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Mapping the Top of Permafrost Using a Direct Current Resistivity Survey

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DISCLAIMER

Summary

Data from a direct current resistivity survey and geologic logs from boreholes were used to map the top of permafrost at a remote Air Force installation in Alaska. This study resulted from a remedial investigation that was conducted at Eielson Air Force base near Fairbanks, Alaska under the federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) regulations. The depth and continuity of the permafrost was important in determining the fate of petroleum contamination that was inadvertently discharged to the ground during earlier Air Force operations. The results indicate that the top of permafrost forms a highly irregular surface. In general, however, the top of permafrost forms a diagonal ridge at the center of the contour grid that is bordered on each side by troughs.

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Introduction

Petroleum products were inadvertently discharged to the ground from past leaks and spills at a remote Air Force facility located near Fairbanks, Alaska. As a result of these spills, petroleum products have been detected in a shallow groundwater well near the facility. To determine the fate of the contaminants in the environment, an effort was undertaken to characterize the hydrogeologic environment at the site. Because permafrost can act as a barrier to water and contaminant movement, it was important for this characterization to determine the continuity and lateral extent of the permafrost. A resistivity survey was performed to map the top of the permafrost in support of the hydrogeological study in the area. The objective was to identify two general layers (the unfrozen ground above permafrost and permafrost). Resistivity surveys have been extensively used in permafrost mapping (Ogilvy 1970, Dement'ev 1959, MacKay 1969, Barnes and MacCarthy 1964, Ferrians and Habson 1973).

Description of Study Area

The Blair Lakes target facility is located in the interior of Alaska approximately 160 km south of the Arctic Circle (Figure 1). The target facility is essentially a self-contained satellite installation located approximately 40 km to the northeast of the main Air Force base and is used to operate an aircraft target range. The facility is located on the broad glacial outwash plain of the Tannana Valley in an area of discontinuous permafrost (Pewe 1982). The facility consists of an approximately 350-m x 350-m gravel pad with a vehicle maintenance shop, storage buildings, and living quarters (Figure 2). Just outside the gravel pad area are aircraft target ranges. Average summer temperatures range between 7 and 16°C. Average winter temperatures range between -26 and -13°C.

Geology. The geology of the study area is illustrated in the cross sections shown in Figure 3 (west-east) and 4 (north-south). Ten monitoring wells at the site are completed in the shallow aquifer above the permafrost. There are also two water supply wells completed below the permafrost. Geologic logs were available only for the newer of the two water supply wells. The newer well was completed at a depth of 52.7 m.

The upper 2.5 m of sediment is dominated by fine-grained deposits (silt, sandy silt, silty clay, gravelly sandy silt). These fine-grained lithologies appear to occur as interfingering 0.5- to 2-m-thick lenses/layers. However, gravel layers (silty gravel, silty sandy gravel) from 0.25- to 1-m-thick may also be present, especially at the land surface. Much of the Blair Lakes Target Facility is built on gravel fill taken locally from gravel pits. Organic- and silt-rich deposits of peat or "muskeg" are found away from the gravel pad. Sediments below the 2.5-m depth generally consist of sandy gravel, with some ash identified at the 50- to 56.8-m interval.

Hydrology. Depth to groundwater generally ranges between 2.1 to 3 m below land surface (bls). Locally perched water conditions, however, do occur near the heated buildings. Unconfined aquifer

