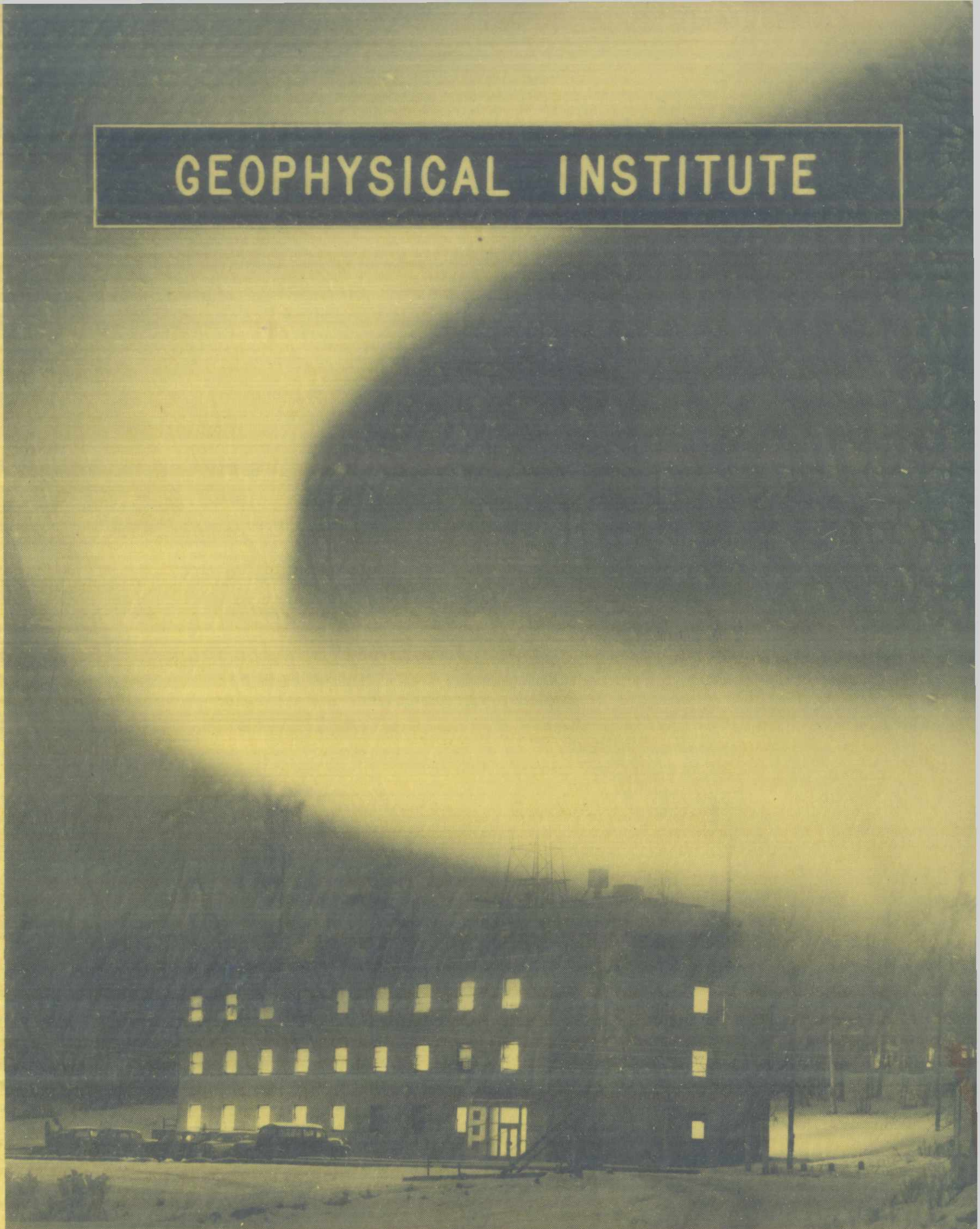

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EARTH POTENTIAL ELECTRODES IN PERMAFROST AND TUNDRA

by

V. P. Hessler and A. R. Franzke

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Introduction

During the past two years, the authors installed a number of electrodes in the permafrost and tundra area of Point Barrow to obtain earth potential data. As ground temperatures decreased during the winter, the resistances of the first set of electrodes increased by several orders of magnitude and thus became useless. A second set of electrodes, with sodium chloride incorporated in the fill, proved entirely adequate for recording earth potentials. The installations and procedure for determining electrode resistances are described herein. Electrode resistance data versus time and ground temperatures are also presented.

