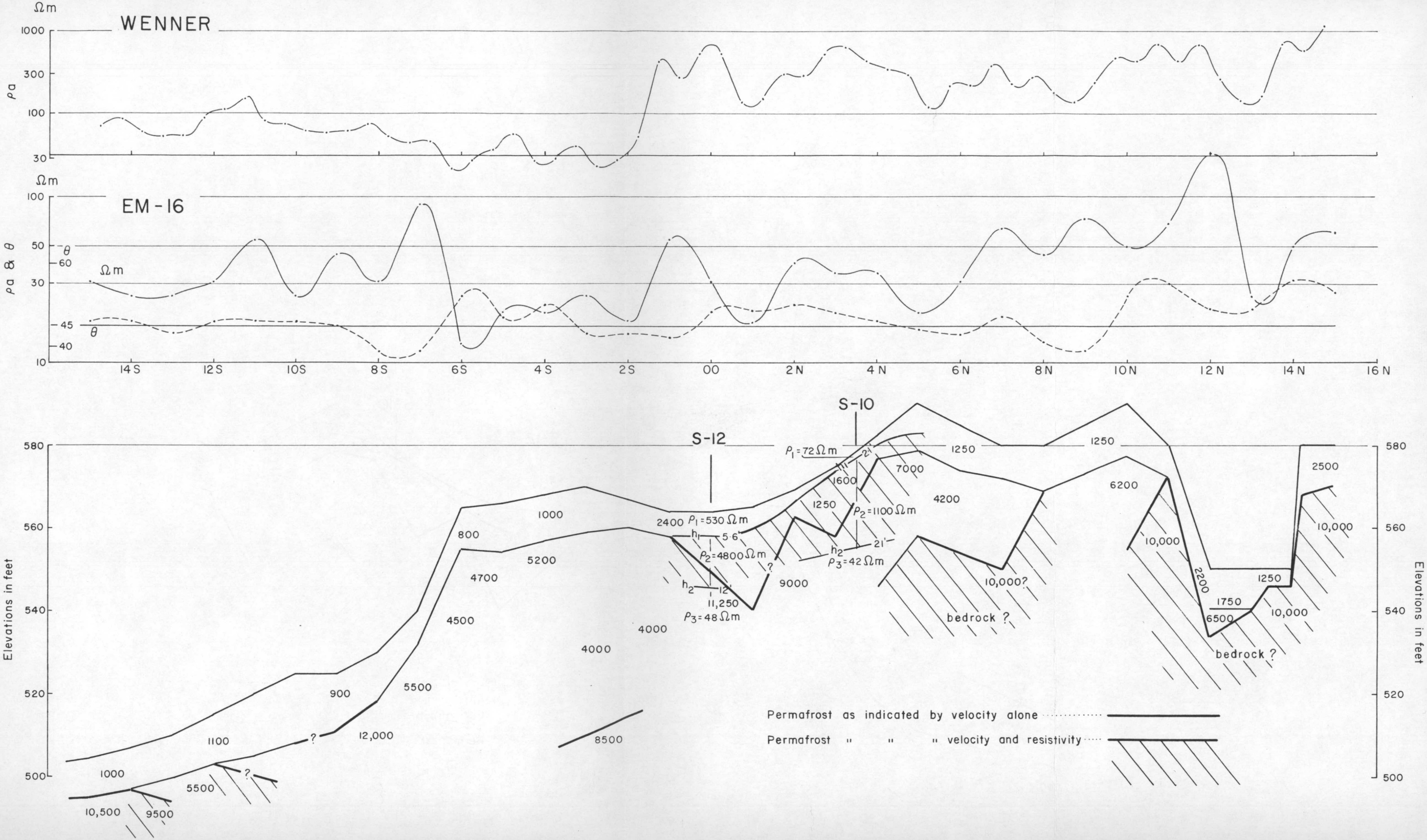
APPENDIX B

LIST OF RECOMMENDED DRILL HOLES

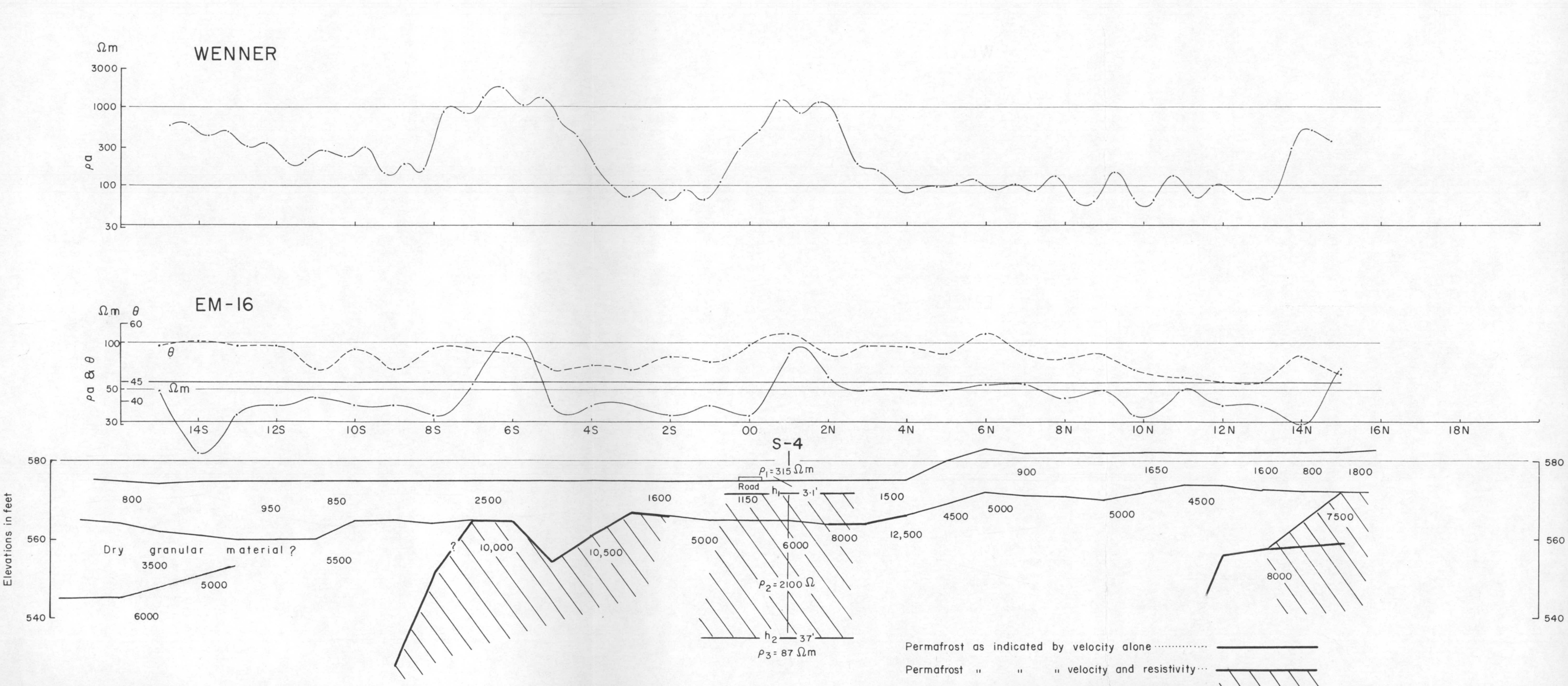
Line	station
Mile 305	between 41 and 52
Martin River diversion	615
Transect 5	5 + 50S
" 6	8 + 00S
" 7	9 + 00S, 0 + 00, 10 + 00N
" 11	6 + 00E, 3 + 00W
" 12	6 + 00E, 10 + 00W
" 19	2 + 00W, 5 + 00W, 10 + 00W
" 20	994, 973