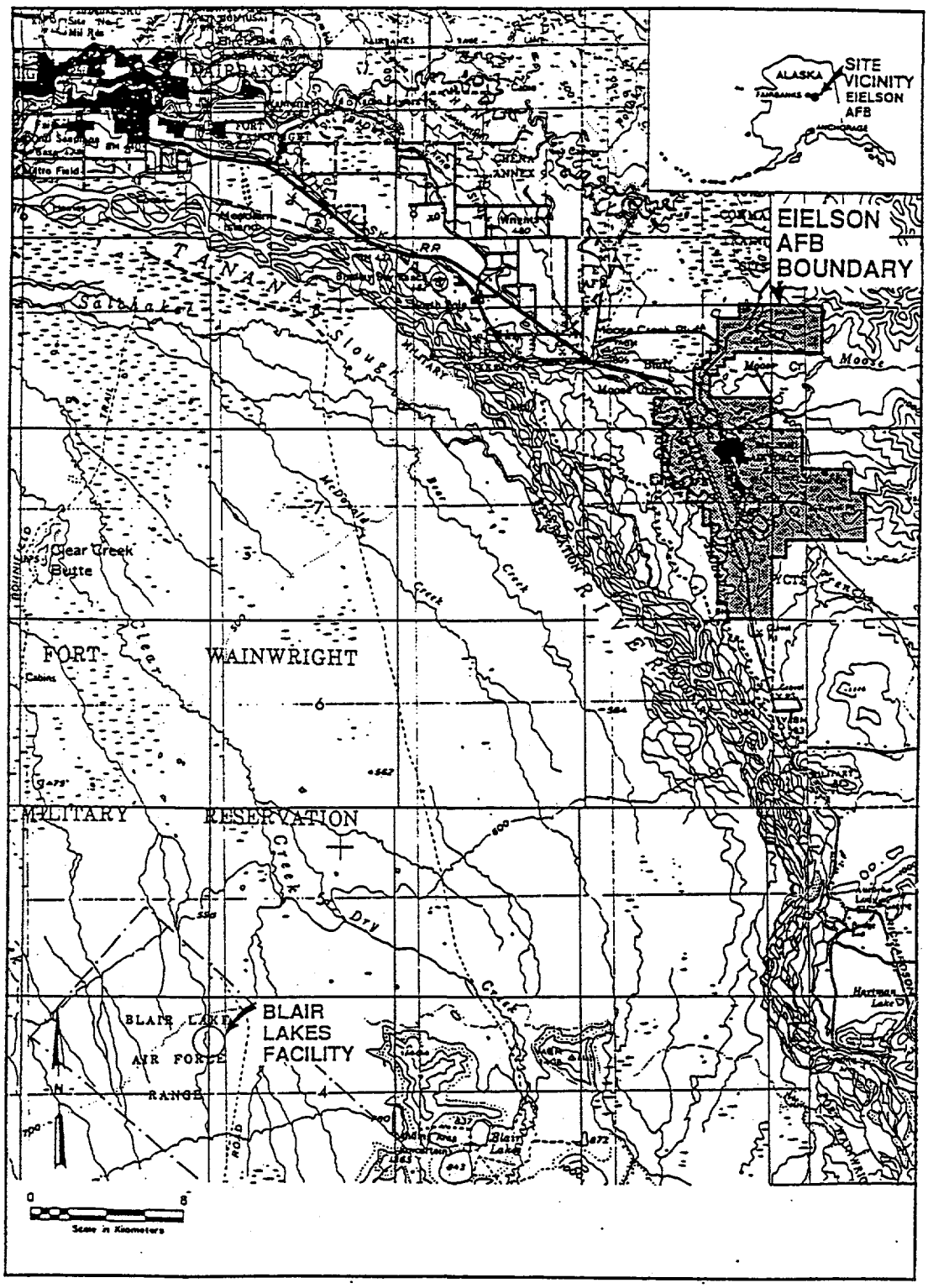

Figure 1. Regional Map

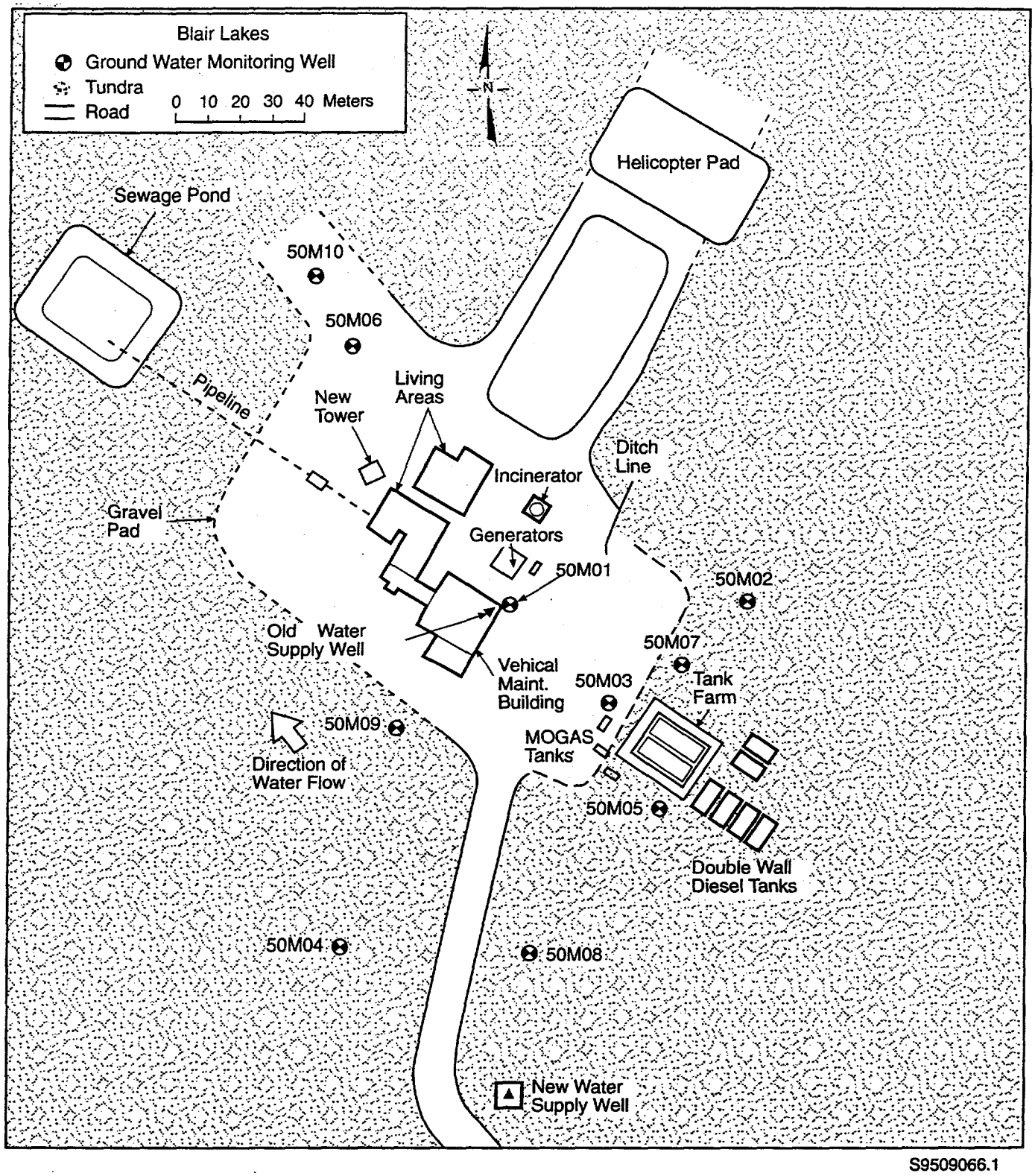

Figure 2. Study Area

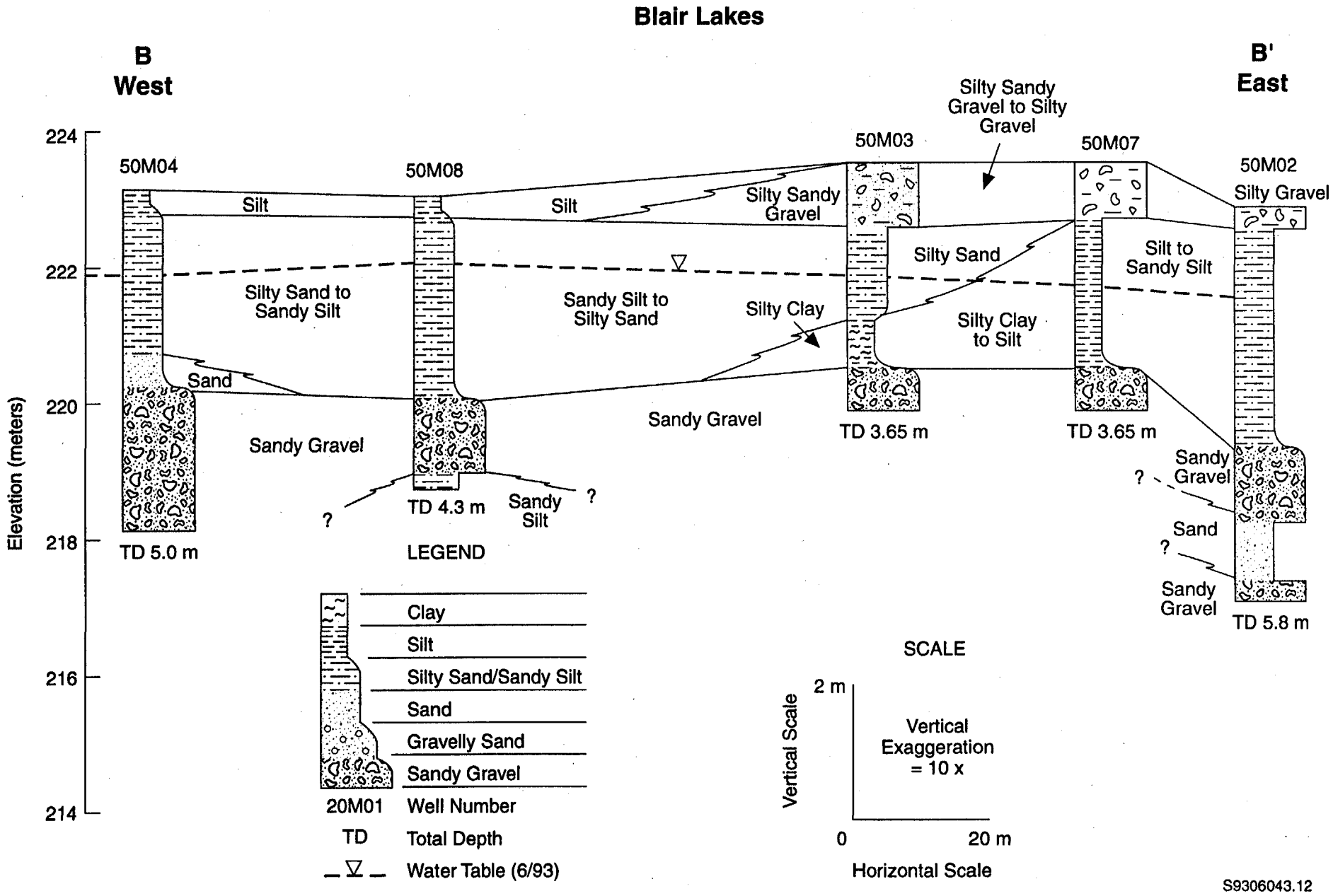

Figure 3. Cross Section West-East (B-B'), Blair Lakes Target Facility

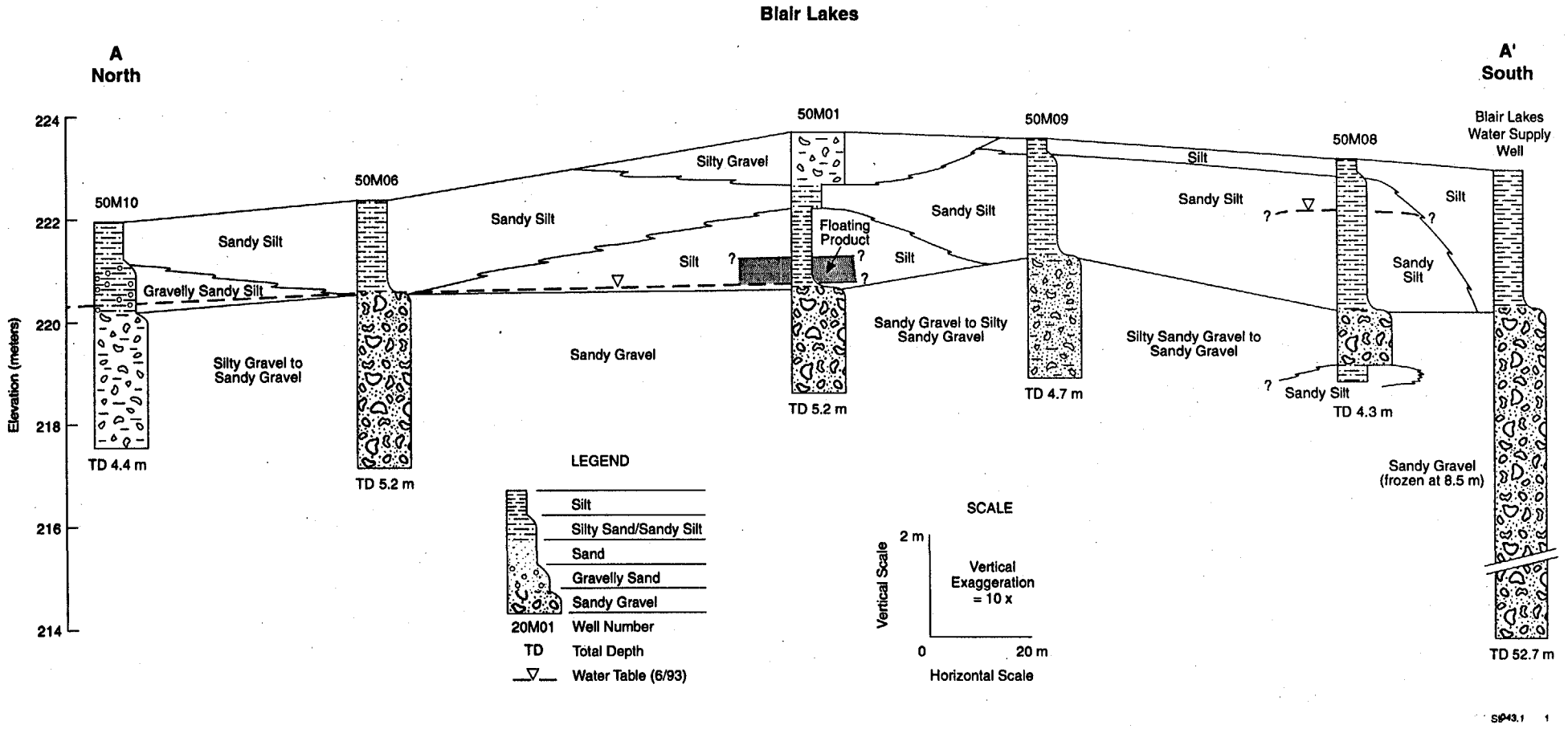

Figure 4. Cross Section North-South (A-A'), Blair Lakes Target Facility

conditions are encountered in the saturated alluvial deposits above the permafrost layer. Hydraulic conductivity values from six aquifer tests (slug tests) range from 3.15 to 51.84 m/day. Near-surface groundwater flows to the north, with velocities ranging from 0.27 to 4.31 m/day and an azimuth direction of 339.2°.

Permafrost. Permafrost is discontinuous throughout the Tanana River floodplain sediments (Nelson 1978). Near Fairbanks, permafrost of the undisturbed flood plan can extend from 0.6 m to depths of at least 80 m (Pewe et al. 1982). Locally, the outwash plain is perennially frozen and characterized by a low ice content with ice primarily restricted to pore spaces.

At the Blair Lakes target facility, permafrost was observed in boreholes 50SB05 at 2.74 m (9 ft), 50SB07 at 2.45 (8.2 ft) and 50M03, at 2.13 m (7 ft). In well 50M03 no free water was encountered, and the well was subsequently abandoned. Permafrost was also detected at a depth of 9.2 m in the new water supply well and at 2.9 m in a soil test pit near well 50M02.

Data Acquisition

A direct current (DC) resistivity survey was conducted at the site in May 1993. The permafrost surface was identified by locating the boundary between the lower resistivity unfrozen soil and the much higher resistivity frozen soil (permafrost) beneath it. The surface DC resistivity method measures resistivity to different depths of investigation by varying the electrode spacing. The electrode array used in this particular study was a Wenner array in which four electrodes were arranged along a line so there was always equal spacing between all electrodes. For each survey line, apparent resistivity readings were made for a range of electrode ('a') spacings to produce an apparent resistivity versus 'a' spacing sounding curve. Fifteen DC resistivity soundings were measured, which resulted in 15 apparent resistivity versus 'a' spacing sounding curves (see Figure 1 for map of the study area). The edited sounding curves were used as input to RESIX Plus™ evaluation software. RESIX Plus™ is a forward and inverse modeling DOS-based software package for interpreting DC resistivity sounding data in terms of a layered-earth (one dimensional) model.

For each measured sounding curve, the RESIX Plus™ user prescribes a best guess geoelectric section model (depth versus resistivity) from which the software generates a synthetic resistivity sounding curve (resistivity versus electrode 'a' spacing) using linear filters. If necessary, the user refines the model to obtain a closer fit between the synthetic and actual sounding curves by adjusting the resistivity, thickness, and/or number of layers in the model. Once the two sounding curves are relatively close, the geoelectric model is entered into the inversion routine, which uses ridge regression to iteratively adjust the model by varying layer thickness and resistivity to obtain the best fit between the synthetic and actual sounding curves. The user can also mask aberrant data points on the measured sounding curve, making them transparent to software calculations. If the fit between the sounding curves is still unsatisfactory, the user can repeat the whole process using a different starting model with, for example, a different number of layers. Arriving at a best-fit geoelectric model is an iterative process and requires a significant amount of user input and interpretation.

Results

From the 15 resistivity soundings recorded, 13 were used along with the top of permafrost picks from 5 boreholes in the study area. Two of the soundings were rejected due to very abnormal sounding curves that could not be modeled accurately or realistically. It is believed that excessive "noise" in these two soundings was caused by buried utilities near the facilities. Each sounding required separate analysis using the RESIX Plus™ software because DC resistivity measurements are generally not continuous over large areas.

Although the original objective was to identify two general layers (the unfrozen ground above permafrost and permafrost), most of the final best-fitting geoelectric models contained more than two layers, and an interpretation had to be made to determine which layer represented the permafrost.

The final depth-to-top of permafrost (from ground surface) contour map of the study area that was generated exhibits a diagonal ridge at the center of the grid, which is bordered on each side by troughs (Figure 5). The ridge has a high of 1.6 m bls which slopes to a low of 9.2 bls to the southwest and 6.7 mbg to the northeast. At the southwest corner of the grid there is a very steep gradient in the top of the permafrost surface due to a large discrepancy between a well pick (9.2 bls) and an adjacent interpreted resistivity sounding (4.0 bls). The five other well picks (at the center of the grid) agree well with the surrounding interpreted resistivity soundings. Note that all interpreted resistivity soundings and well picks were honored in the gridded contour map.

Conclusions

Although the top of the permafrost appears to be highly variable, ranging from 1.6 to 9.2 m bls, the permafrost appears to be continuous across the site. Although the original objective was to identify two general layers (the unfrozen ground above permafrost and permafrost) most of the final best-fitting geoelectric models contained more than two layers and an interpretation had to be made to determine which layer represented the permafrost. Evaluation of the resistivity soundings requires a significant amount of user knowledge and interpretation to generate and choose the best-fitting and realistic geoelectric model and, from those models, to pick the top of permafrost. Actual data from the boreholes was invaluable for these interpretations.

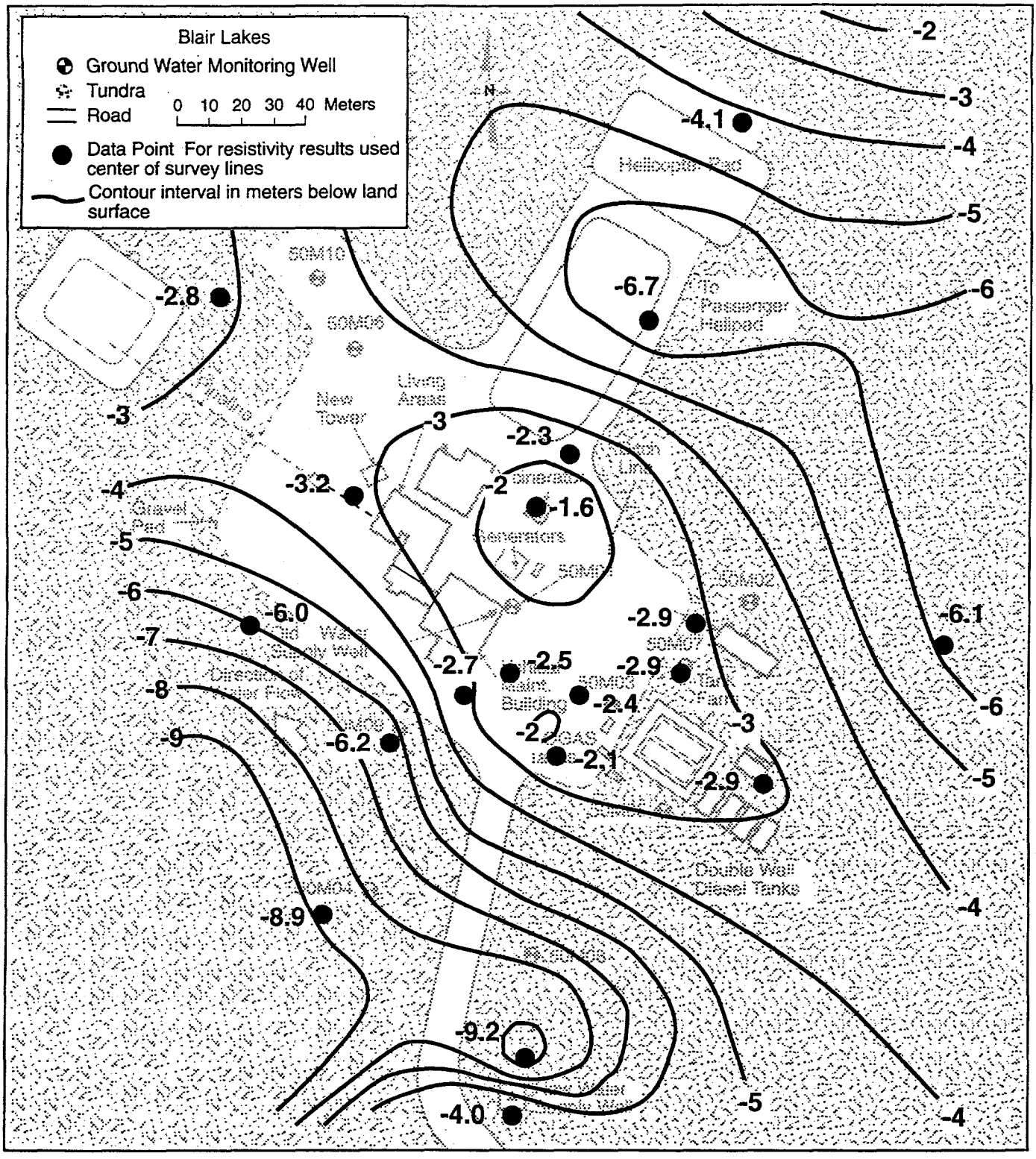

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Figure 5. Top of Permafrost Contour Map

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Appendix

This appendix contains the data used to generate the top-of-permafrost map.

Fifteen DC resistivity soundings were measured that resulted in 15 apparent resistivity versus 'a' spacing profiles. The profiles were analyzed on a personal computer using the DC resistivity interpretation software RESIX Plus, by Interpex Limited of Golden, Colorado. RESIX Plus is a forward and inverse modeling program for interpreting resistivity sounding data in terms of a layered earth (one-dimensional) model. Data points that were scattered from the curve profile due to excessive noise were masked to leave a smooth curve. A first-guess geoelectric section model (depth versus resistivity) was created from which the software generated a synthetic resistivity sounding curve using linear filters. The model was manually refined to get a fairly close fit between the synthetic and the actual sounding curves. This model was entered into the inversion routine, which uses ridge regression to iteratively adjust the model by varying depth and resistivity, to obtain the best fit between the synthetic and actual sounding curves.

Once a satisfactory best-fit model was determined, an equivalence analysis was performed to show alternative models that fit the data nearly as well as the best-fit model, but which differed from it in terms of depths and/or resistivities. The software accomplishes this by setting an error threshold, 1.2 times the best-fit error, and then varying the model to find the variation that produces a fit equal to this error threshold. This is done twice for each model parameter (layer thickness and resistivity), once to find the upper bound and once to find the lower bound. Models with different numbers of layers were also tried and compared with each other. The final model chosen for each sounding was determined on the basis of best-fit, minimal variance in equivalence models, and geologic accuracy. The top of permafrost was picked from the final models by locating the top depth of the first substantial layer from the surface with a resistivity greater than 1000 ohm-m.

From the 15 soundings recorded, 13 were used to construct the top-of-permafrost surface contour map. Two soundings were rejected, soundings number 7 and 15 located just southeast of the building complex, because they had very abnormal apparent resistivity 'a' spacing profiles that could not be modeled accurately or realistically. Sounding 15 was recorded adjacent to sounding 7 to verify the readings from the latter. These profiles are characterized by a sharp increase in apparent resistivity from an 'a' spacing of 1.5 m to 10 m followed by a sudden sharp decrease. The profile for sounding 7 shows another sharp increase starting from 25 m. The erroneous, but continuous, nature of these results suggest that the readings were affected by coherent noise, most likely from the buried power line running between the main complex and the fuel island.

The sounding profile and model figures as well as the results in text form is included following the descriptions for each of the sounding results. The dotted lines in the model figures represent the alternative models derived from equivalence analysis.

Sounding 1

The interpretation of results for the first sounding, the test survey, was fairly straightforward. The best-fit model, with a fitting error of 1.6%, is a geoelectric section with three layers: a very thin, low resistivity surface layer; a 6-m-thick, 333 ohm-m resistivity layer; and a high-resistivity (2744 ohm-m) bottom layer starting at 6.1 m. The bottom layer was picked as permafrost. The parameter bounds from equivalence analysis were well-confined with the depth to the permafrost layer ranging from between 5.7 m and 6.6 m.

Sounding 2

The second sounding was interpreted similarly to the first (three layers, with about the same resistivities), but the depth to the top of the permafrost layer is shallower (4.1 m) and not as well bounded in the equivalence analysis (3.4 m to 4.9 m). The fitting error is also a little higher (2.8%) but still very good.

Sounding 3

The apparent resistivity versus 'a' spacing profile for sounding 3 was more complicated than the first two soundings but a well-confined model was still obtainable. The best-fit geoelectric section (fitting error = 3.1%) contains five layers with a thin (0.5-m), very high resistivity ($\sim$20000 ohm-m) layer at the 2.1-m depth and another very high resistivity bottom layer at the 6.7-m depth. Both these layers are well-confined by equivalence analysis. The bottom high resistivity layer was picked as permafrost. The shallow, thin, high-resistivity layer could be interpreted as a lens of ice. The sounding was located on the heli-pad, which was made of gravelly fill overlying the natural muskeg. The fill could be acting as a thermal insulator keeping the temperature cold enough to support ice.

Sounding 4

A well-confined model for sounding 4 could not be designed. The best-fit model (fitting error = 3.5%) contains six layers with the highest resistivity layer (4700 ohm-m) starting at 2.3 m. The equivalence bounds of the depth to the high resistivity layer range from 1.6 m to 4.1 m. There are also two other thin, very shallow high resistivity layers separated by low-resistivity layers in the model. The deepest, thickest high-resistivity layer was picked as permafrost. The data from this sounding may be noisy due to the proximity of standing water and a possible dump site identified by Harding Lawson Associates.