The Untreated Electrodes

The first set of five electrodes was laid out as shown in Fig. 1. The X electrode was installed to give a pair in the geomagnetic meridian, and East was added because of an unsatisfactory soil condition at West electrode. Although the tundra area selected appears quite uniform, the soil at North, South, and X electrodes is clayey, at West electrode it is peat, and at East it is a soil-peat mixture.

The electrodes are lead sheets 8 ft. x 8 in., cut into inch wide strips, spread in a crowfoot pattern, and installed in a 6 ft. x 6 ft. excavation down to permafrost. The average depth to permafrost in August 1955 was 12 in. The excavated material was tamped in carefully around the electrode and then overlaid with sections of tundra vegetation to approximate the undisturbed conditions of the area. Lines were extended from each electrode to a "wanigan" that houses the recording equipment.

Electrode Resistance Measurements

All electrode resistance measurements were made with an ohmmeter of the type used in electronic circuit testing. Electrode pairs were connected to the ohmmeter and readings taken quickly to minimize the effect of polarization. Direct and reversed readings were taken to compensate for the error caused by chemical potential between the electrodes. The average of the two readings, which sometimes differed as much as five per cent, was used to calculate the individual electrode resistance. The ohmmeter gives somewhat pessimistic results as indicated by experience with a low range Megger Ground Tester which utilizes an ac source and thus eliminates errors due to polarization. However, acquisition of more accurate resistance measuring equipment would not have been justified because knowledge of the electrode resistance values was not required for the calibration of the earth potential equipment.

Resistance readings were taken at frequent intervals between every possible electrode pair, and individual electrode resistance values were calculated from sets of three readings with the following equations:

$$R_1 = (R_{12} + R_{13} - R_{23})/2$$

$$R_2 = (R_{23} + R_{21} - R_{31})/2$$

$$R_3 = (R_{31} + R_{32} - R_{12})/2$$

The subscripts 1, 2, and 3 may stand for any three of the five electrodes. As a check, the resistance of, say N, was calculated in terms of N, S, and W data, and again in terms of N, E, and X data. All resistance values presented for the untreated electrodes are averages of two or more such calculations.

Ground Temperature Data

Ground temperature data were supplied by the U.S. Weather Bureau, Barrow Station. The temperature-sensing devices are thermistors installed at various ground depths in the quadrangle of the station. The site of the untreated electrode group is in open country about one mile from the weather station. Thus, it is probable that the recorded temperature to a depth of a few feet may vary from the actual values at the electrodes, particularly during rapid air temperature changes, because of differences in snow and vegetation cover. Reliable ground temperature data for September-December 1956 are unavailable because of instrumentation difficulties.

Untreated Electrode Resistance Data

The resistance and temperature data for the untreated electrodes are presented in Table I and in Figs. 2 and 3.

The resistance-line curves for all five electrodes show the same general form as noted for the north and south electrode resistance loci of Fig. 2, and by the more extensive data of Table I. It may be noted from the table that the south electrode resistance sometimes varied oppositely to the other electrodes. This is probably error due to the calculating procedure in which the low electrode resistance value is determined from the small difference of two large numbers.

The four temperature curves of Fig. 2 are for ground surface, and depths of 4, 11, and 22 feet. The more extensive data of Table I show that the ground temperature at 1 ft., the average depth of the electrodes, was practically the same as the surface temperature. A maximum difference of 9.2° occurred during a period of rapid temperature rise, but most of the time this temperature difference was less than 2°.