WENNER
Ωm
3000
1000
300
100
30
ρa
EM - 16
Ωm θ
60
100
45
50
40
30
ρa & θ
θ
Ωm
14S
12S
10S
8S
6S
4S
2S
00
2N
4N
6N
8N
10N
12N
14N
16N
18N
600
580
560
540
Elevations in feet
Present Road
S-1
S-3
900
1050
850
2000
4500
dry granular
?
2500
4800
5700
4700
5200
5500
7500
(10,000?)
ρ_1 = 280 Ωm
ρ_1 = 118 Ωm
h_1 = 4.6'
h_1 = 15'
7500
(10,000)
7000
2400
2100
6000
5000
7500
1650
5000
1750
4500
4800
1800
3000
10,000
possibly
bedrock
ρ_2 = 23,000 Ωm
ρ_2 = 2200 Ωm
h_2 = 30'
$\rho_3 \leq$ 280 Ωm
h_2 = 44'
ρ_3 = 130 Ωm
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity

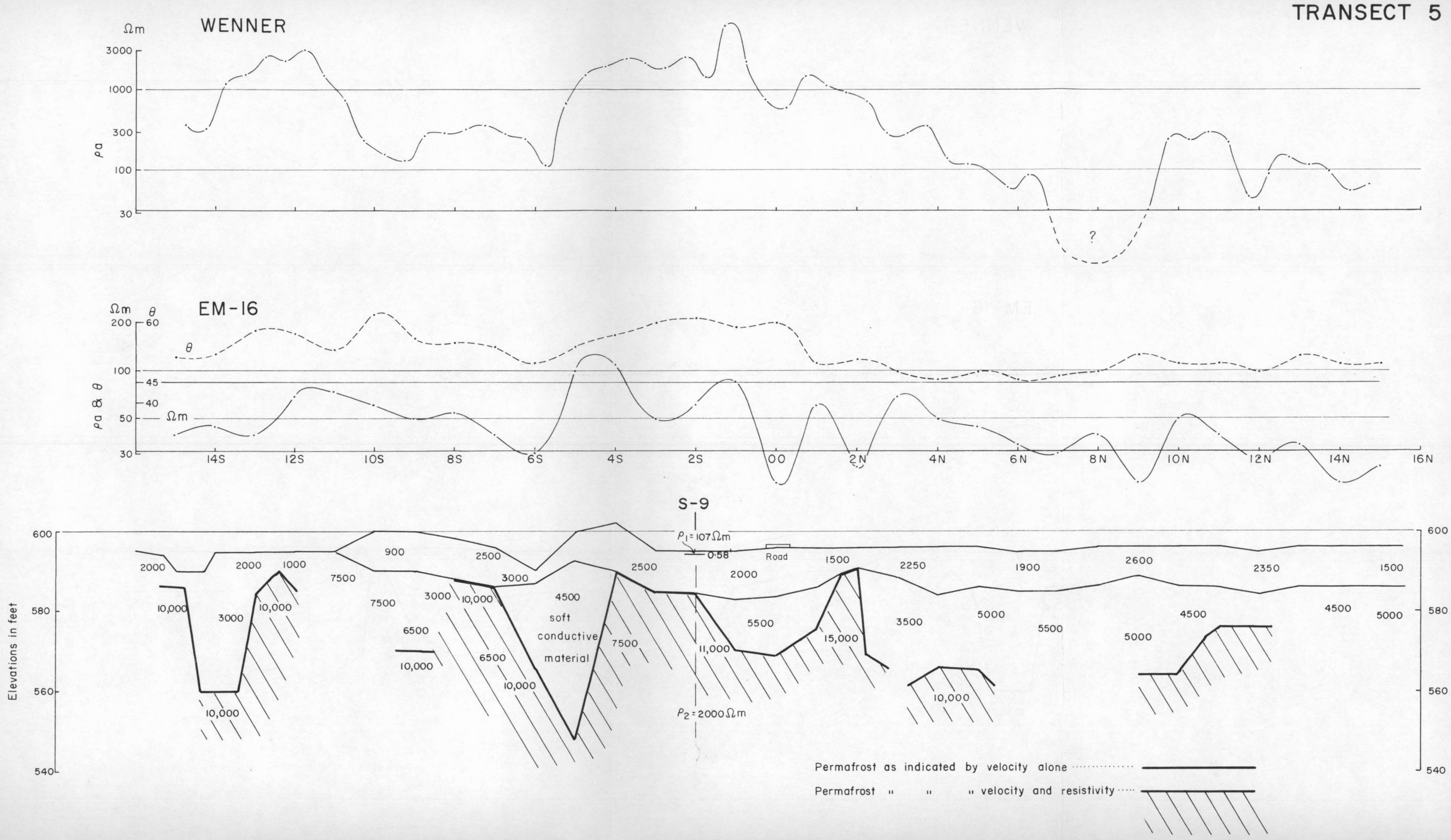
TRANSECT 2


WENNER
EM-16
ρa
ρa & θ
Ωm
θ
S-12
S-10
bedrock ?
Elevations in feet
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity

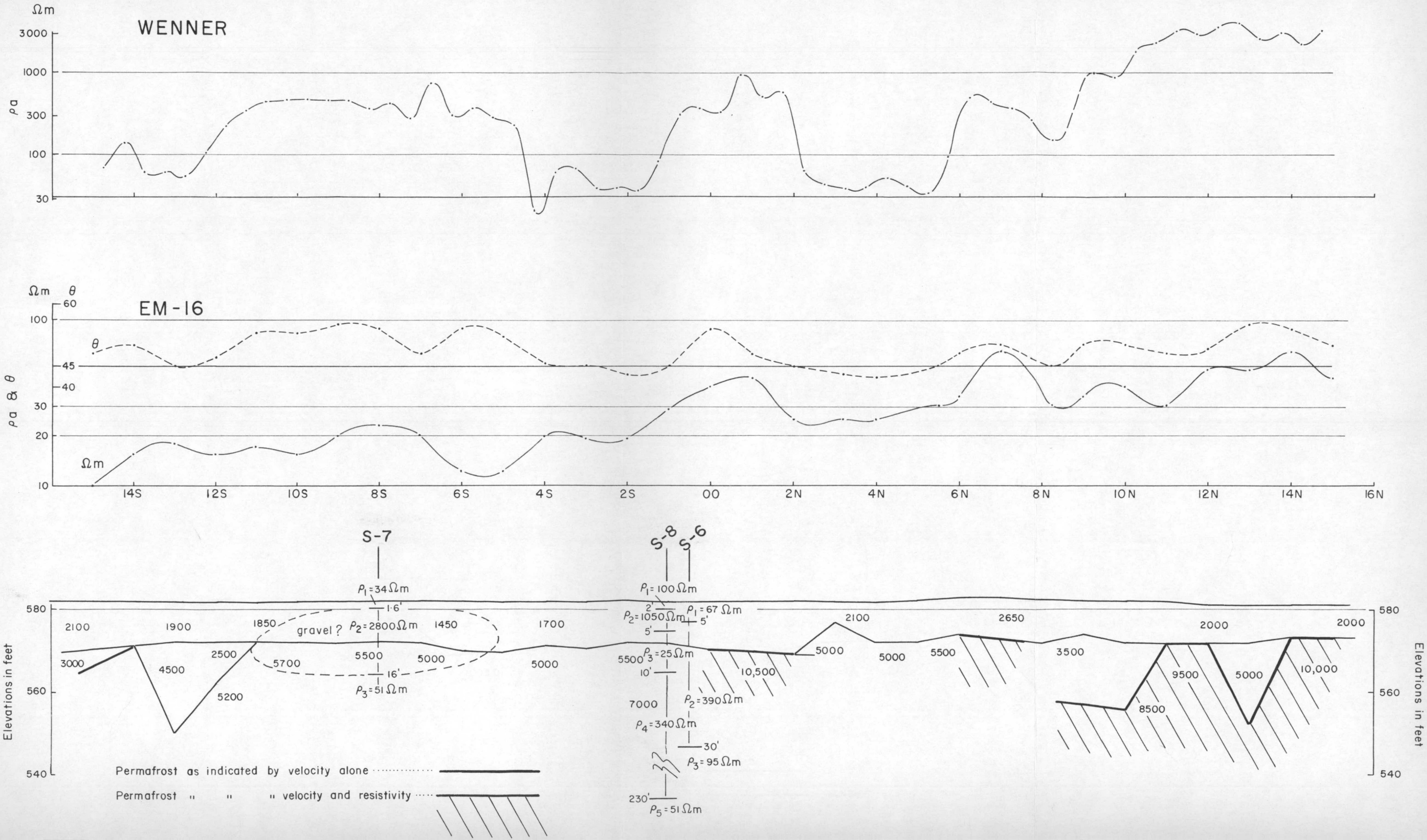
TRANSECT 4



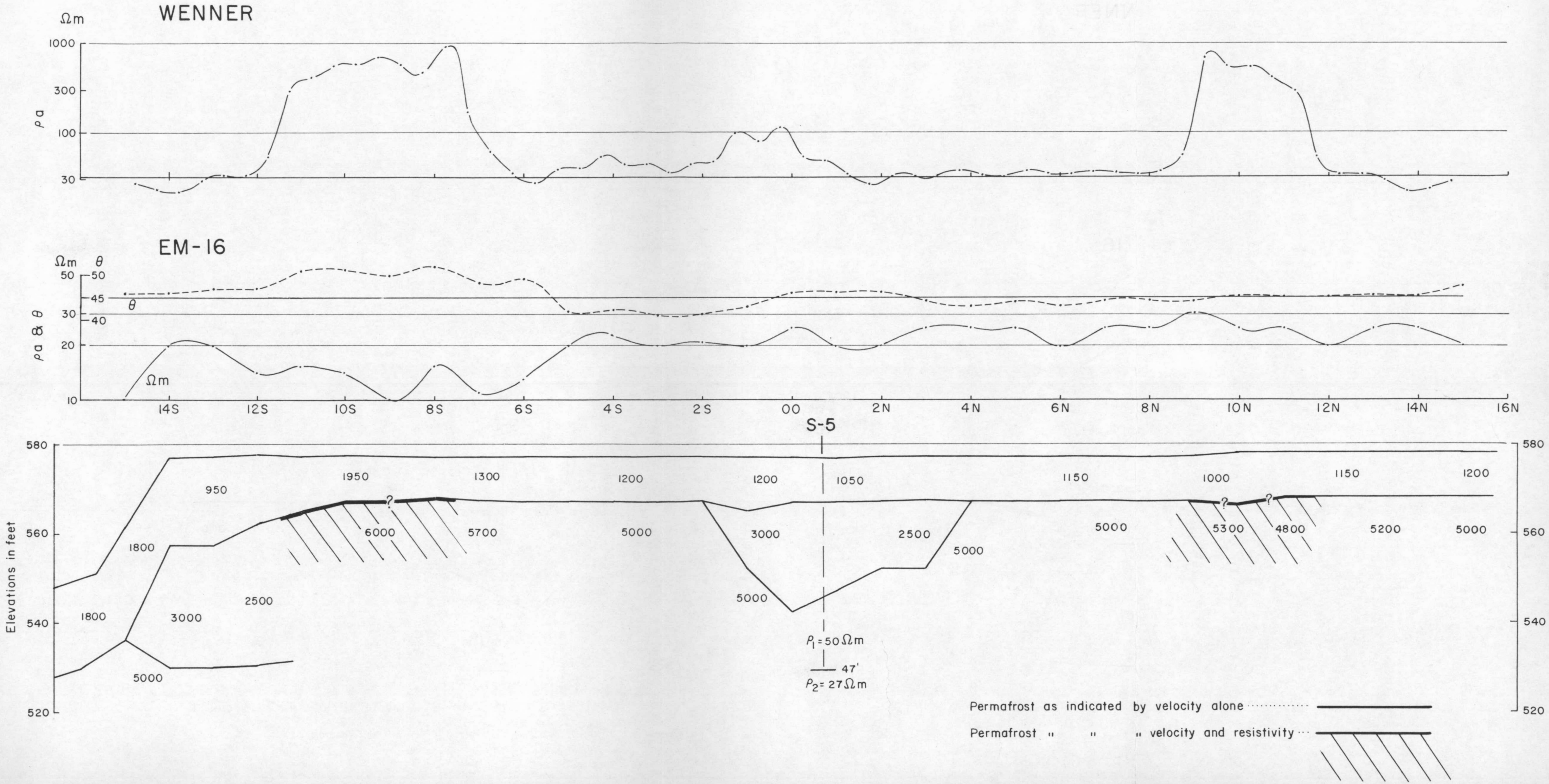
WENNER
Ωm
3000
1000
300
100
30
ρa
EM-16
Ωm θ
60
100
45
50
40
30
θ
Ωm
ρa & θ
14S
12S
10S
8S
6S
4S
2S
00
2N
4N
6N
8N
10N
12N
14N
16N
18N
S-4
ρ1 = 315 Ωm
Road
h1 — 3·1'
ρ2 = 2100 Ω
h2 — 37'
ρ3 = 87 Ωm
580
560
540
Elevations in feet
800
950
850
2500
1600
1150
1500
900
1650
1600
800
1800
4500
5000
5000
4500
7500
Dry granular material ?
3500
5000
6000
5500
?
10,000
10,500
5000
6000
8000
12,500
8000
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity

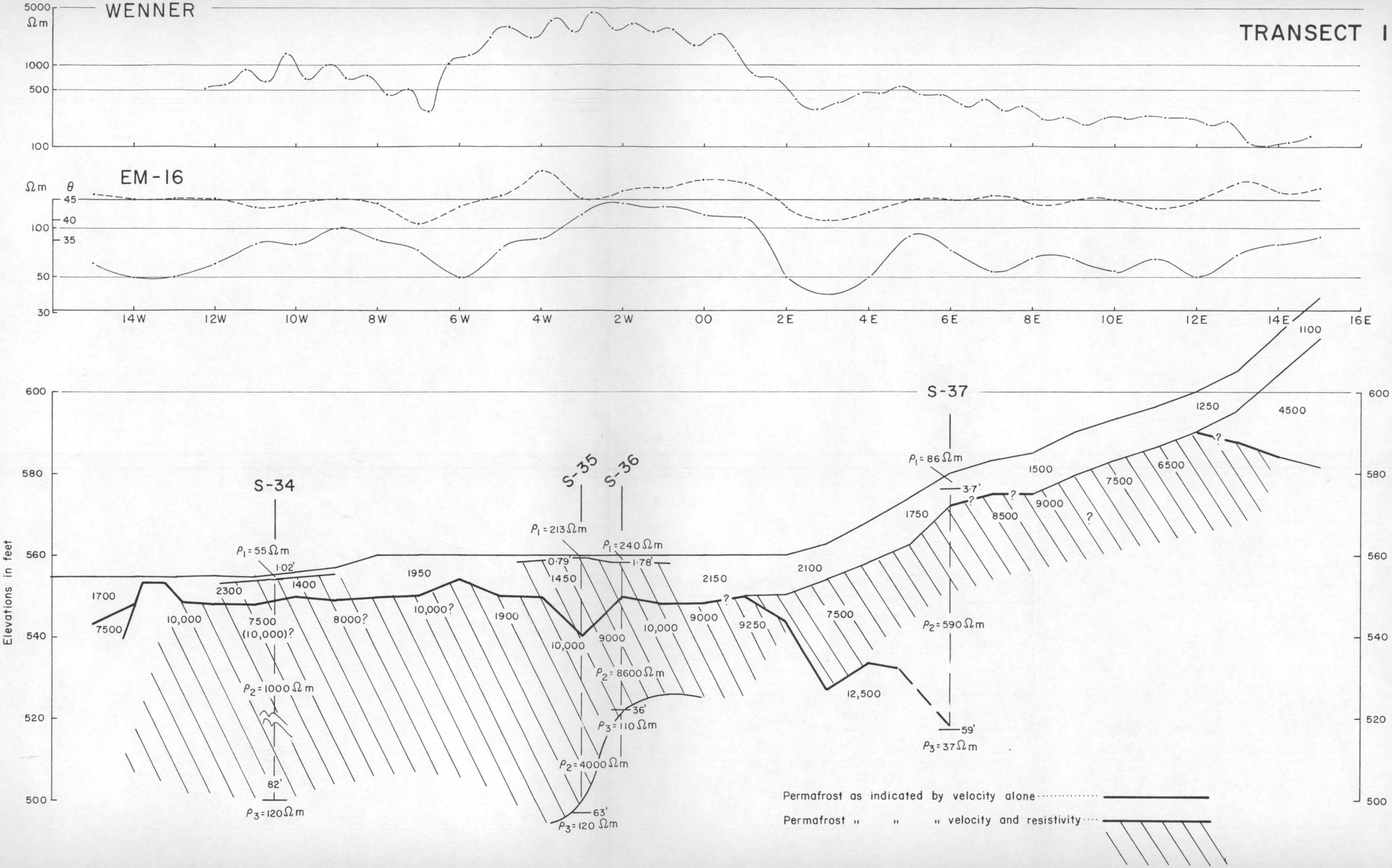


TRANSECT 5
WENNER
Ωm
ρa
3000
1000
300
100
30
?
EM-16
Ωm θ
ρa & θ
200 60
100
45
40
50
30
θ
Ωm
14S
12S
10S
8S
6S
4S
2S
00
2N
4N
6N
8N
10N
12N
14N
16N
S-9
ρ1 = 107 Ωm
0.58'
ρ2 = 2000 Ωm
Road
soft conductive material
Elevations in feet
600
580
560
540
2000
2000
1000
7500
900
2500
3000
2500
2000
1500
2250
1900
2600
2350
1500
10,000
3000
10,000
7500
3000
10,000
4500
5500
3500
5000
5500
4500
5000
4500
5000
6500
6500
7500
11,000
15,000
10,000
10,000
10,000
10,000
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity

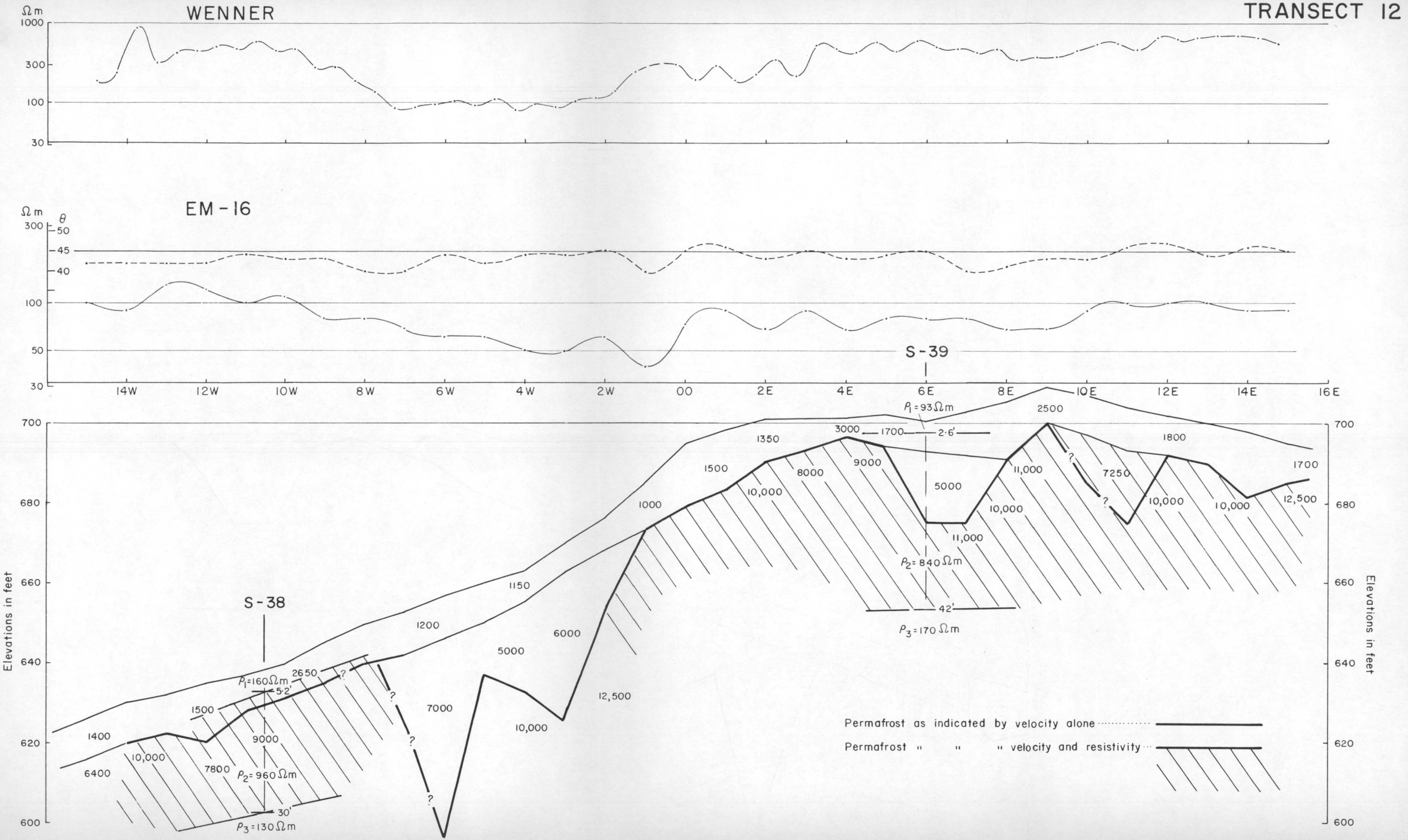


WENNER
Ωm
ρa
3000
1000
300
100
30
EM-16
Ωm θ
60
100
45
40
30
20
10
ρa & θ
θ
Ωm
14S
12S
10S
8S
6S
4S
2S
00
2N
4N
6N
8N
10N
12N
14N
16N
S-7
S-8
S-6
ρ1 = 34 Ωm
1.6'
ρ2 = 2800 Ωm
16'
ρ3 = 51 Ωm
ρ1 = 100 Ωm
2'
ρ2 = 1050 Ωm
5'
ρ3 = 25 Ωm
10'
ρ4 = 340 Ωm
230'
ρ5 = 51 Ωm
ρ1 = 67 Ωm
5'
ρ2 = 390 Ωm
30'
ρ3 = 95 Ωm
gravel ?
2100
1900
1850
1450
1700
2100
2650
2000
2000
3000
4500
2500
5200
5700
5500
5000
5000
5500
7000
5000
10,500
5000
5500
3500
9500
5000
10,000
8500
580
560
540
Elevations in feet
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity


WENNER
Ωm
1000
300
100
30
ρa
EM-16
Ωm θ
50 50
45
θ
30
40
20
ρa & θ
Ωm
10
14S 12S 10S 8S 6S 4S 2S 00 2N 4N 6N 8N 10N 12N 14N 16N
S-5
580
560
540
520
Elevations in feet
950
1950
1300
1200
1200
1050
1150
1000
1150
1200
1800
6000
5700
5000
3000
2500
5000
5000
5300
4800
5200
5000
1800
3000
2500
5000
5000
$P_1 = 50\,\Omega m$
47'
$P_2 = 27\,\Omega m$
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity

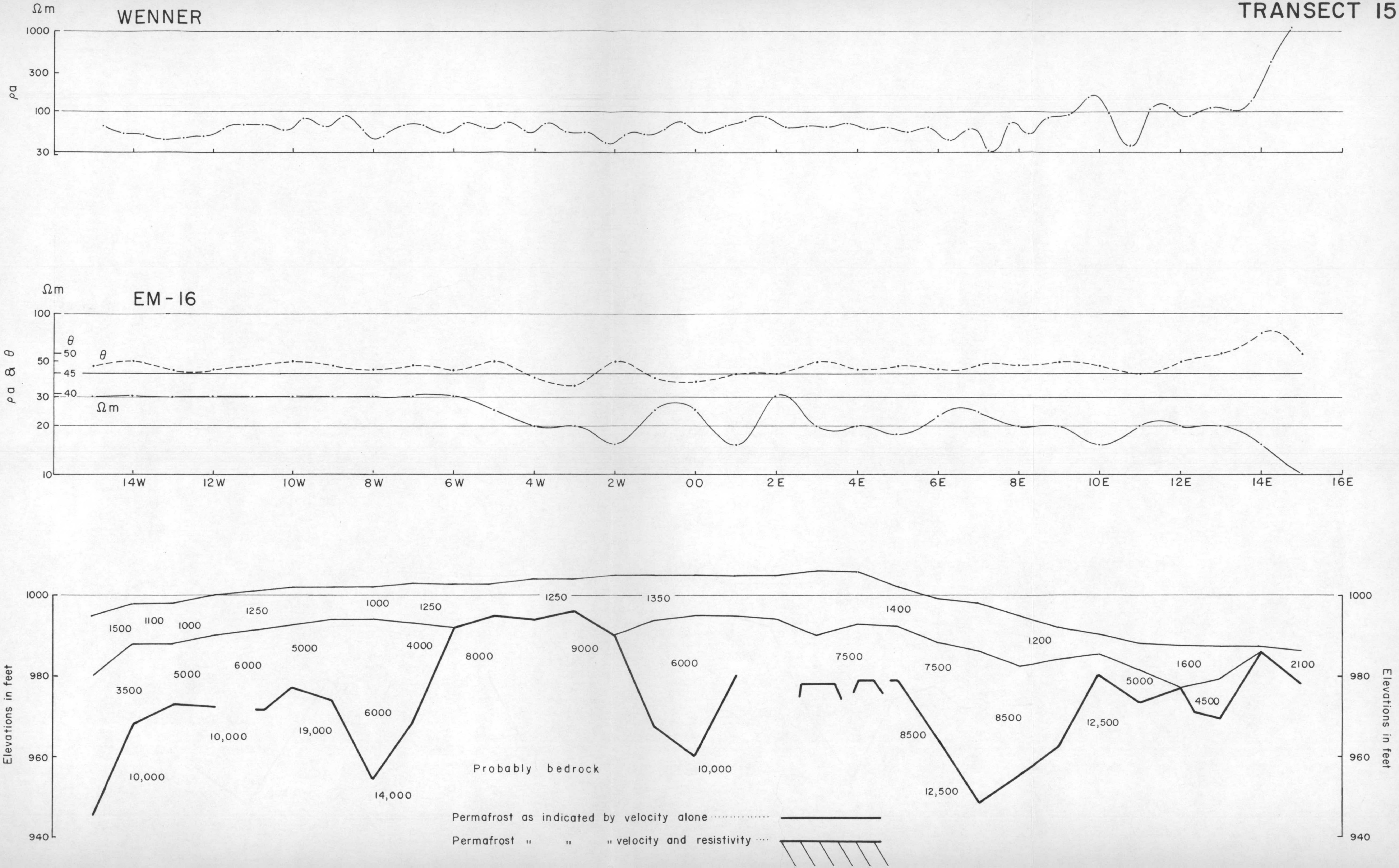


TRANSECT II
WENNER
5000 Ωm
1000
500
100
EM-16
Ωm θ
45
40
100
35
50
30
14W
12W
10W
8W
6W
4W
2W
00
2E
4E
6E
8E
10E
12E
14E
16E
600
580
560
540
520
500
Elevations in feet
S-34
S-35
S-36
S-37
ρ_1 = 55 Ωm
1.02'
ρ_1 = 213 Ωm
0.79'
ρ_1 = 240 Ωm
1.78'
ρ_1 = 86 Ωm
3.7'
1700
7500
2300
1400
10,000
7500 (10,000)?
8000?
1950
10,000?
1900
1450
10,000
9000
2150
9000
9250
2100
7500
12,500
1750
8500
1500
9000
7500
6500
1250
4500
1100
?
ρ_2 = 1000 Ωm
ρ_2 = 8600 Ωm
ρ_2 = 4000 Ωm
ρ_2 = 590 Ωm
36'
ρ_3 = 110 Ωm
82'
ρ_3 = 120 Ωm
63'
ρ_3 = 120 Ωm
59'
ρ_3 = 37 Ωm
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity

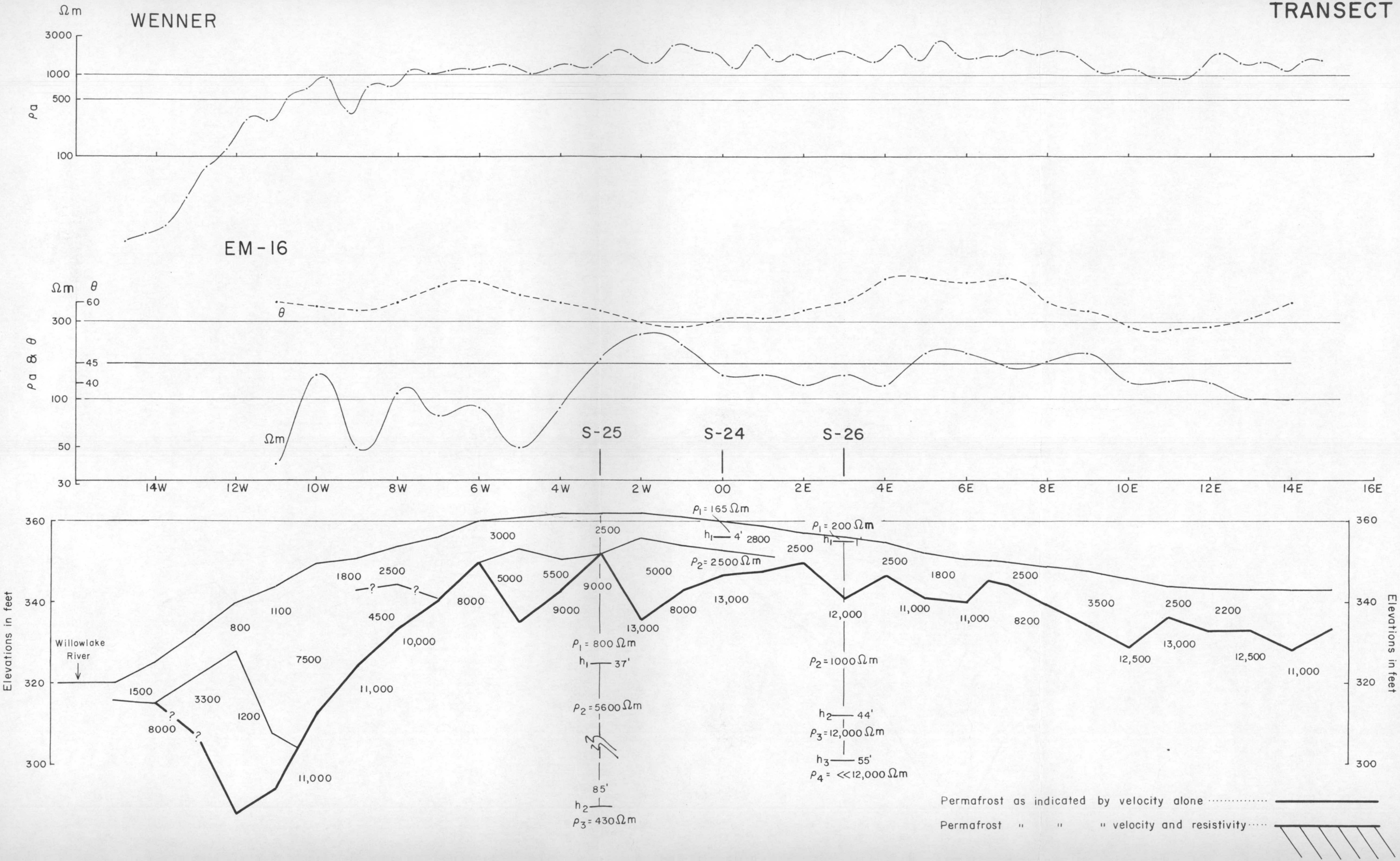


TRANSECT 12
WENNER
Ωm
1000
300
100
30
EM-16
Ωm
θ
300
50
45
40
100
50
30
14W
12W
10W
8W
6W
4W
2W
00
2E
4E
6E
8E
10E
12E
14E
16E
S-39
ρ_1=93Ωm
2·6'
ρ_2=840Ωm
42'
ρ_3=170Ωm
S-38
ρ_1=160Ωm
5·2'
ρ_2=960Ωm
30'
ρ_3=130Ωm
Elevations in feet
700
680
660
640
620
600
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity

TRANSECT 15



WENNER
Ωm
ρa
1000
300
100
30
EM-16
Ωm
ρa & θ
θ
100
50
45
40
30
20
10
Ωm
14W
12W
10W
8W
6W
4W
2W
00
2E
4E
6E
8E
10E
12E
14E
16E
Elevations in feet
1000
980
960
940
1500
1100
1000
1250
1000
1250
1250
1350
1400
1200
1600
2100
3500
5000
6000
5000
4000
8000
9000
6000
7500
7500
5000
4500
10,000
19,000
6000
8500
8500
12,500
10,000
14,000
Probably bedrock
10,000
12,500
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity



WENNER
Ωm
ρa
3000
1000
500
100
EM-16
Ωm θ
ρa & θ
60
300
45
40
100
50
30
θ
Ωm
S-25
S-24
S-26
14W
12W
10W
8W
6W
4W
2W
00
2E
4E
6E
8E
10E
12E
14E
16E
Elevations in feet
360
340
320
300
Willowlake River
ρ1 = 165 Ωm
h1 4'
ρ1 = 200 Ωm
h1 1'
ρ2 = 2500 Ωm
ρ1 = 800 Ωm
h1 37'
ρ2 = 5600 Ωm
85'
h2
ρ3 = 430 Ωm
ρ2 = 1000 Ωm
h2 44'
ρ3 = 12,000 Ωm
h3 55'
ρ4 = <<12,000 Ωm
3000
2500
2800
2500
1800
2500
5000
5500
9000
5000
13,000
2500
1800
2500
8000
9000
13,000
8000
12,000
11,000
11,000
8200
3500
2500
2200
1100
800
4500
10,000
7500
11,000
1500
3300
8000
1200
11,000
12,500
13,000
12,500
11,000
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity

MILE 307
WENNER
Ωm
ρa
1000
300
100
30
EM - 16
Ωm
ρa & θ
θ
100
30
10
60
45
40
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52
Elevations in feet
600
580
560
540
520
Dry granular material
Dry granular material
850 800 1000 1200 800 850 1350 1550 1700 1300 1300 1300 1500 1400 1800 2000 1700 1000 1100
950 800 900 1000 800 700 600 800 700
1800 2200 1800 1700 2000 2000 2250 4500 2500
4800 4500 6000 5000 5800 5800 6200 5800 6000 3700 3500 6500 5500 6300 6000
4500 6000 5500 4700 6200 6000 4300 4500 5000 6000 5000 5000 4600 1450 1450 1400
8700 7500 7500? 10,000 4300
Tr - 4
S - 4
ρ_1 = 315 Ωm h_1 = 31'
ρ_2 = 2100 Ωm
h_2 = 37'
ρ_3 = 82 Ωm
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity

MILE 308


Ωm
ρa
Ωm θ
ρa & θ
S-15
Elevations in feet
ρ1 = 64 Ωm
h1
3.4'
ρ2 = 2200 Ωm
h2
68'
ρ3 = 73 Ωm
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity


WENNER
Ωm
ρa
1000
300
100
30
EM-16
Ωm
ρa & θ
θ
100
30
60
10
45
40
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
Elevations in feet
620
600
580
560
800
850
900
1000
800
850
1000
1000
1900
1200
1750
1300
2000
1150
800
1000
1200
500
5000
4800
7000
7500
1000
5000
6000
5000
500
5300
5000
5000
11,000
5000
9500
9400
800
7500
3500
10,000
9000
5000
9000
7500
5000
4500
5000
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity


WENNER
Ωm
ρa
1000
300
100
30
EM-16
Ωm θ
ρa & θ
60
45
40
θ
Ωm
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50
S-2
Tr-5
S-9
(200' south)
ρ1 = 55 Ωm
ρ1 = 107 Ωm
h1 = 0.58'
4.4'
ρ2 = 4500 Ωm
ρ2 = 2000 Ωm
119'
h2 = 160' min.
ρ3 = 55 Ωm
ρ3 = 107 Ωm
Elevations in feet
600
580
560
540
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity


WENNER
Ωm
ρa
EM-16
Ωm θ
ρa & θ
Tr.-6
S-6
(50' south)
S-8
(100' south)
ρ_1 = 67 Ωm
h_1 = 5'
ρ_2 = 390 Ωm
h_2 = 30'
ρ_3 = 95 Ωm
ρ_1 = 100 Ωm
h_1 = 2'
ρ_2 = 1050 Ωm
h_2 = 5'
ρ_3 = 25 Ωm
h_3 = 10'
ρ_4 = 340 Ωm
h_4 = 230'
ρ_5 = 51 Ωm
fill
Elevations in feet
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity


WENNER
Ωm
ρa
100
30
10
EM-16
Ωm 45
θ
40
Ωm
ρa & θ
30
20
10
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
Elevations in feet
600
580
560
540
1300
5000
1400
5000
5500
5000
4200
5000
1100
1050
6500
950
5000
5000
1400
5000
7500?
thin lense ?
1150
5000
1200
3700
5000
5700
1750
4500
950
4800
900
4500
900
5000
6000
800
6500
5000
1100
4200
4500
900
4000
1250
5000
1000
6200
?
10,000 ?
thin lenses
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity


WENNER
Ωm
ρa
100
30
10
EM-16
Ωm θ
ρa & θ
30 45
40
20
10
θ
Ωm
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54
Tr-7
S-5
Elevations in feet
580
560
540
520
500
1100 1000 800 1200 900 950 1050 900 950 1200 1400 1050 900 850 900 850 1000 1200
3250 7500 7500 scattered lenses 5000 5500 3000 4700 5000 3500 3500 3800 2800 2500 6000 10,000 8500 4250 5000 9500 5000 4800 5000
7500
$\rho_1 = 50\ \Omega m$
$h_1 = 47'$
10,000 7500
scattered lenses
$\rho_2 = 27\ \Omega m$
9500 11,000
7500
7500
2500 fine sand 2800 4000 5000 5000 6000 5000
9500 fine sand 2500 5000 4500
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity
7500


WENNER
Ωm
1000
ρa
300
100
EM-16
Ωm θ
θ
30
45
40
35
20
10
ρa & θ
Ωm
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52
580
560
540
520
500
Elevations in feet
1000 1000 1000 1000 900 900 950 1300 1100 1000 1100 1100 1000 1100 1500 1300 900 1600 1400 1300
2000 2500 2500 3000 4700 5000 4500 4700 5700 3000 2800 2500 5500 3000 2500 5000 4500 5500
4500 6000 8500? 5000 4500 6000 4500 2500 2500 3000 5000 3000 2700 4500 4700 5300 5000 6000
5500 6000 5500 5000 5200 7500 5000
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity

MARTIN RIVER CENTRE LINE
DIVERSION 580-638
WENNER
Ωm
1000
100
10
ρa
EM-16
ρa & θ
θ
Ωm
580
582
584
586
588
590
592
594
596
598
600
602
604
606
608
610
612
614
616
618
620
622
624
626
628
630
632
634
636
638
Elevations in feet
S-11
S-12
P_1 = 110 Ωm
h_1 = 0.8'
P_1 = 530 Ωm
h_1 = 5.6'
P_2 = 2100 Ωm
P_2 = 4800 Ωm
h_2 = 18'
h_2 = 12
P_3 = 49 Ωm
P_3 = 48 Ωm
bedrock
Flowing towards viewer (North)
MARTIN R.
Rock ?
Permafrost as indicated by velocity alone
Permafrost " " " velocity and resistivity
6200

MARTIN RIVER CENTRE LINE
DIVERSION 638 - 698
WENNER
Ωm
1000
100
10
ρa
EM-16
Ωm θ
60
100
θ45
40
Ωm
50
30
ρa & θ
638
640
642
644
646
648
650
652
654
656
658
660
662
664
666
668
670
672
674
676
678
680
682
684
686
688
690
692
694
696
698
S-13
S-14
ρ1 = 1110 Ωm
h1 — 7.5'
ρ2 = 2100 Ωm
h2 — 60'
ρ3 = 79 Ωm
ρ1 = 1300 Ωm
h1 — 64'
ρ2 = 68 Ωm
Elevations in feet
620
600
580
560
540
800
1000
1300
1200
3000
5000
6000
1250
3500
700
1500
2000
4000
4500
5500
6500
7000
1150
5700
4700
1000
750
800
1100
4200
900
9000
850
4400
4600
5400
4800
3200
5200
2500
1800