Sounding 5

The interpretation for sounding 5 produced a well-confined model with a very low fitting error (1.3%). However, the results were very different from the previous soundings. A 4.5-m-thick high resistivity (2000 ohm-m) layer starts at the 1.6-m depth, underlain by a 500-ohm-m layer, which in turn is underlain by a high-resistivity layer starting at 30 m. The top of permafrost was picked at 1.6 m, the top of the first high-resistivity layer, since that layer is the first substantial high-resistivity layer from the surface. Because the objective of the entire survey was to locate the top of permafrost, the electrode array width was not extended beyond 130 m. Therefore, it would not be valid to make any specific interpretations for depth below 20 m. It appears likely, by the shape of the apparent resistivity profile and the final model that there is a melted zone within the permafrost starting above the 10-m depth. The gravelly fill used to support the building complex may be providing insulation for ice to exist, identical to the situation in sounding 3.

Sounding 6

The interpreted geoelectric section chosen for sounding 6 was not the absolute best-fitting model possible, but was the most simple, realistic, and well-confined one (and still had a fitting error of only 2.7%). The model consists of only two layers: a 100-ohm-m resistivity surface layer and a 2300-ohm-m resistivity layer, interpreted as permafrost, starting at the 2.9-m depth. The equivalence bounds for the depth to the top of the permafrost are from 2.6 m to 3.1 m. The location of this sounding was off the back-filled area. The shape of the apparent resistivity profile matches the profiles of the two previous soundings that were entirely off the back-filled area (soundings 1 and 2).

Sounding 8

The results for sounding 8 contained three spurious data points that were masked for the interpretation. The most simple, realistic, best-fit model for this sounding (fitting error = 3.9%) incorporates three layers, the middle of which is the high-resistivity (2770-ohm-m) layer. This layer begins at 2.4 m (equivalence bounds of 2.1 m to 2.7 m), where the top of permafrost was picked, and is 8.6-m-thick. As with previous soundings, there likely exists a melted zone within the permafrost below the 10-m depth.

Sounding 9

The ninth sounding was modeled using three layers, the most appropriate number of layers for the apparent resistivity profile shape. The high resistivity (1285-ohm-m) bottom layer, which starts at the 6.2-m depth, was interpreted as permafrost. The equivalence bounds for the permafrost depth are from 5.4 m to 7.4 m and the model fitting error is 3.4%.

Sounding 10

The final model chosen for sounding 10 consists of four layers and has a very low fitting error of 1.5%. The model contains a thin, high-resistivity layer near the surface and a substantial high resistivity (1846-ohm-m) bottom layer, which was interpreted as permafrost. The depth to the top of the bottom layer is 8.9 m with equivalence bounds of 7.7 m to 10.6 m.

Sounding 11

The results from sounding 11 presented many difficulties for interpretation. The apparent resistivity profile has many inflection points. At first, all the data points were included in the interpretation, and a complicated five-layer model was incorporated. This model gave an acceptable fitting error of 3.4% but was poorly confined. Since the data points for the first two 'a' spacings seemed to be giving the interpretation routine a lot of difficulty, they were masked. This did not cause much concern since the surface of the sounding location was very disturbed and, thus, very apt to cause noise in the shallow readings. When the first two data points were masked, a simple two-layer model produced accurate (fitting error = 2.3%) and well-confined results. This model was used for the final geoelectric section giving a permafrost depth of 6 m with equivalence bounds of 5.3 m to 6.8 m.

Sounding 12

Sounding 12, taken adjacent to the sewage pond, was interpreted using a six-layer best-fit (fitting error = 3.4%) model. The apparent resistivity profile was complicated but very consistent, which was the impetus for a many-layered model. The top of the permafrost was picked as the top of the first high-resistivity (3700-ohm-m) layer at the 2.9-m depth. The bounds for this value from equivalence analysis is 2.2 m to 3.9 m. Once again, from the shape of the profile and the final interpreted geoelectric section, there appears to be a melted zone starting above the 10-m depth. This seems quite plausible considering the proximity of the sewage pond.

Sounding 13

The results from sounding 13 contain a sharp discontinuity in the apparent resistivity profile between an 'a' spacing of 2 m and 5 m. Three data points were masked to eliminate this discontinuity and to leave a more rounded profile. A four-layer model was used in the interpretation resulting in a 2.3% fitting error and a high-resistivity (1577-ohm-m) bottom layer starting at 3.2 m, which was interpreted as the permafrost top. The depth parameter bounds from equivalence analysis were not really well-confined (2.8 m to 4.2 m for the bottom layer top) but represented the best that could be accomplished.

Sounding 14

Sounding 14 was performed next to the new water supply well so the results could be compared with the borehole log constructed when the well was drilled. The most simple, realistic model to fit the nondistinct apparent resistivity profile is a three-layer geoelectric model with an extremely high-resistivity (constrained to 50,000 ohm-m) bottom layer beginning at the 4.0 m depth, which was chosen as the permafrost top. The equivalence bounds on that depth are 3.3 m to 4.4 m. The borehole log mentions "frozen" material beginning at the 8.5-m depth, significantly deeper than was predicted by the DC resistivity sounding. The log is quite vague and somewhat questionable, though. The next closest sounding, about 75 m to the northwest, did yield a permafrost top of 29 ft, much closer to the well log value.

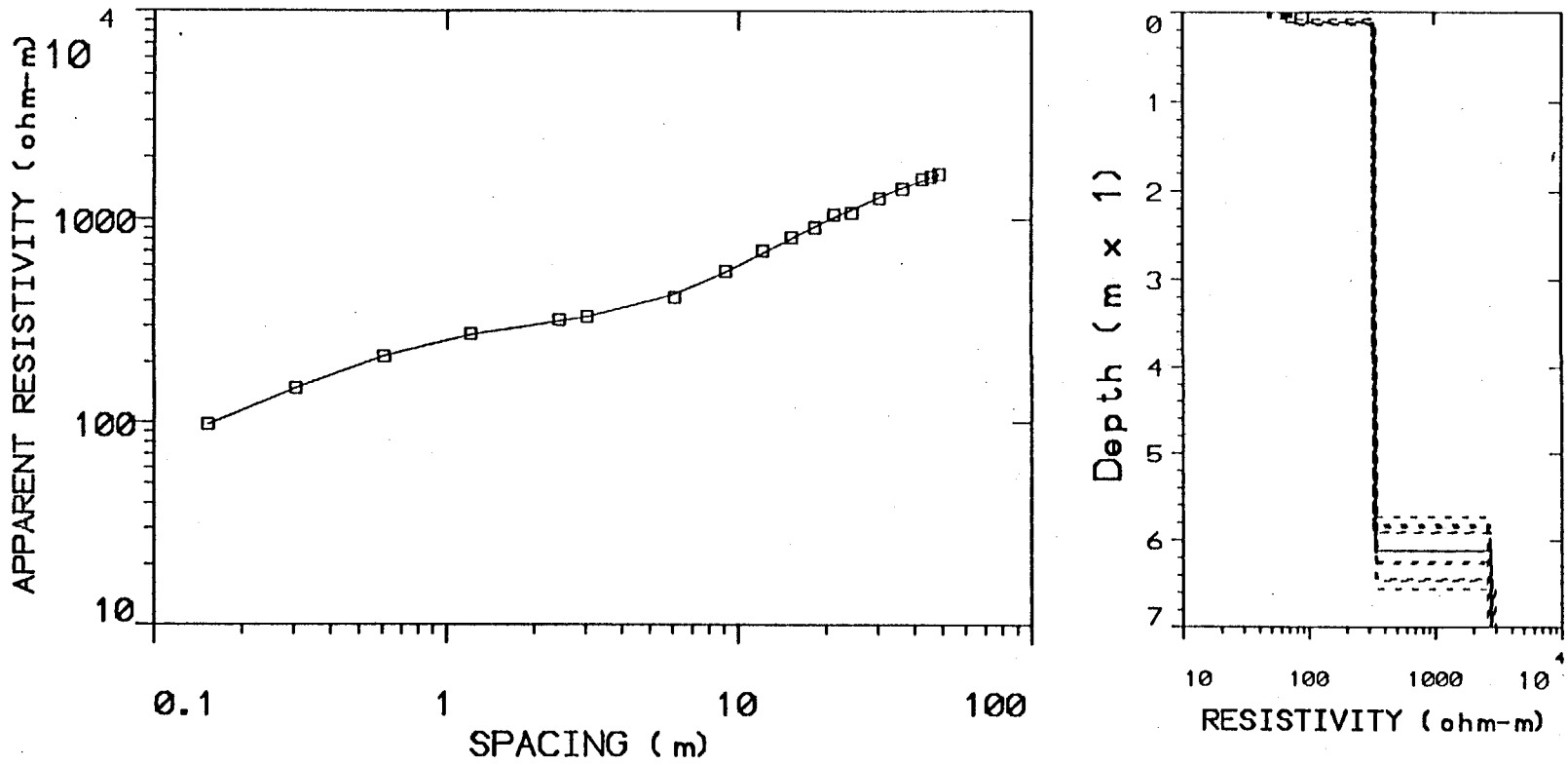

Figure A.1. Site 50 Eielson Air Force Base, 5/20/93, Data Set: BLK.TEST, Azimuth: 45°NE, Sounding: 1

DATA SET: BLK.TEST

CLIENT: US Air Force
LOCATION: Site 50 Eielson AFB
COUNTY: Blair Lakes Air Force Range
PROJECT: Permafrost Study
ELEVATION: 750.00
DATE: 5/20/93
SOUNDING: 1
AZIMUTH: 45 NE
EQUIPMENT: Abem SAS 300
SOUNDING COORDINATES: X: 127.4100 Y: -50.2900

Wenner Configuration

FITTING ERROR: 1.556 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			750.0		
1	67.13	0.121	749.8	0.00181	8.17
2	333.7	6.00	743.8	0.0179	2002.8
3	2744.5				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	47.926	67.133	80.134
	2	320.716	333.743	347.493
	3	2561.980	2744.507	2981.436
THICK	1	0.079	0.122	0.154
	2	5.622	6.001	6.429
DEPTH	1	0.079	0.122	0.154
	2	5.734	6.123	6.562

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.152	97.50	97.43	0.0718
2	0.304	148.0	148.3	-0.211
3	0.609	213.0	213.5	-0.226
4	1.21	274.3	273.2	0.380
5	2.43	323.3	319.5	1.19
6	3.04	335.2	335.3	-0.0268
7	6.09	417.6	430.6	-3.12
8	9.14	557.4	554.5	0.530
9	12.19	697.3	682.6	2.09
10	15.24	814.1	804.0	1.24
11	18.28	908.0	915.8	-0.865
12	21.33	1045.9	1018.3	2.63
13	24.38	1072.7	1112.3	-3.68
14	30.48	1264.3	1278.2	-1.09
15	36.57	1402.2	1419.7	-1.24
16	42.67	1555.5	1541.6	0.888
17	45.72	1609.1	1596.4	0.788
18	48.76	1655.1	1647.6	0.454

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	T 1	T 2
P 1	1.00				
P 2	0.00	1.00			
P 3	0.00	0.00	1.00		
T 1	0.00	0.00	0.00	0.99	
T 2	0.00	0.00	0.00	0.00	1.00

Figure A.1. (contd)

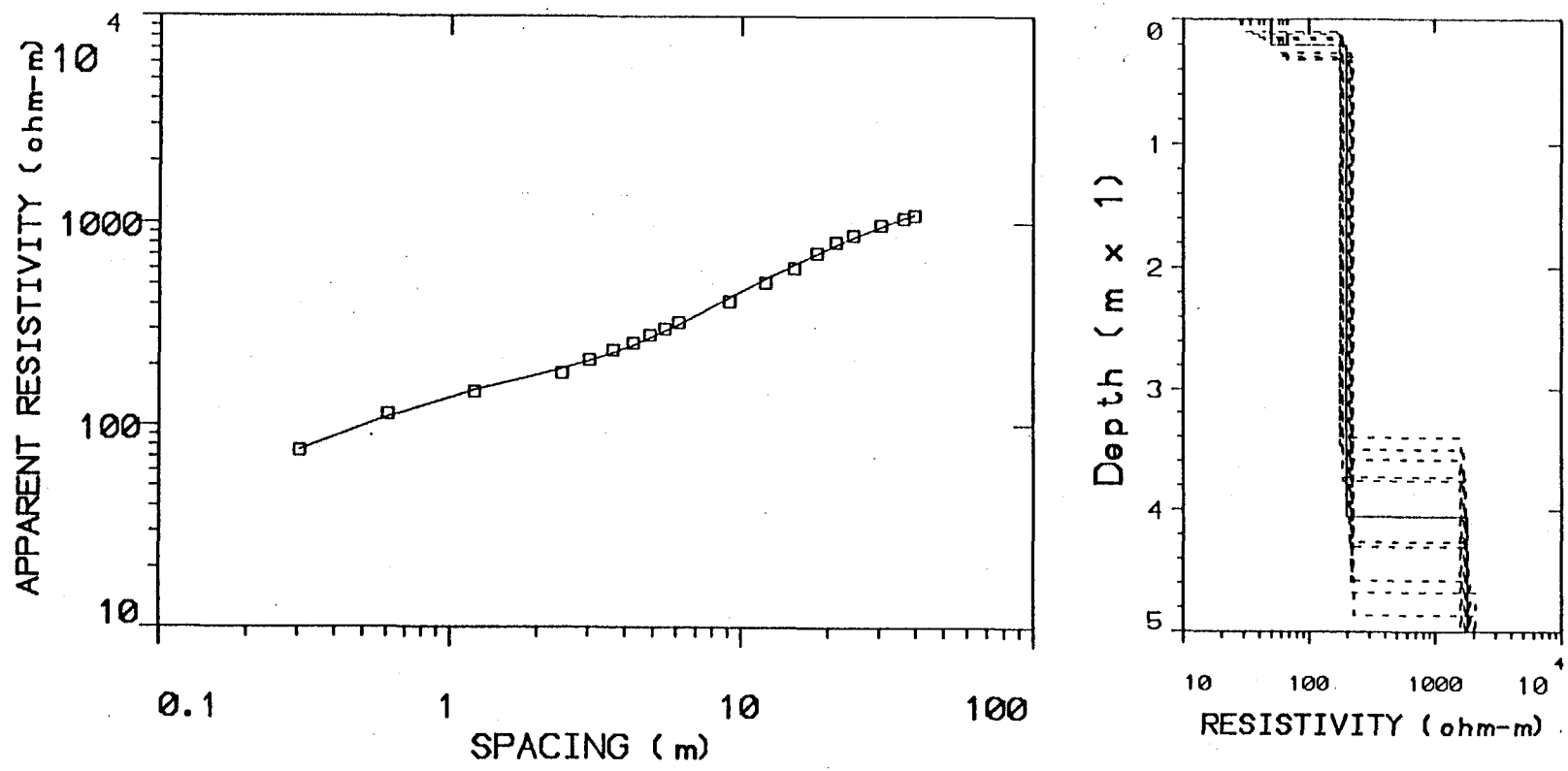

Figure A.2. Site 50 Eielson Air Force Base, 5/21/93, Data Set: BLK.NE1, Azimuth: 135°SE, Sounding: 2

DATA SET: BLK.NE1

CLIENT: US Air Force DATE: 5/21/93
LOCATION: Site 50 Eielson AFB SOUNDING: 2
COUNTY: Blair Lakes Air Force Range AZIMUTH: 135 SE
PROJECT: Permafrost Study EQUIPMENT: Abem SAS 300
ELEVATION: 750.00
SOUNDING COORDINATES: X: 101.8000 Y: 99.6700