The close correlation between the electrode resistance and near surface ground temperatures is evident in Fig. 2 and throughout the data of Table I. Note the maximum resistance values during the cold period of late February and early March. A comparison of the 18 December and 4 March data gives some indication of the effect of ground temperature below the level of the electrodes. The resistance-temperature relation is also exemplified by the resistance versus temperature locus of Fig. 3. The hysteresis effect may be due to temperature time lag at the greater depths. The series of reversals on the ascending curve are for the period 18 December to 9 February. It should be noted that the major increase in resistance occurred as the ground temperature at the electrode decreased from 0°F to -12°F.

The winter electrode resistance values are far too high for satisfactory earth potential recording with most recording potentiometers. They are also too high to permit the use of transistor amplifiers which have inherently low input impedance. Vacuum tube amplifiers overcome the input impedance problem, but introduce the difficult problem of stability, particularly under field conditions. Thus, it was essential to decrease the electrode resistance, if possible.

First, consider the expensive procedure of increasing the size of the electrodes. Theoretical considerations show that the resistance of a hemispherical shell electrode, installed with its plane surface at ground level, in homogeneous soil varies inversely with the radius. Applying this relation as a rough approximation to the square outline of the electrodes indicates that the 6 ft. x 6 ft. outline would have to be increased to 30 ft. x 30 ft. to reduce the resistance to 20 per cent of the observed values. This would result in useable values for the N, S, and X electrodes, but not for the very high resistance of the E and W electrodes. Obviously, this solution to the problem is impractical.

The effect of the high electrode resistance can be alleviated somewhat by increasing the electrode spacing because the magnitude of the earth potential voltage is directly proportional to the electrode spacing whereas, the electrode resistance is essentially independent of spacing. However, the increased space and line wire required revokes this as a practical solution to the problem.

Therefore, the only practical procedure for reducing the electrode resistance seemed to be a moderate increase in electrode dimensions and to treat the fill-soil with sodium chloride. Heretofore, chemical treatment of the fill-soil had been avoided because of the possibility of introducing variable chemical potentials between electrode pairs.

The Treated Electrodes

During the summer of 1956, a second set of electrodes was installed in similar terrain and soil about four miles from the first set. For the common electrode, two concentric circular trenches 8 ft. and 16 ft. in diamter and 8 in. wide were excavated to permafrost which was at a depth of 8 in. A 50 ft. length of 4 in. wide lead strip was placed in the bottom of the outer trench and tamped in carefully with sodium chloride treated soil. A 25 ft. lead strip was placed in the bottom of the inner trench and covered to a depth of 4 in. Then, a second strip was placed above the first and the fill was completed. One hundred pounds of sodium chloride were incorporated in the fill. Individual lines were extended from the two inner and the outer lead strips to the recording equipment. The West electrode installation is identical with the common electrode.

The location of the south electrode is at an old beachhead where it was impractical to duplicate the form of the common and west electrodes. Here a lead strip about 24 ft. long was installed in a 12 ft. x 18 in x 24 in. deep trench and tamped in carefully with the addition of about 50 lb. of sodium chloride to the fill material.

The common-west and common-south electrode spacings are each 1000 ft.

Treated Electrode Resistance Data

The treated electrode resistance values for the period October 1956 to May 1957 are presented in Table II and Fig. 4. R_c and R_w are the resistance values for the three lead strips of each of these electrodes connected in parallel. R_c, R_w, and R_s were measured and calculated as for the untreated electrodes. R_{oiw} is the resistance measured between the outer and one of the inner strips of the west electrode. R_{oic} is the corresponding resistance value for the common electrode. R_{iiw} is the measured resistance between the upper and lower inner strips of the west electrode.

Discussion of Treated Electrode Resistance

The resistance of these electrodes is entirely satisfactory for recording earth potentials even with the comparatively low input impedance amplifiers. The low resistance can be definitely attributed to the nature of the installation and not to a difference in seasons. Measurements on the untreated set after 1 January 1957 show a very high resistance cycle similar to that of the previous winter.

For other applications it would be desirable to further reduce the electrode resistance. How may this be accomplished? It is known that the line and electrode material resistance is very small. Thus most of the resistance must result from metal-to-soil contact resistance and/or high resistivity of the frozen soil. The R_{iiw} values indicate that the metal-to-soil contact resistance is negligible. The two inner sections are separated by about 4 inches with a homogeneous sodium chloride impregnated fill between and around them. The installation was made so carefully that the possibility of an inadvertant metal to metal contact is completely precluded. The low R_{iiw} values also show that the treated soil resistivity is very small.