Wenner Configuration

FITTING ERROR: 2.758 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			750.0		
1	49.64	0.207	749.7	0.00418	10.30
2	199.6	3.84	745.9	0.0192	767.5
3	1796.5				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	28.374	49.647	68.300
	2	175.982	199.603	225.343
	3	1578.438	1796.551	2090.225
THICK	1	0.098	0.207	0.326
	2	3.255	3.845	4.567
DEPTH	1	0.098	0.207	0.326
	2	3.401	4.053	4.865

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.304	75.26	75.62	-0.468
2	0.609	113.7	110.8	2.51
3	1.21	147.0	150.8	-2.53
4	2.43	183.8	193.2	-5.12
5	3.04	212.5	211.8	0.328
6	3.65	239.0	231.4	3.17
7	4.26	257.4	252.1	2.03
8	4.87	281.9	273.9	2.83
9	5.48	303.3	296.3	2.30
10	6.09	325.5	319.2	1.94
11	9.14	413.6	432.4	-4.54
12	12.19	513.2	536.1	-4.46
13	15.24	603.2	628.5	-4.19
14	18.28	712.4	710.9	0.211
15	21.33	804.3	784.6	2.45
16	24.38	873.3	850.9	2.55
17	30.48	976.7	965.3	1.17
18	36.57	1057.1	1060.0	-0.274
19	39.62	1095.4	1101.5	-0.553

CURRENT RESOLUTION MATRIX NOT AVAILABLE

Figure A.2. (contd)

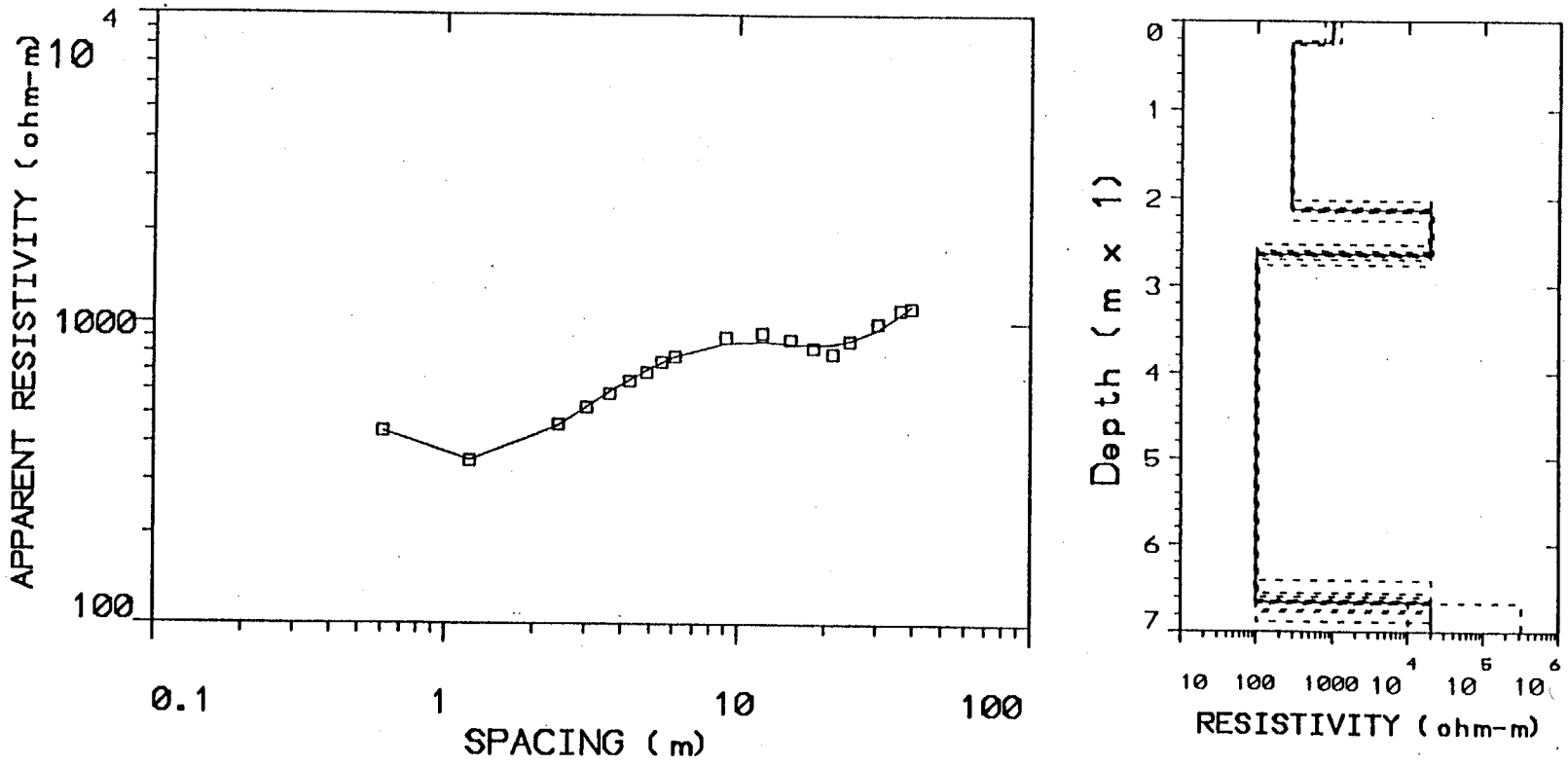

Figure A.3. Site 50 Eielson Air Force Base, 5/21/93, Data Set: BLK.NE2, Azimuth: 135°SE, Sounding: 3

DATA SET: BLK.NE2

CLIENT: US Air Force DATE: 5/21/93
LOCATION: Site 50 Eielson AFB SOUNDING: 3
COUNTY: Blair Lakes Air Force Range AZIMUTH: 135 SE
PROJECT: Permafrost Study EQUIPMENT: Abem SAS 300
ELEVATION: 750.00
SOUNDING COORDINATES: X: 68.5800 Y: 50.9000

Wenner Configuration

FITTING ERROR: 3.100 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			750.0		
1	959.4	0.246	749.7	2.565E-04	236.0
2	285.3	1.88	747.8	0.00660	537.3
3	19789.8	0.504	747.3	2.550E-05	9984.9
4	100.0	4.02	743.3	0.0402	402.3
5	20000.0				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	744.441	959.495	1231.605
	2	273.388	285.322	297.974
	3	18686.904	19789.814	21478.225
	4	95.132	100.035	106.161
	5	10205.463	20000.000	320000.000
THICK	1	0.216	0.246	0.276
	2	1.777	1.883	2.005
	3	0.471	0.505	0.555
	4	3.778	4.022	4.246
DEPTH	1	0.216	0.246	0.276
	2	2.023	2.129	2.251
	3	2.526	2.634	2.757
	4	6.412	6.656	6.880

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.609	436.2	436.0	0.0504
2	1.21	346.2	348.2	-0.576
3	2.43	459.6	456.6	0.646
4	3.04	522.8	526.3	-0.673
5	3.65	581.4	591.5	-1.73
6	4.26	640.8	649.1	-1.29
7	4.87	686.4	698.3	-1.73
8	5.48	741.1	739.4	0.228
9	6.09	773.7	773.2	0.0640
10	9.14	896.3	859.4	4.11
11	12.19	926.9	869.6	6.17
12	15.24	880.9	857.6	2.65
13	18.28	827.3	849.0	-2.62
14	21.33	790.9	854.0	-7.96
15	24.38	873.3	874.4	-0.130
16	30.48	995.9	955.4	4.06
17	36.57	1103.1	1072.7	2.75
18	39.62	1120.3	1139.5	-1.70

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.01								
P 2	0.02	0.25							
P 3	0.00	0.01	0.00						
P 4	0.00	0.00	0.00	0.00					
P 5	0.00	0.00	0.00	0.00	0.00				
T 1	0.02	0.03	0.00	0.00	0.00	0.04			
T 2	0.00	-0.17	-0.01	0.00	0.00	0.01	0.16		
T 3	0.00	0.05	0.01	0.01	0.00	0.00	-0.05	0.08	
T 4	0.00	-0.01	-0.01	-0.01	0.00	0.00	0.01	-0.06	0.14
	P 1	P 2	P 3	P 4	P 5	T 1	T 2	T 3	T 4

Figure A.3. (contd)

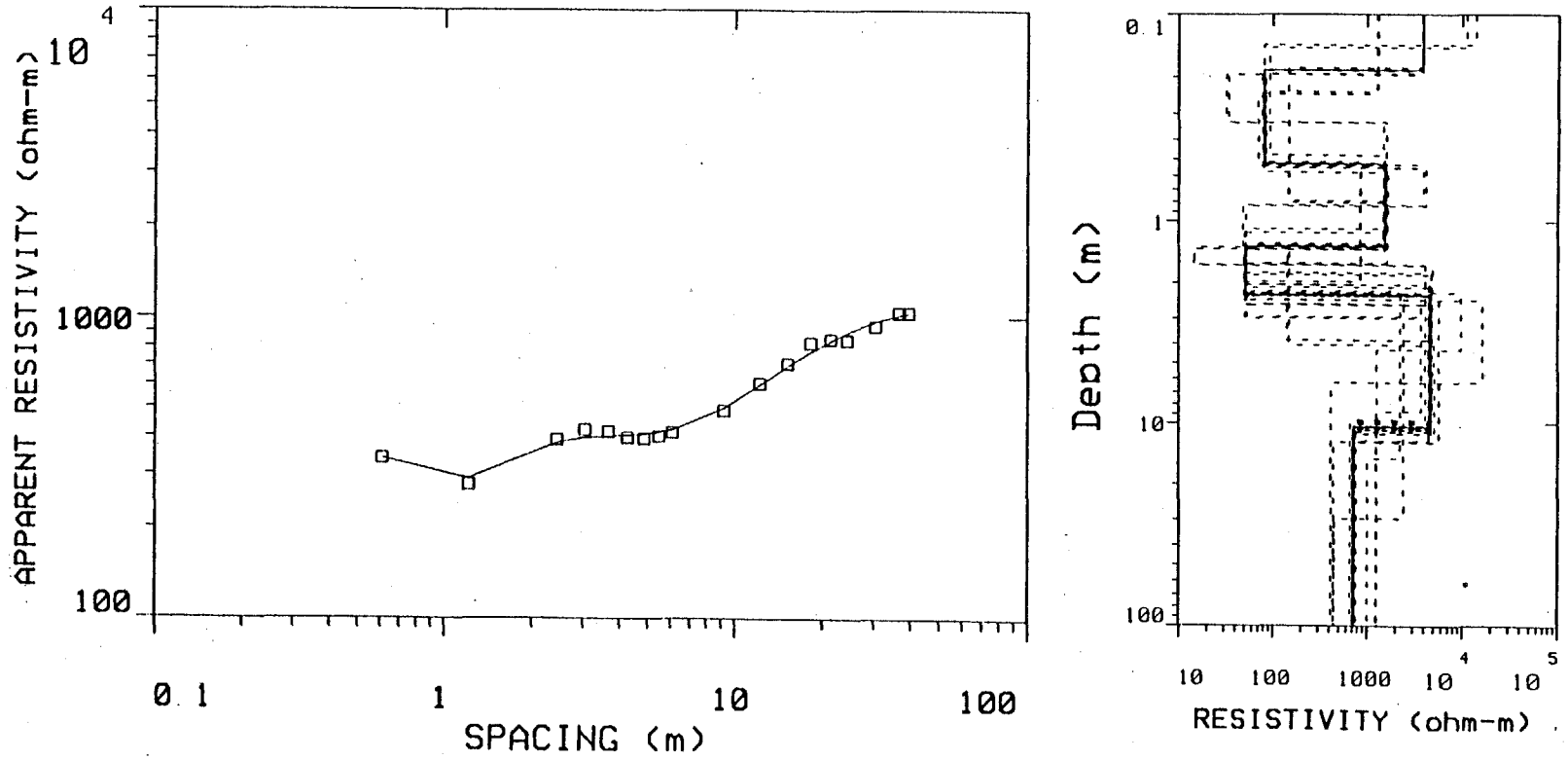

Figure A.4. Site 50 Eielson Air Force Base, 5/21/93, Data Set: BLK.NE3, Azimuth: 135°SE, Sounding: 4

DATA SET: BLK.NE3

CLIENT: US Air Force
LOCATION: Site 50 Eielson AFB
COUNTY: Blair Lakes Air Force Range
PROJECT: Permafrost Study
ELEVATION: 750.00
SOUNDING COORDINATES: X: 5.4900 Y: 20.4200

DATE: 5/21/93
SOUNDING: 4
AZIMUTH: 135 SE
EQUIPMENT: Abem SAS 300

Wenner Configuration

FITTING ERROR: 3.455 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			750.0		
1	3907.3	0.185	749.8	4.742E-05	724.0
2	81.23	0.337	749.4	0.00415	27.41
3	1571.5	0.795	748.6	5.064E-04	1250.8
4	51.37	0.958	747.7	0.0186	49.25
5	4688.2	8.18	739.5	0.00175	38369.6
6	731.8				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	1287.847	3907.325	13923.519
	2	32.206	81.235	148.023
	3	847.653	1571.581	4252.059
	4	14.620	51.371	149.111
	5	2240.859	4688.277	16552.729
	6	415.000	731.819	1269.588
THICK	1	0.141	0.185	0.240
	2	0.135	0.337	0.627
	3	0.294	0.796	1.524
	4	0.273	0.959	2.784
	5	2.084	8.184	27.293
DEPTH	1	0.141	0.185	0.240
	2	0.329	0.523	0.807
	3	0.831	1.319	2.042
	4	1.632	2.277	4.062
	5	4.318	10.461	29.609

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.609	340.1	339.8	0.0770
2	1.21	277.3	290.1	-4.63
3	2.43	392.2	383.2	2.28
4	3.04	421.3	396.6	5.84
5	3.65	415.9	401.8	3.36
6	4.26	396.8	404.5	-1.95
7	4.87	395.2	407.9	-3.20
8	5.48	403.3	413.5	-2.54
9	6.09	413.6	421.9	-1.98
10	9.14	488.3	497.0	-1.78
11	12.19	601.3	595.1	1.03
12	15.24	704.7	689.0	2.23
13	18.28	826.2	770.5	6.74
14	21.33	848.6	838.5	1.19
15	24.38	842.6	893.9	-6.08
16	30.48	940.3	973.6	-3.53
17	36.57	1036.6	1021.0	1.71
18	39.62	1040.7	1035.6	0.486

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.05										
P 2	0.00	0.50									
P 3	0.00	0.01	0.51								
P 4	0.00	-0.01	0.03	0.49							
P 5	0.00	0.00	-0.01	0.02	0.40						
P 6	-0.01	0.00	0.01	-0.03	0.27	0.37					
T 1	0.21	0.03	0.00	0.00	0.00	0.00	0.95				
T 2	0.00	-0.49	-0.03	0.00	-0.01	0.01	0.02	0.49			
T 3	0.00	-0.03	0.49	0.01	-0.02	0.02	0.00	0.01	0.48		
T 4	0.00	0.00	0.00	-0.49	-0.05	0.02	0.00	0.00	0.02	0.51	
T 5	0.00	0.00	-0.01	-0.01	0.36	0.27	0.00	-0.01	-0.01	-0.01	0.33
	P 1	P 2	P 3	P 4	P 5	P 6	T 1	T 2	T 3	T 4	T 5

Figure A.4. (contd)

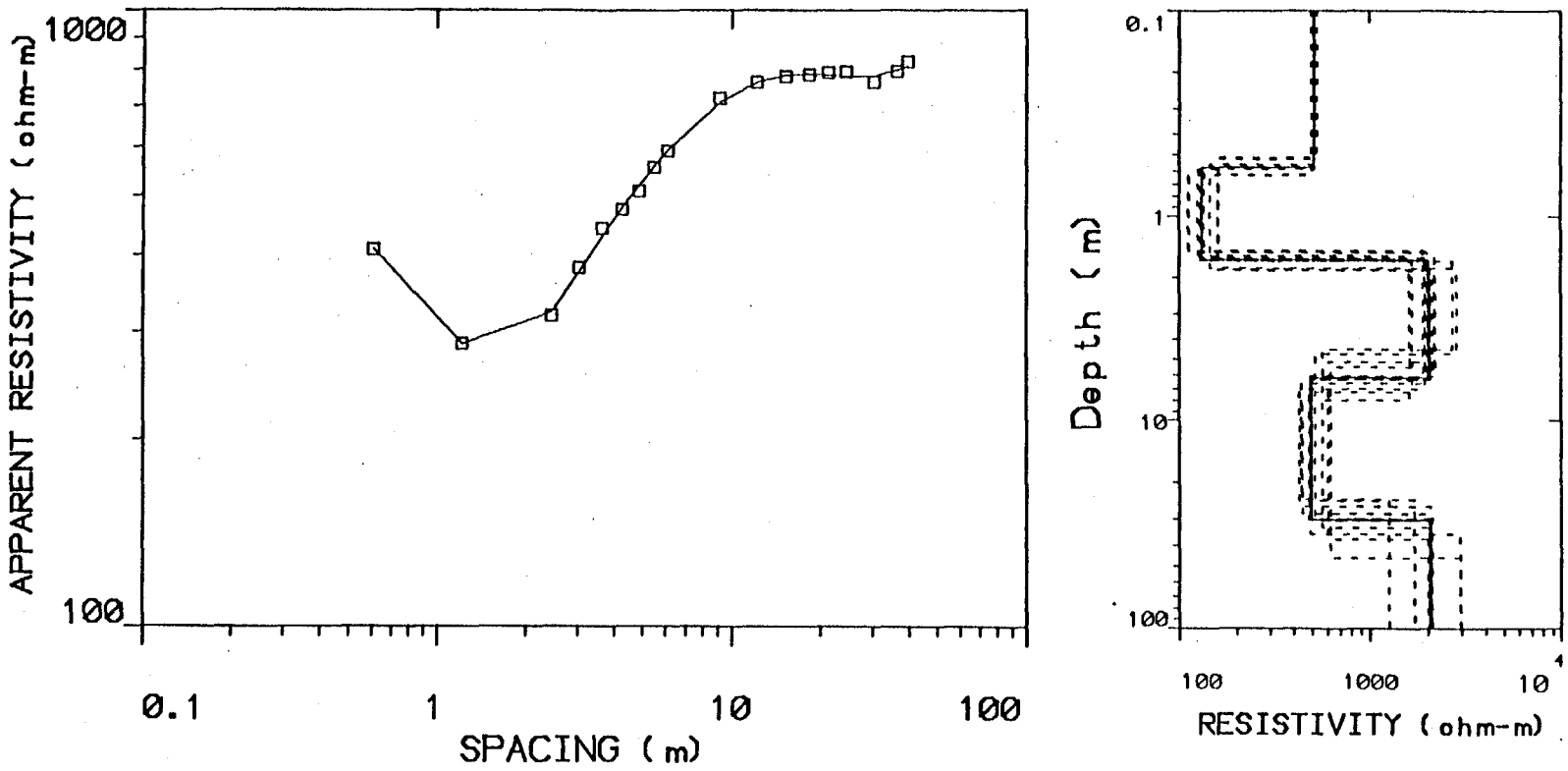

Figure A.5. Site 50 Eielson Air Force Base, 5/21/93, Data Set: BLK.NE4, Azimuth: 135°SE, Sounding: 5

DATA SET: BLK.NE4

CLIENT: US Air Force
LOCATION: Site 50 Eielson AFB
COUNTY: Blair Lakes Air Force Range
PROJECT: Permafrost Study
ELEVATION: 750.00
SOUNDING COORDINATES: X: 30.4800 Y: 8.8400

DATE: 5/21/93
SOUNDING: 5
AZIMUTH: 135 SE
EQUIPMENT: Abem SAS 300

Wenner Configuration

FITTING ERROR: 1.330 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			750.0		
1	514.6	0.577	749.4	0.00112	297.2
2	130.7	1.05	748.3	0.00809	138.1
3	2021.6	4.53	743.8	0.00224	9173.1
4	493.9	23.86	719.9	0.0483	11787.3
5	2063.1				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	497.176	514.672	536.995
	2	110.022	130.720	160.230
	3	1599.923	2021.666	2827.945
	4	429.549	493.998	622.720
	5	1253.087	2063.101	2975.371
THICK	1	0.517	0.578	0.633
	2	0.852	1.057	1.322
	3	2.824	4.537	6.348
	4	17.438	23.861	40.382
DEPTH	1	0.517	0.578	0.633
	2	1.475	1.635	1.849
	3	4.487	6.172	7.961
	4	24.018	30.033	45.850

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.609	408.3	408.8	-0.127
2	1.21	286.5	286.4	0.0122
3	2.43	318.6	322.8	-1.31
4	3.04	380.7	376.1	1.20
5	3.65	441.7	428.5	2.97
6	4.26	473.7	476.9	-0.664
7	4.87	508.6	520.4	-2.31
8	5.48	556.0	559.2	-0.566
9	6.09	591.7	593.5	-0.289
10	9.14	719.9	710.2	1.34
11	12.19	763.0	763.9	-0.123
12	15.24	779.4	783.3	-0.500
13	18.28	785.9	786.4	-0.0510
14	21.33	790.9	783.3	0.959
15	24.38	792.1	780.0	1.53
16	30.48	764.1	781.8	-2.31
17	36.57	795.1	798.6	-0.433
18	39.62	824.1	811.9	1.47

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.99								
P 2	-0.06	0.48							
P 3	-0.01	-0.14	0.53						
P 4	0.00	0.03	-0.07	0.80					
P 5	0.00	-0.01	0.02	0.00	0.22				
T 1	0.03	0.24	0.05	-0.01	0.00	0.88			
T 2	-0.03	-0.31	-0.13	0.02	-0.01	0.14	0.81		
T 3	-0.01	-0.02	0.39	0.18	-0.04	0.02	0.02	0.58	
T 4	0.00	0.03	0.01	-0.21	-0.33	-0.01	0.02	0.11	0.61
	P 1	P 2	P 3	P 4	P 5	T 1	T 2	T 3	T 4

Figure A.5. (contd)

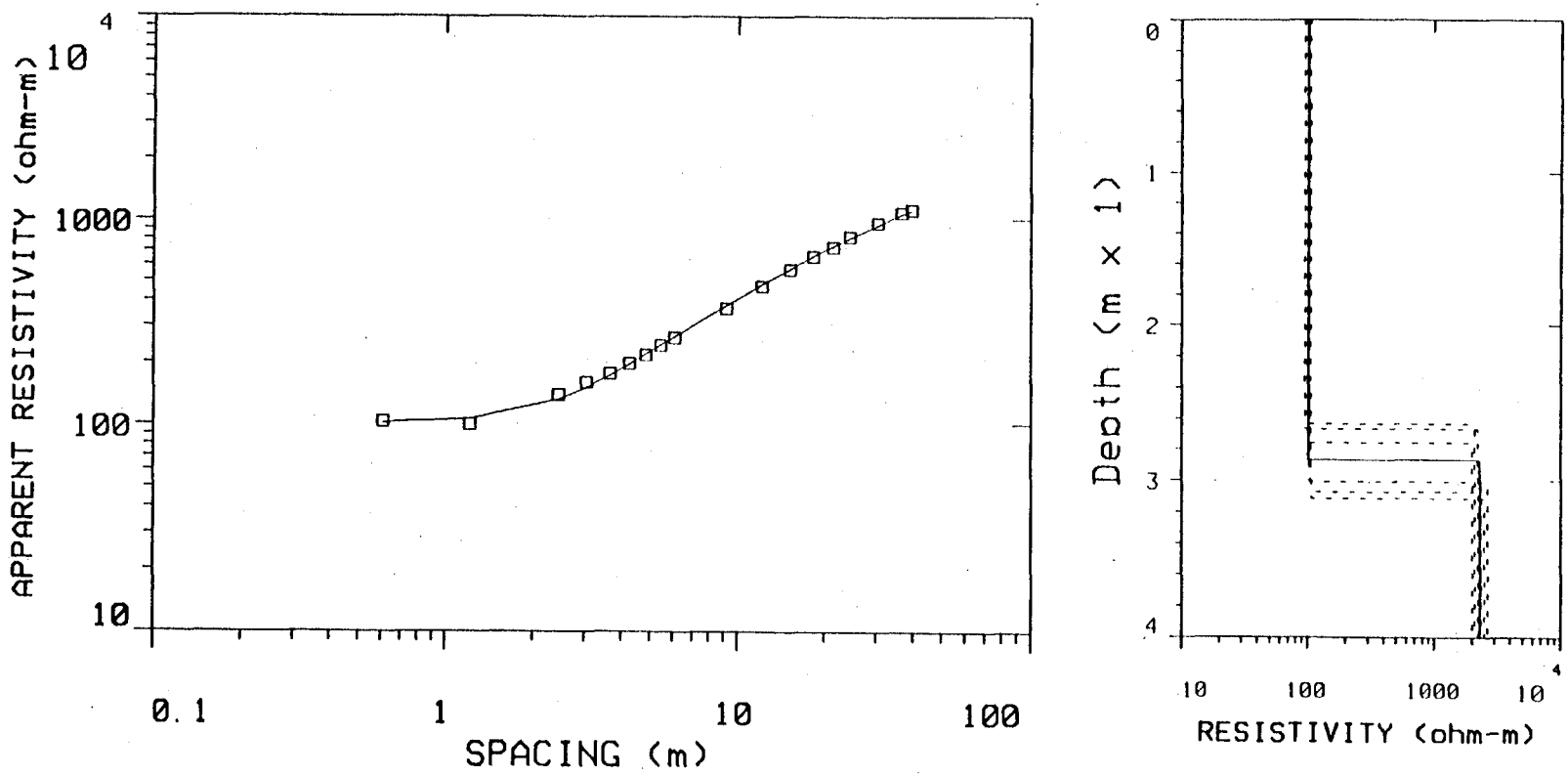

Figure A.6. Site 50 Eielson Air Force Base, 5/21/93, Data Set: BLK.SE2B, Azimuth: 45°NE, Sounding: 6

DATA SET: BLK.SE2B

CLIENT: US Air Force
LOCATION: Site 50 Eielson AFB
COUNTY: Blair Lakes Air Force Range
PROJECT: Permafrost Study
ELEVATION: 750.00
SOUNDING COORDINATES: X: 76.5100 Y: -76.2000

DATE: 5/21/93
SOUNDING: 6
AZIMUTH: 45 NE
EQUIPMENT: Abem SAS 300

Wenner Configuration

FITTING ERROR: 2.747 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			750.0		
1	100.6	2.86	747.1	0.0285	288.6
2	2278.5				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	94.710	100.606	106.445
	2	2006.707	2278.565	2635.566
THICK	1	2.634	2.869	3.112
DEPTH	1	2.634	2.869	3.112

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.609	102.6	101.3	1.29
2	1.21	99.43	105.9	-6.58
3	2.43	138.5	131.7	4.85
4	3.04	159.1	151.0	5.08
5	3.65	176.2	172.6	2.05
6	4.26	197.8	195.5	1.19
7	4.87	216.0	218.9	-1.33
8	5.48	240.6	242.4	-0.743
9	6.09	262.3	265.7	-1.29
10	9.14	363.6	377.4	-3.78
11	12.19	468.8	479.4	-2.26
12	15.24	566.9	572.7	-1.03
13	18.28	651.5	658.4	-1.06
14	21.33	727.9	737.4	-1.30
15	24.38	818.1	810.5	0.927
16	30.48	955.6	941.4	1.48
17	36.57	1070.9	1055.1	1.47
18	39.62	1110.4	1106.5	0.348

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	T 1
P 1	1.00		
P 2	0.00	1.00	
T 1	0.00	0.00	1.00

Figure A.6. (contd)

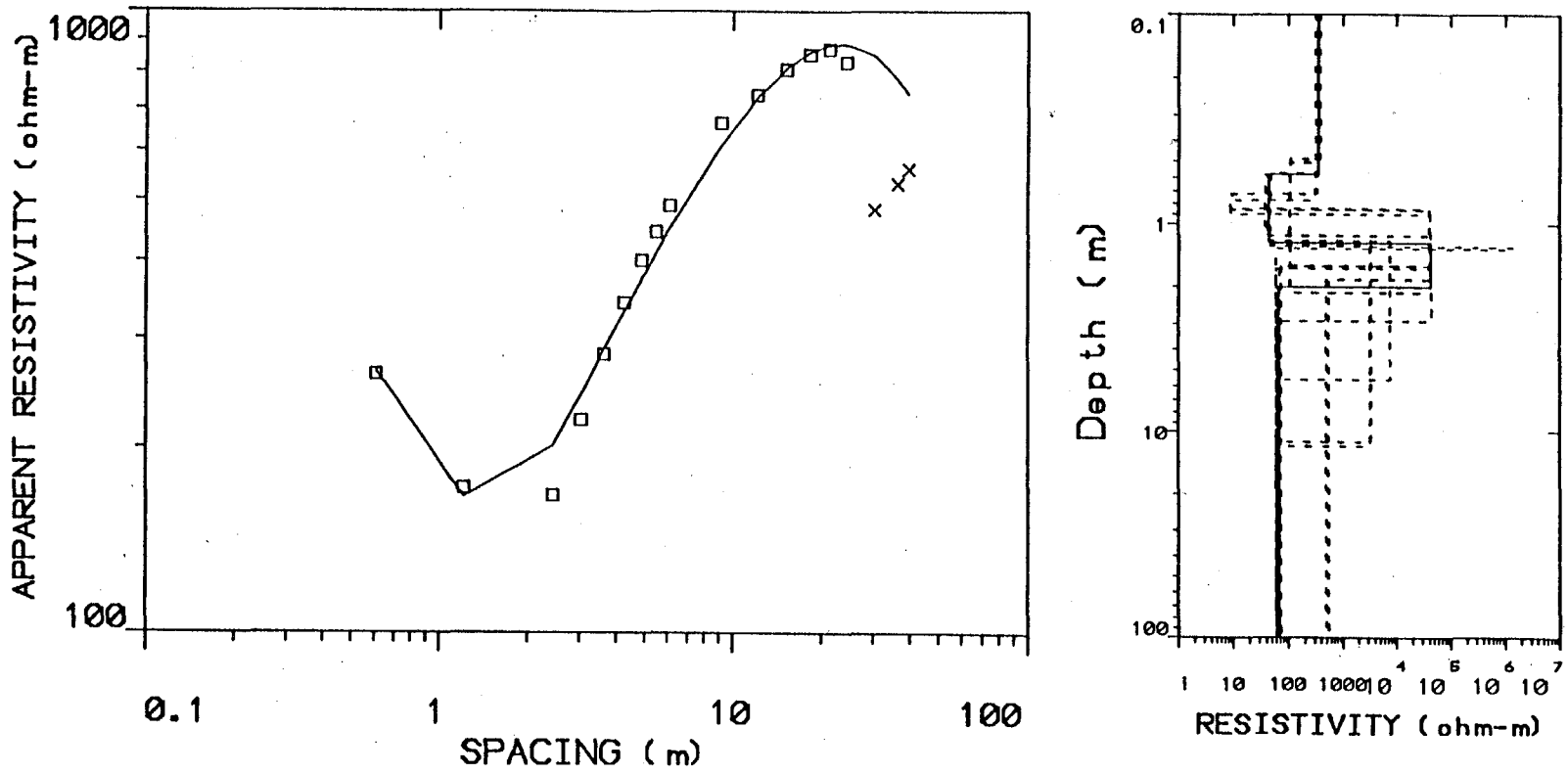

Figure A.7. Site 50 Eielson Air Force Base, 5/22/93, Data Set: BLK.SE1, Azimuth: 45°NE, Sounding: 7