Apparently the resistance of the treated electrodes is due almost entirely to the resistivity of the untreated soil. This suggests treating a considerable volume of soil around the electrode material as an economical means of further reducing the electrode resistance.

Summary

Untreated electrodes are impractical for earth potential recording during the winter months in a tundra and permafrost region such as Point Barrow. There is a close correlation between ground temperatures, to a depth of a few feet, and electrode resistance. Pronounced increases in resistance occur at temperatures below 0° F.

Sodium chloride treated electrodes result in satisfactory electrode resistances for earth potential recording. Resistances of less than 5000 ohms can be maintained throughout the winter with a relatively inexpensive electrode installation.

Acknowledgements

The authors wish to express their appreciation to the Arctic Institute of North America and Office of Naval Research for the grant (Contracts No. ONR-161 and 188) in support of this study; to the Arctic Research Laboratory for logistic support and laboratory facilities; and to the U.S. Weather Bureau for supplying the ground temperature data.

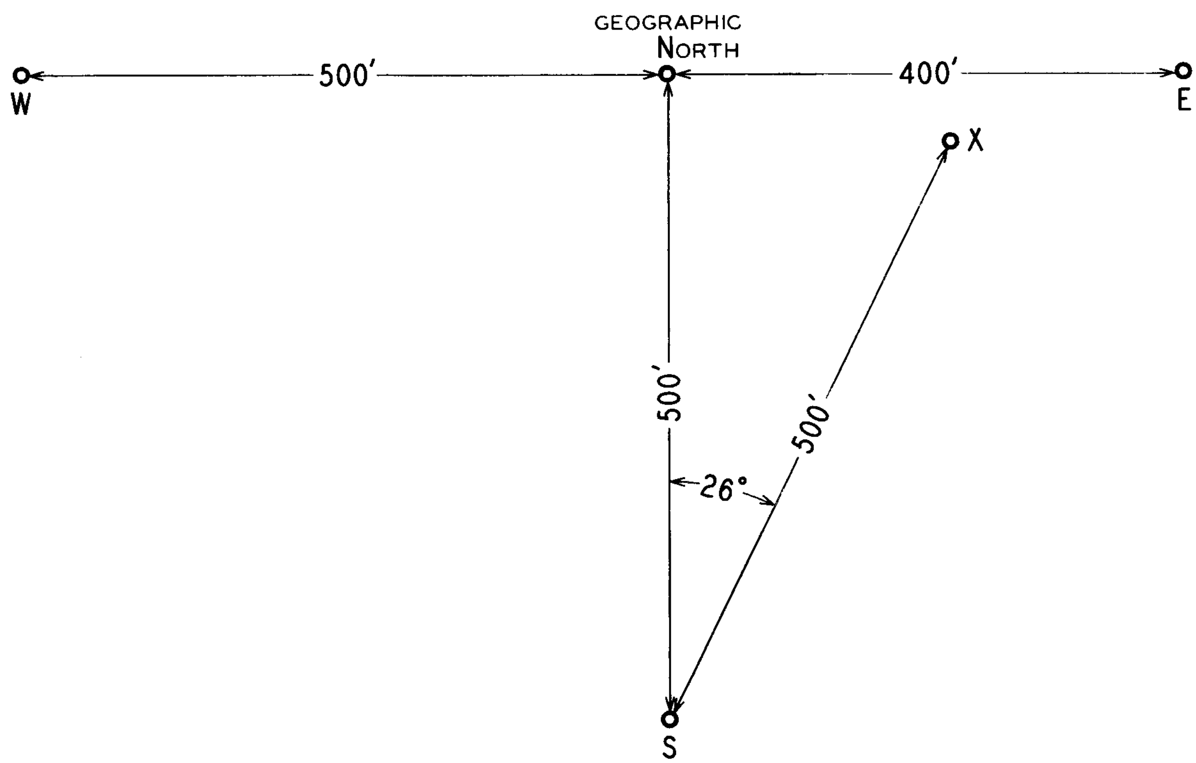

Fig. 1. Layout of Untreated Electrode Set.