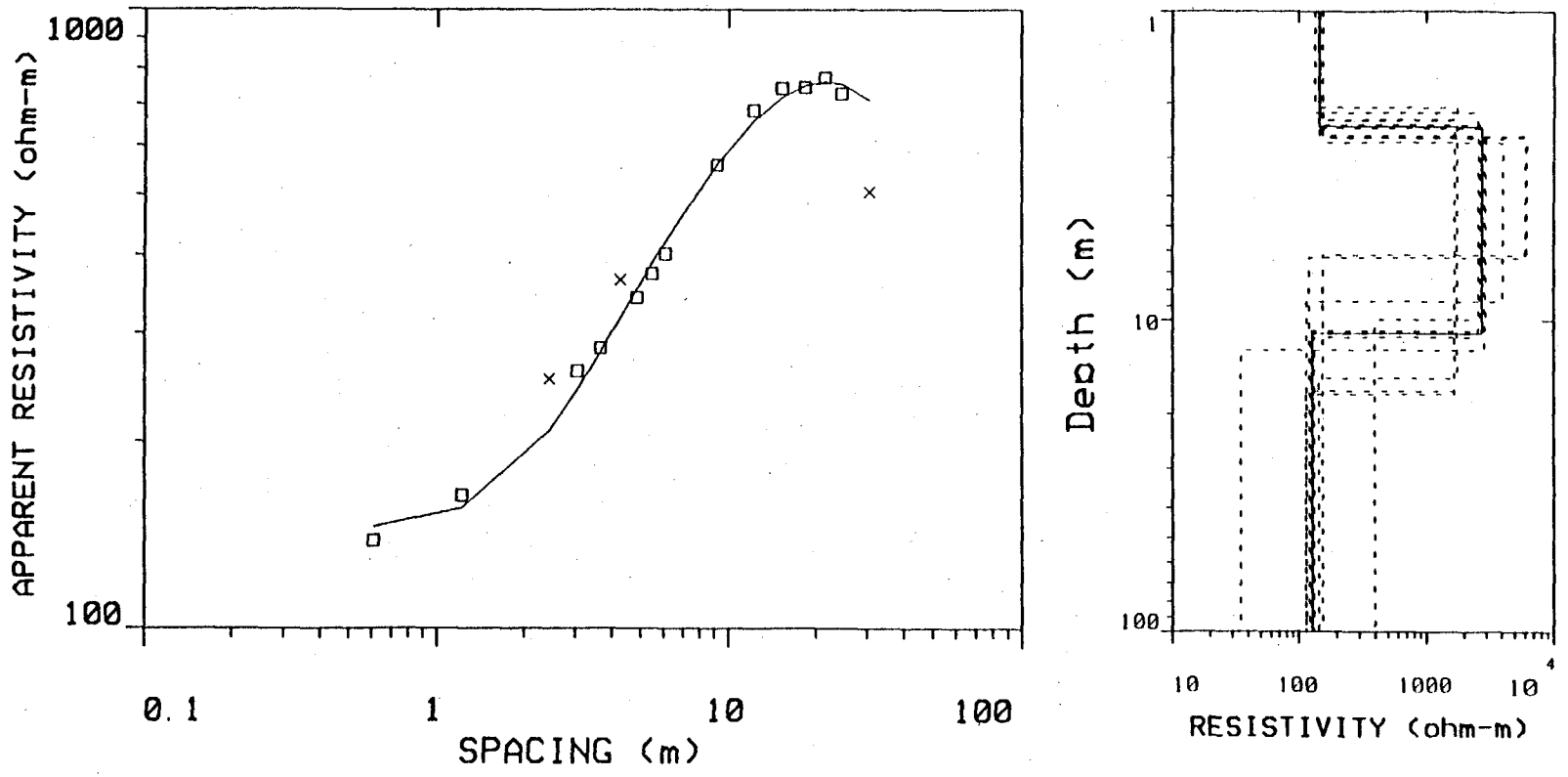

Figure A.8. Site 50 Eielson Air Force Base, 5/22/93, Data Set: BLK.SE3B, Azimuth: 45°NE, Sounding: 8

DATA SET: BLK.SE3B

CLIENT: US Air Force
LOCATION: Site 50 Eielson AFB
COUNTY: Blair Lakes Air Force Range
PROJECT: Permafrost Study
ELEVATION: 750.00
SOUNDING COORDINATES: X: 31.7000 Y: -43.2800

DATE: 5/22/93
SOUNDING: 8
AZIMUTH: 45 NE
EQUIPMENT: Abem SAS 300

Wenner Configuration

FITTING ERROR: 3.888 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			750.0		
1	144.0	2.38	747.6	0.0165	342.9
2	2768.9	8.64	738.9	0.00312	23945.3
3	127.2				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	132.653	144.081	154.707
	2	1675.323	2768.995	6251.673
	3	34.667	127.232	393.687
THICK	1	2.073	2.380	2.678
	2	3.631	8.648	15.008
DEPTH	1	2.073	2.380	2.678
	2	6.182	11.028	17.286

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.609	138.6	145.8	-5.18
2	1.21	163.9	156.4	4.57
3	2.43	252.8	208.3	17.57
4	3.04	260.4	243.2	6.60
5	3.65	283.6	280.0	1.26
6	4.26	364.3	316.9	13.03
7	4.87	341.3	352.9	-3.38
8	5.48	372.6	387.5	-4.00
9	6.09	400.6	420.6	-4.98
10	9.14	558.4	559.4	-0.173
11	12.19	683.3	656.3	3.94
12	15.24	742.1	717.6	3.30
13	18.28	744.6	750.1	-0.738
14	21.33	772.2	760.4	1.52
15	24.38	727.7	754.2	-3.63
16	30.48	503.6	709.5	-40.86

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	T 1	T 2
P 1	0.99				
P 2	0.00	0.57			
P 3	0.00	0.03	0.07		
T 1	-0.01	-0.04	0.01	0.99	
T 2	0.00	0.45	0.11	0.04	0.50

Figure A.8. (contd)

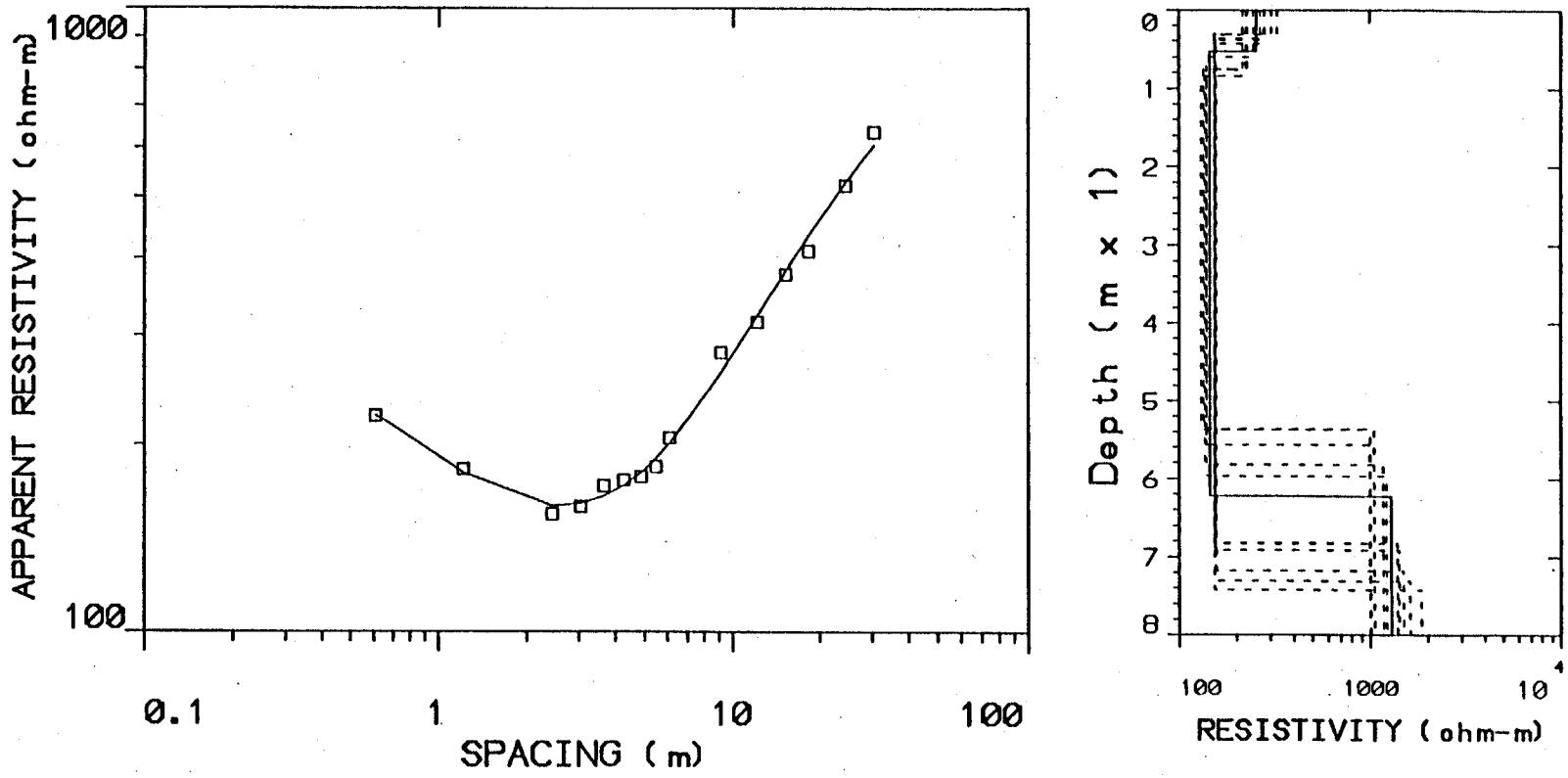

Figure A.9. Site 50 Eielson Air Force Base, 5/22/93, Data Set: BLK.SW1, Azimuth: 135°SE, Sounding: 9

DATA SET: BLK.SW1

CLIENT: US Air Force DATE: 5/22/93
LOCATION: Site 50 Eielson AFB SOUNDING: 9
COUNTY: Blair Lakes Air Force Range AZIMUTH: 135 SE
PROJECT: Permafrost Study EQUIPMENT: Abem SAS 300
ELEVATION: 750.00
SOUNDING COORDINATES: X: -14.0200 Y: -45.7200

Wenner Configuration

FITTING ERROR: 3.402 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			750.0		
1	255.6	0.524	749.4	0.00205	134.1
2	144.7	5.70	743.7	0.0394	825.0
3	1284.8				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	216.732	255.634	327.016
	2	130.503	144.710	156.754
	3	999.560	1284.870	1858.574
THICK	1	0.302	0.525	0.846
	2	4.530	5.701	6.989
DEPTH	1	0.302	0.525	0.846
	2	5.363	6.226	7.419

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.609	222.1	222.7	-0.255
2	1.21	182.3	180.3	1.06
3	2.43	154.5	159.4	-3.15
4	3.04	158.9	160.7	-1.14
5	3.65	171.6	165.3	3.71
6	4.26	175.0	172.0	1.73
7	4.87	177.1	180.4	-1.87
8	5.48	184.0	190.1	-3.27
9	6.09	204.9	200.7	2.03
10	9.14	280.9	261.1	7.05
11	12.19	314.8	323.0	-2.58
12	15.24	375.3	380.9	-1.47
13	18.28	409.0	433.9	-6.08
14	24.38	520.9	526.7	-1.12
15	30.48	633.9	604.9	4.57

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	1.00					
P 2	0.00	1.00				
P 3	0.00	0.00	1.00			
T 1	0.00	0.00	0.00	0.99		
T 2	0.00	0.00	0.00	0.00	1.00	
	P 1	P 2	P 3	T 1	T 2	

Figure A.9. (contd)

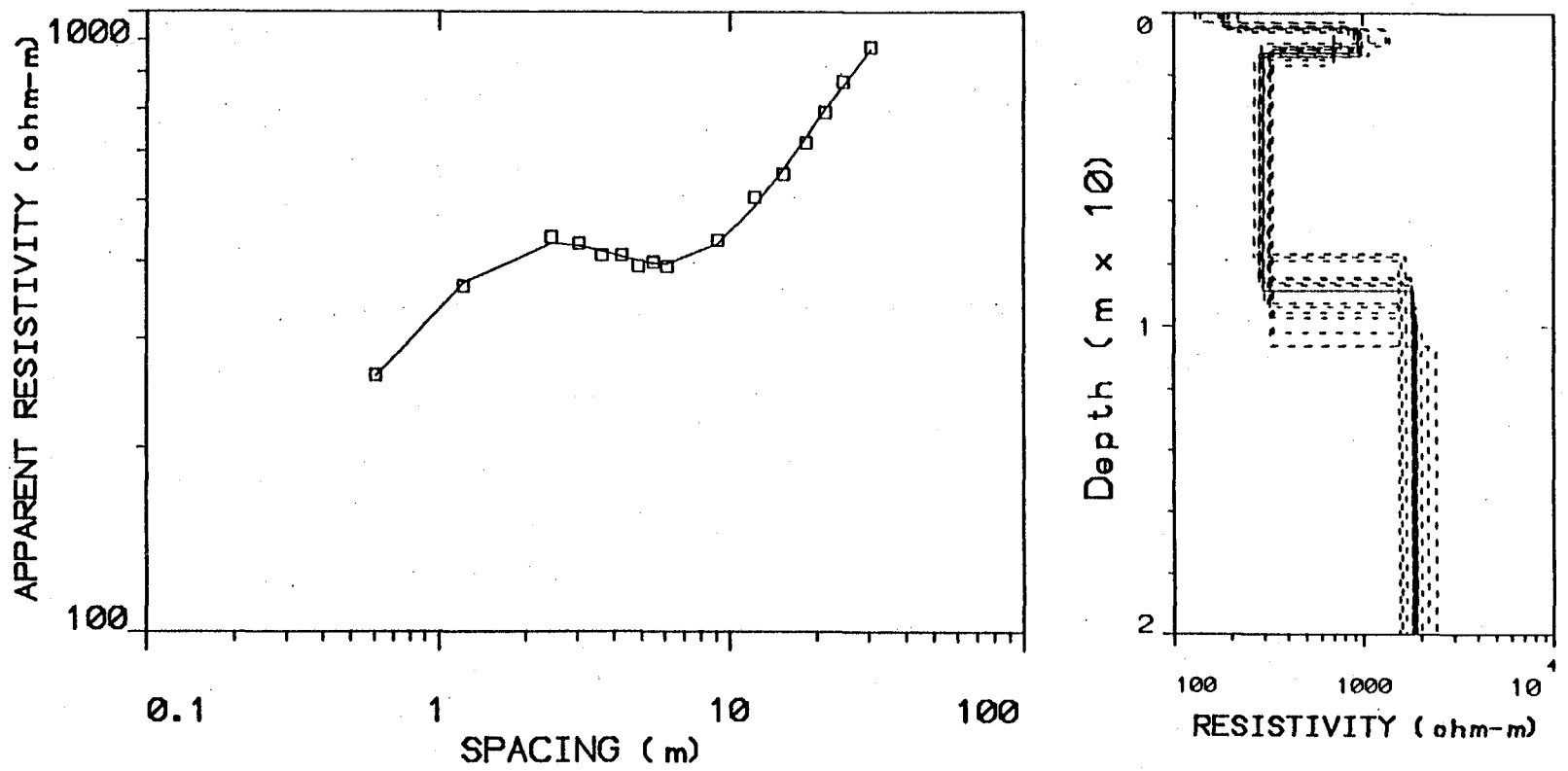

Figure A.10. Site 50 Eielson Air Force Base, 5/22/93, Data Set: BLK.SW2, Azimuth: 135°SE, Sounding: 10

DATA SET: BLK.SW2

CLIENT: US Air Force
LOCATION: Site 50 Eielson AFB
COUNTY: Blair Lakes Air Force Range
PROJECT: Permafrost Study
ELEVATION: 750.00
SOUNDING COORDINATES: X: -44.5000 Y: -87.7800

DATE: 5/22/93
SOUNDING: 10
AZIMUTH: 135 SE
EQUIPMENT: Abem SAS 300

Wenner Configuration

FITTING ERROR: 1.492 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			750.0		
1	182.2	0.475	749.5	0.00261	86.59
2	937.5	0.792	748.7	8.449E-04	742.7
3	296.2	7.61	741.1	0.0256	2254.6
4	1845.8				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	129.398	182.282	217.956
	2	698.430	937.573	1380.883
	3	264.460	296.277	333.885
	4	1541.922	1845.803	2411.156
THICK	1	0.291	0.475	0.632
	2	0.469	0.792	1.235
	3	6.257	7.610	9.505
DEPTH	1	0.291	0.475	0.632
	2	0.974	1.267	1.686
	3	7.684	8.877	10.643

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.609	262.3	262.0	0.118
2	1.21	364.6	368.7	-1.12
3	2.43	436.6	427.3	2.14
4	3.04	427.0	423.9	0.743
5	3.65	408.8	415.4	-1.60
6	4.26	408.8	406.8	0.501
7	4.87	393.4	400.3	-1.74
8	5.48	398.8	396.6	0.560
9	6.09	392.2	395.9	-0.939
10	9.14	432.0	427.4	1.07
11	12.19	505.6	490.1	3.06
12	15.24	551.5	561.4	-1.79
13	18.28	619.3	632.2	-2.07
14	21.33	691.7	699.2	-1.07
15	24.38	772.2	761.4	.38
16	30.48	877.1	872.2	0.562

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.85						
P 2	-0.05	0.62					
P 3	0.03	0.02	0.94				
P 4	0.01	0.03	-0.05	0.84			
T 1	-0.21	-0.16	0.06	0.03	0.66		
T 2	0.00	0.42	0.07	0.04	0.08	0.36	
T 3	0.05	0.02	-0.10	-0.13	0.09	0.12	0.82
	P 1	P 2	P 3	P 4	T 1	T 2	T 3

Figure A.10. (contd)

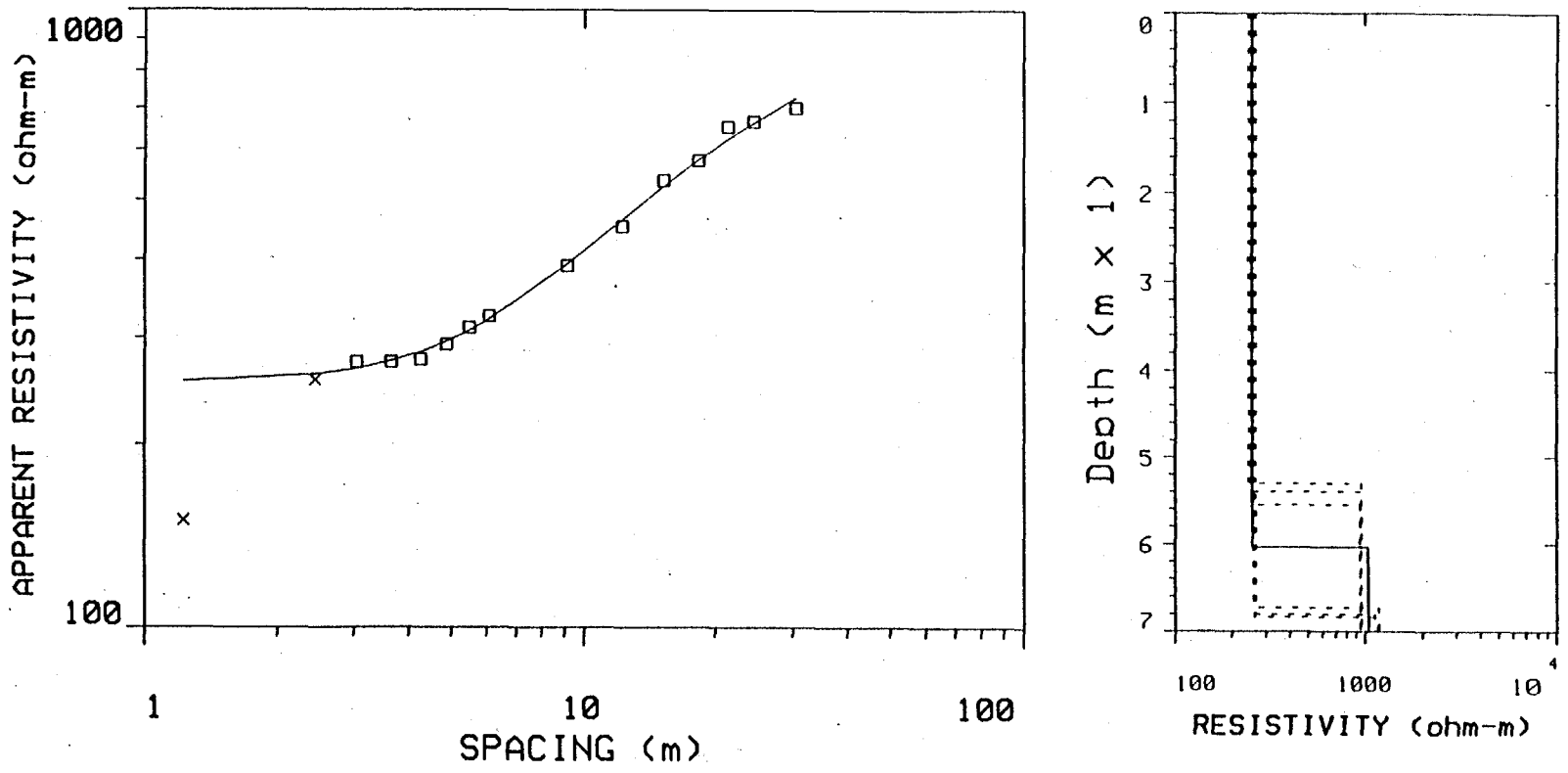

Figure A.11. Site 50 Eielson Air Force Base, 5/22/93, Data Set: BLK.SW3C, Azimuth: 135°SE, Sounding: 11

DATA SET: BLK.SW3C

CLIENT: US Air Force DATE: 5/22/93
LOCATION: Site 50 Eielson AFB SOUNDING: 11
COUNTY: Blair Lakes Air Force Range AZIMUTH: 135 SE
PROJECT: Permafrost Study EQUIPMENT: Abem SAS 300
ELEVATION: 750.00
SOUNDING COORDINATES: X: -48.4600 Y: -6.4000

Wenner Configuration

FITTING ERROR: 2.277 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			750.0		
1	253.3	6.04	743.9	0.0238	1530.6
2	1038.7				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	241.576	253.360	264.664
	2	939.508	1038.778	1178.484
THICK	1	5.305	6.041	6.832
DEPTH	1	5.305	6.041	6.832

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	1.21	149.6	254.3	-69.89
2	2.43	255.1	260.5	-2.15
3	3.04	273.2	266.5	2.45
4	3.65	273.7	274.5	-0.297
5	4.26	275.9	284.2	-3.02
6	4.87	292.0	295.4	-1.18
7	5.48	310.9	307.9	0.964
8	6.09	324.0	321.3	0.838
9	9.14	390.7	393.8	-0.817
10	12.19	451.9	463.7	-2.59
11	15.24	536.2	525.0	2.08
12	18.28	576.8	577.7	-0.157
13	21.33	652.8	622.9	4.57
14	24.38	664.9	662.0	0.441
15	30.48	699.0	725.5	-3.78

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	1.00		
P 2	0.00	1.00	
T 1	0.00	0.00	1.00
	P 1	P 2	T 1

Figure A.11. (contd)

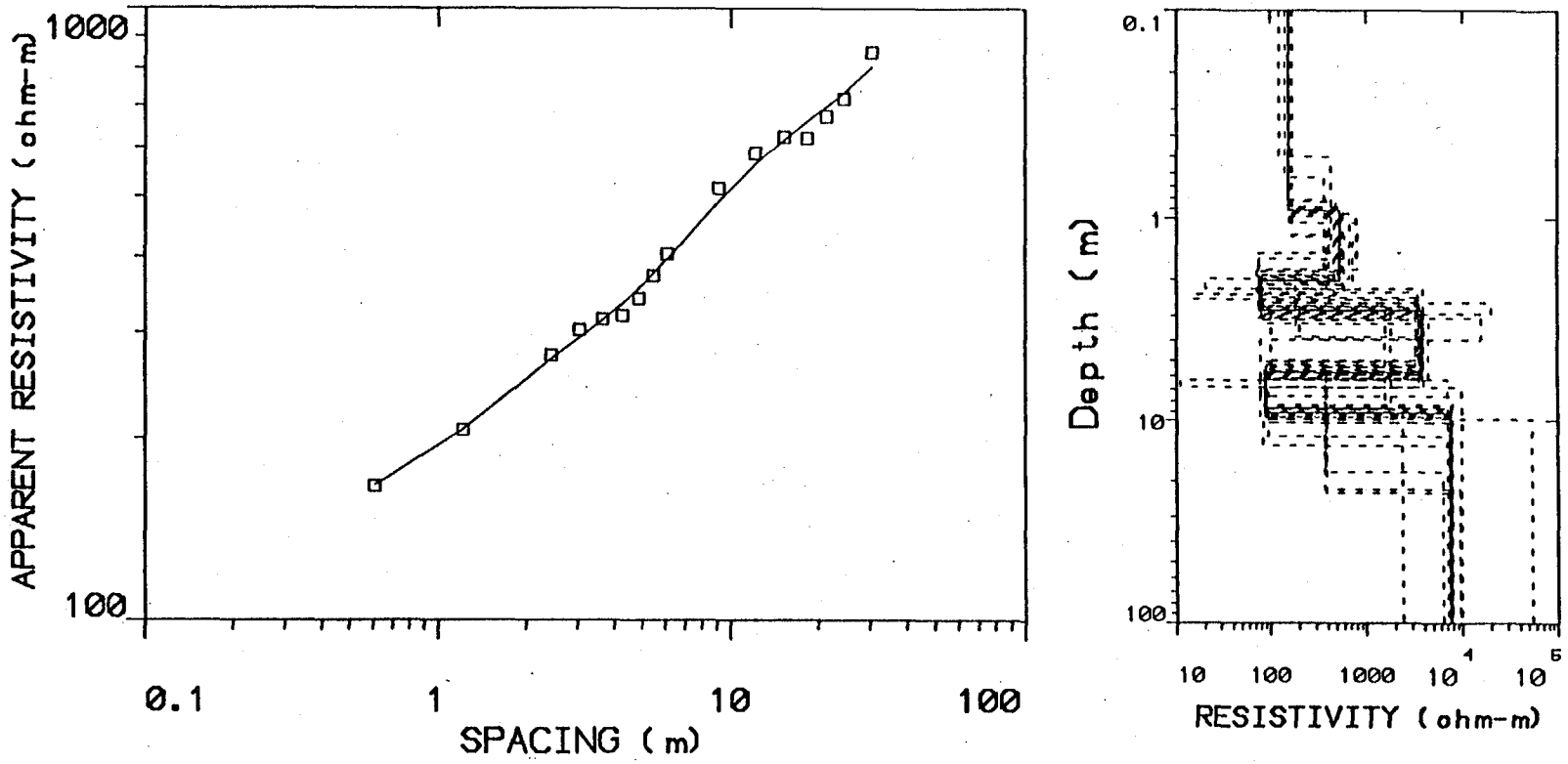

Figure A.12. Site 50 Eielson Air Force Base, 5/22/93, Data Set: BLK.NW1, Azimuth: 45°NE, Sounding: 12

DATA SET: BLK.NW1

CLIENT: US Air Force
LOCATION: Site 50 Eielson AFB
COUNTY: Blair Lakes Air Force Range
PROJECT: Permafrost Study
ELEVATION: 750.00
SOUNDING COORDINATES: X: -40.8400 Y: 80.1600

DATE: 5/22/93
SOUNDING: 12
AZIMUTH: 45 NE
EQUIPMENT: Abem SAS 300

Wenner Configuration

FITTING ERROR: 3.380 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			750.0		
1	153.6	0.912	749.0	0.00594	140.1
2	537.8	1.11	747.9	0.00207	597.3
3	78.60	0.805	747.1	0.0102	63.28
4	3701.0	2.89	744.2	7.825E-04	10718.3
5	88.63	3.41	740.8	0.0385	303.0
6	7549.7				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	122.984	153.621	170.283
	2	368.447	537.839	817.199
	3	14.617	78.608	200.625
	4	1568.507	3701.053	20006.967
	5	10.954	88.635	389.286
	6	2369.519	7549.740	54117.082
THICK	1	0.502	0.912	1.231
	2	0.622	1.111	1.657
	3	0.138	0.805	1.945
	4	0.365	2.896	6.923
	5	0.533	3.419	16.901
DEPTH	1	0.502	0.912	1.231
	2	1.485	2.023	2.541
	3	2.212	2.828	3.941
	4	2.950	5.724	9.861
	5	6.263	9.144	22.789

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.609	166.2	166.9	-0.424
2	1.21	206.0	206.7	-0.321
3	2.43	274.5	271.2	1.22
4	3.04	302.6	293.4	3.02
5	3.65	314.6	313.7	0.278
6	4.26	319.0	333.8	-4.63
7	4.87	340.1	354.2	-4.16
8	5.48	371.2	375.0	-1.00
9	6.09	403.7	395.7	1.97
10	9.14	515.3	490.9	4.73
11	12.19	587.5	563.6	4.08
12	15.24	622.4	617.1	0.851
13	18.28	620.5	659.2	-6.24
14	21.33	671.6	695.9	-3.61
15	24.38	717.0	731.0	-1.95
16	30.48	848.4	804.2	5.20

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	P 4	P 5	P 6	T 1	T 2	T 3	T 4	T 5
P 1	0.99										
P 2	-0.01	0.58									
P 3	0.00	0.09	0.47								
P 4	0.00	-0.03	0.02	0.46							
P 5	0.00	0.01	-0.01	0.05	0.47						
P 6	0.00	0.00	0.00	-0.02	0.07	0.01					
T 1	-0.03	-0.14	0.02	-0.03	0.01	0.00	0.86				
T 2	-0.01	0.42	-0.03	-0.04	0.02	0.00	0.05	0.36			
T 3	0.00	-0.04	-0.48	-0.04	0.01	0.00	0.00	0.08	0.50		
T 4	0.00	-0.02	0.00	0.45	0.03	-0.02	-0.03	-0.03	-0.01	0.44	
T 5	0.00	-0.01	0.01	-0.02	-0.48	-0.07	-0.01	-0.01	-0.01	-0.01	0.49

Figure A.12. (contd)

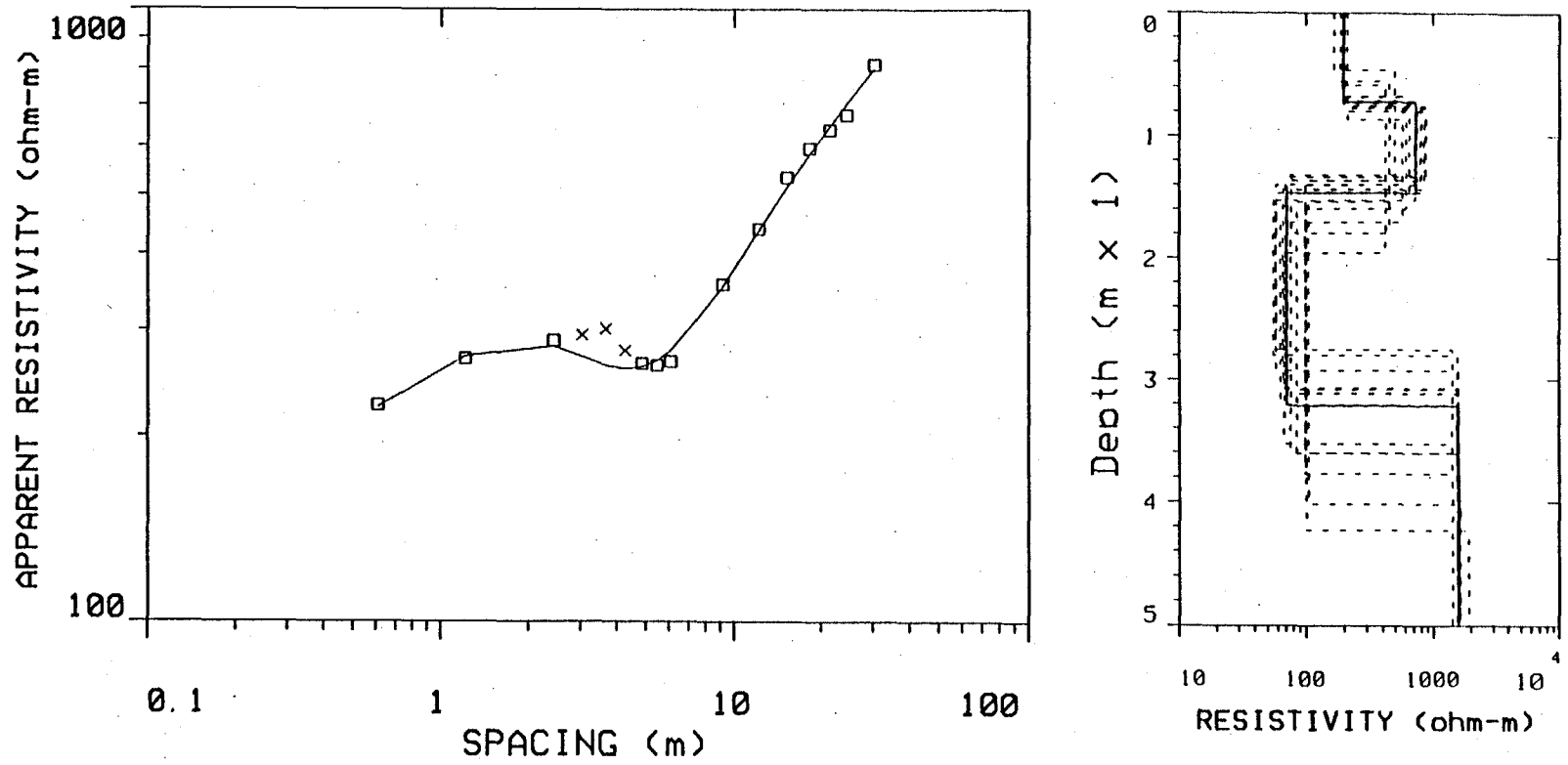

Figure A.13. Site 50 Eielson Air Force Base, 5/22/93, Data Set: BLK.NW2B, Azimuth: 45°NE, Sounding: 13

DATA SET: BLK.NW2B

CLIENT: US Air Force DATE: 5/22/93
LOCATION: Site 50 Eielson AFB SOUNDING: 13
COUNTY: Blair Lakes Air Force Range AZIMUTH: 45 NE
PROJECT: Permafrost Study EQUIPMENT: Abem SAS 300
ELEVATION: 750.00
SOUNDING COORDINATES: X: -15.2400 Y: 20.4200

Wenner Configuration

FITTING ERROR: 2.315 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			750.0		
1	197.1	0.724	749.2	0.00368	142.8
2	733.8	0.740	748.5	0.00101	543.6
3	70.82	1.74	746.7	0.0247	123.9
4	1576.6				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	166.553	197.104	210.830
	2	420.629	733.806	876.016
	3	55.737	70.830	104.344
	4	1414.794	1576.664	1908.680
THICK	1	0.465	0.725	0.865
	2	0.559	0.741	1.370
	3	1.331	1.750	2.639
DEPTH	1	0.465	0.725	0.865
	2	1.320	1.466	1.961
	3	2.751	3.215	4.233

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.609	224.8	223.1	0.772
2	1.21	268.1	270.8	-0.999
3	2.43	287.5	281.3	2.15
4	3.04	293.7	270.3	7.97
5	3.65	300.8	261.7	13.00
6	4.26	276.4	258.2	6.59
7	4.87	263.2	260.0	1.18
8	5.48	261.3	266.5	-2.02
9	6.09	265.4	276.6	-4.22
10	9.14	355.0	352.7	0.653
11	12.19	438.9	436.2	0.613
12	15.24	532.4	513.3	3.58
13	18.28	595.2	582.9	2.07
14	21.33	636.8	645.6	-1.39
15	24.38	674.1	702.5	-4.21
16	30.48	812.0	801.5	1.29

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	P 4	T 1	T 2	T 3
P 1	0.99						
P 2	-0.02	0.34					
P 3	0.01	-0.05	0.25				
P 4	0.00	0.02	-0.04	0.98			
T 1	-0.03	-0.24	0.03	0.00	0.86		
T 2	0.00	0.35	0.16	-0.01	0.10	0.79	
T 3	0.01	0.11	-0.36	-0.03	0.06	0.00	0.79

Figure A.13. (contd)

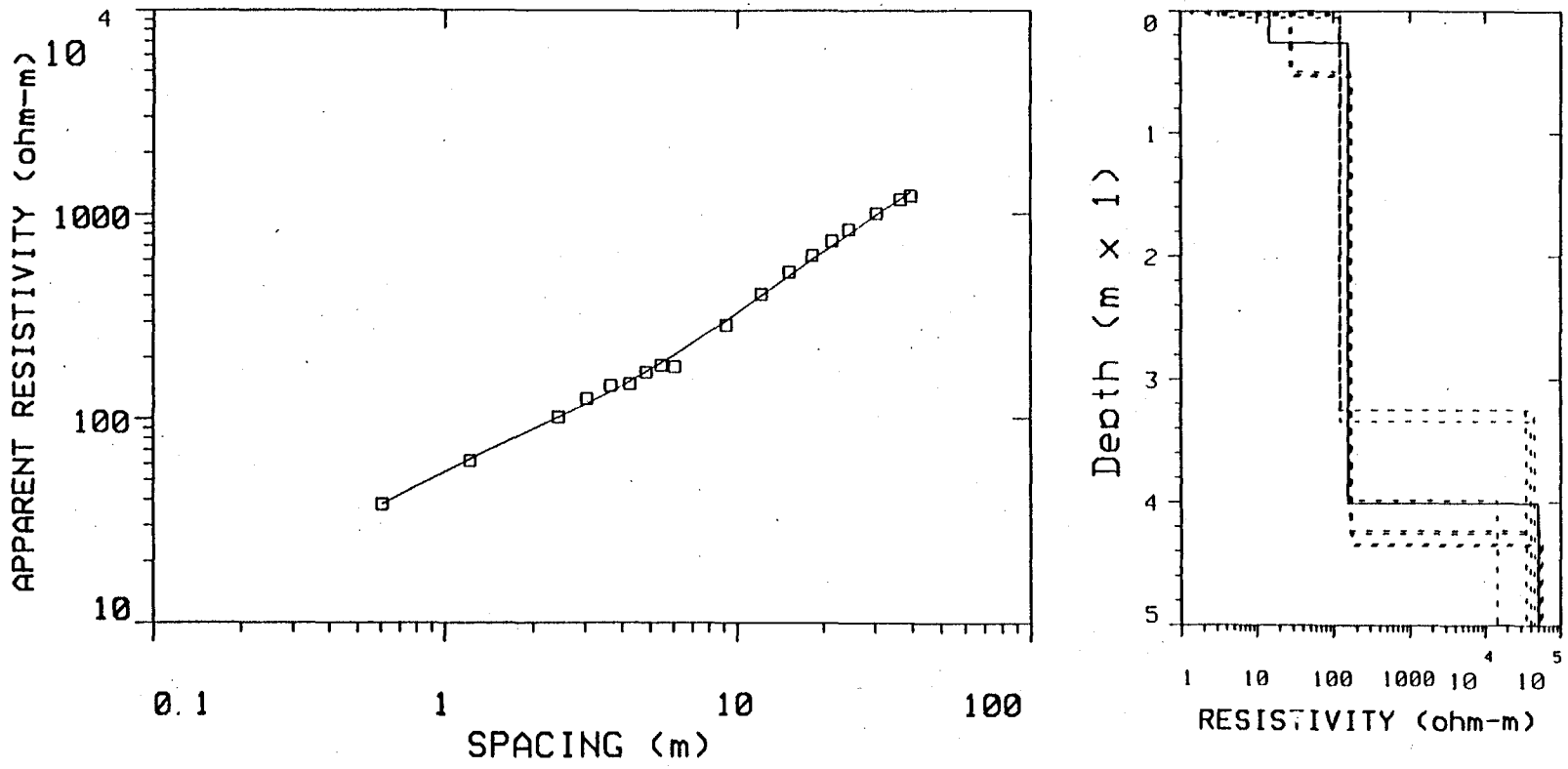

Figure A.14. Site 50 Eielson Air Force Base, 5/23/93, Data Set: BLK.WS1C, Azimuth: 135°SE, Sounding: 14

DATA SET: BLK.WS1C

CLIENT: US Air Force DATE: 5/23/93
LOCATION: Site 50 Eielson AFB SOUNDING: 14
COUNTY: Blair Lakes Air Force Range AZIMUTH: 135 SE
PROJECT: Permafrost Study EQUIPMENT: Abem SAS 300
ELEVATION: 750.00
SOUNDING COORDINATES: X: -25.0000 Y: -486.0000

Wenner Configuration

FITTING ERROR: 5.024 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			750.0		
1	14.69	0.261	749.7	0.0178	3.84
2	156.2	3.75	745.9	0.0240	585.9
3	50000.0				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	1.330	14.693	29.212
	2	121.759	156.214	173.011
	3	14413.109	50000.000	57268.996
THICK	1	0.021	0.262	0.545
	2	3.212	3.751	3.811
DEPTH	1	0.021	0.262	0.545
	2	3.250	4.013	4.356

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.609	37.80	37.79	0.0174
2	1.21	61.82	63.26	-2.34
3	2.43	101.7	101.1	0.603
4	3.04	124.2	118.0	5.06
5	3.65	145.0	134.8	7.01
6	4.26	147.2	152.0	-3.26
7	4.87	169.1	169.6	-0.271
8	5.48	182.0	187.6	-3.10
9	6.09	179.6	206.1	-14.75
10	9.14	287.2	302.3	-5.22
11	12.19	406.0	401.0	1.23
12	15.24	519.9	500.0	3.83
13	18.28	625.1	598.7	4.21
14	21.33	736.0	697.1	5.28
15	24.38	839.6	795.1	5.29
16	30.48	1007.3	990.0	1.72
17	36.57	1176.7	1183.3	-0.564
18	39.62	1232.4	1279.4	-3.81

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	T 1	T 2
P 1	0.67				
P 2	-0.03	1.00			
P 3	-0.01	0.00	0.02		
T 1	-0.34	-0.03	-0.02	0.64	
T 2	-0.03	0.00	-0.01	-0.03	1.00

Figure A.14. (contd)

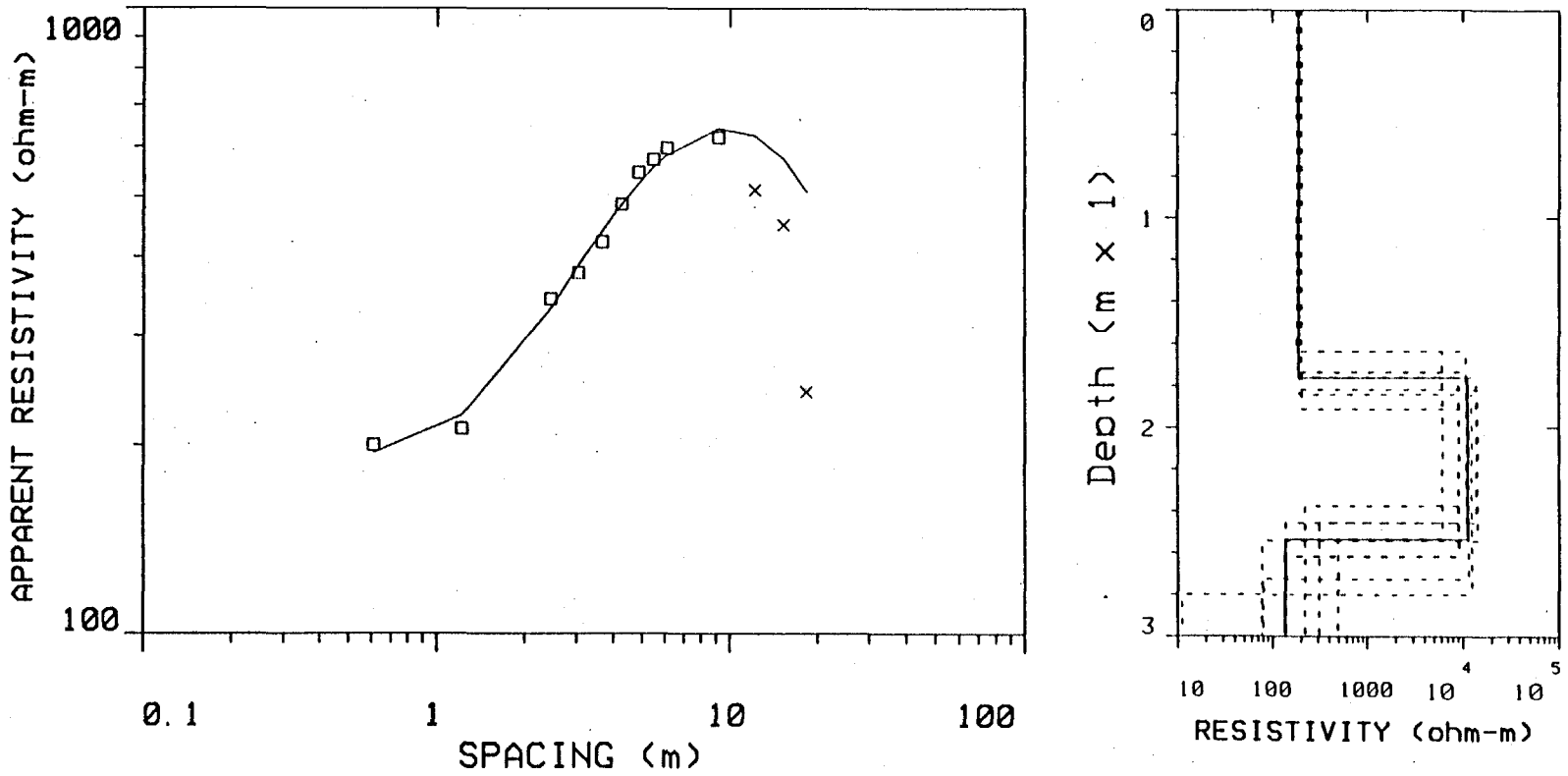

Figure A.15. Site 50 Eielson Air Force Base, 5/23/93, Data Set: BLK.SE4B, Azimuth: 45°SE, Sounding: 15

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