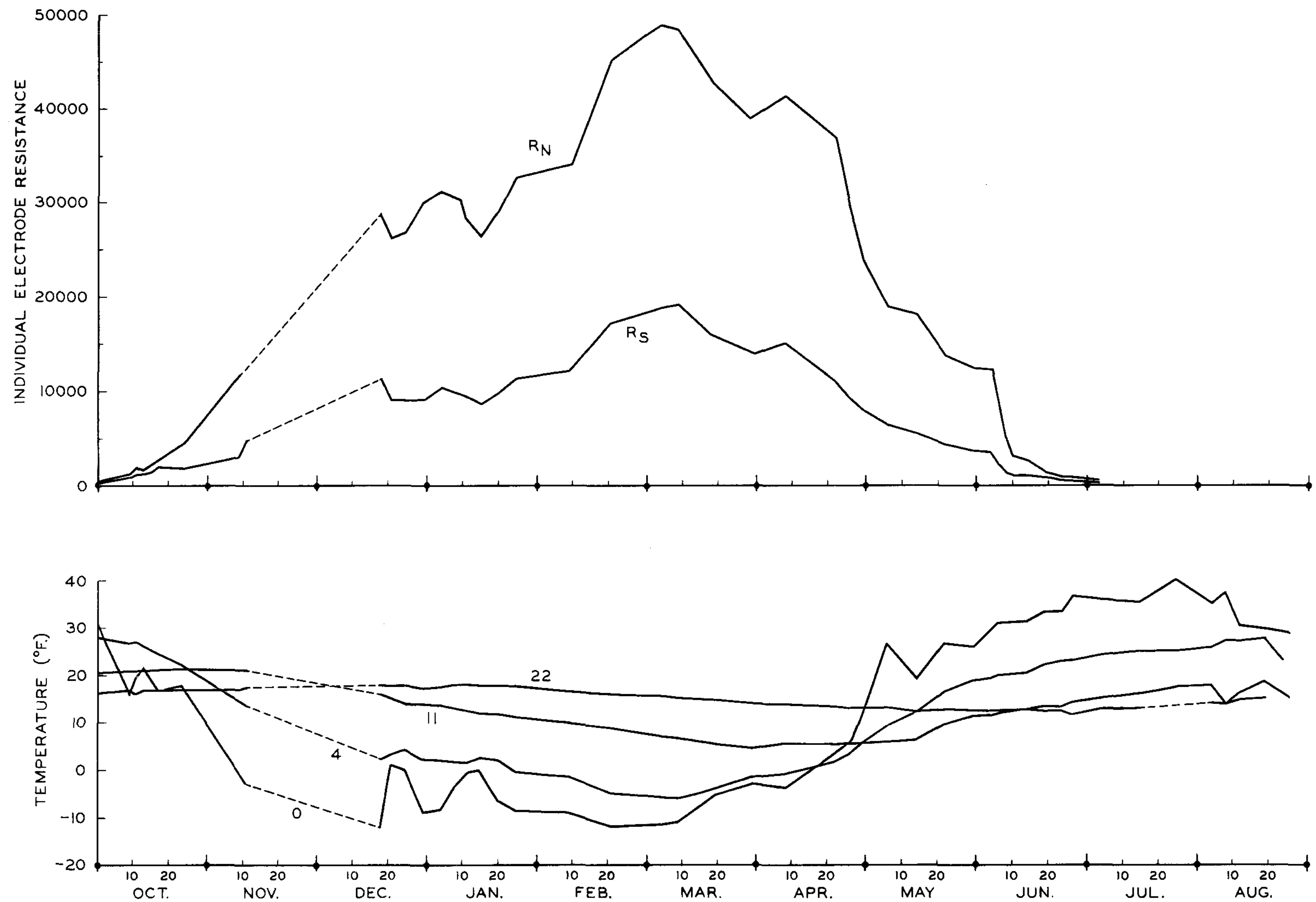

Fig. 2. Resistance and Temperature Data for Untreated Electrodes, Oct. 1955 - Aug. 1956.

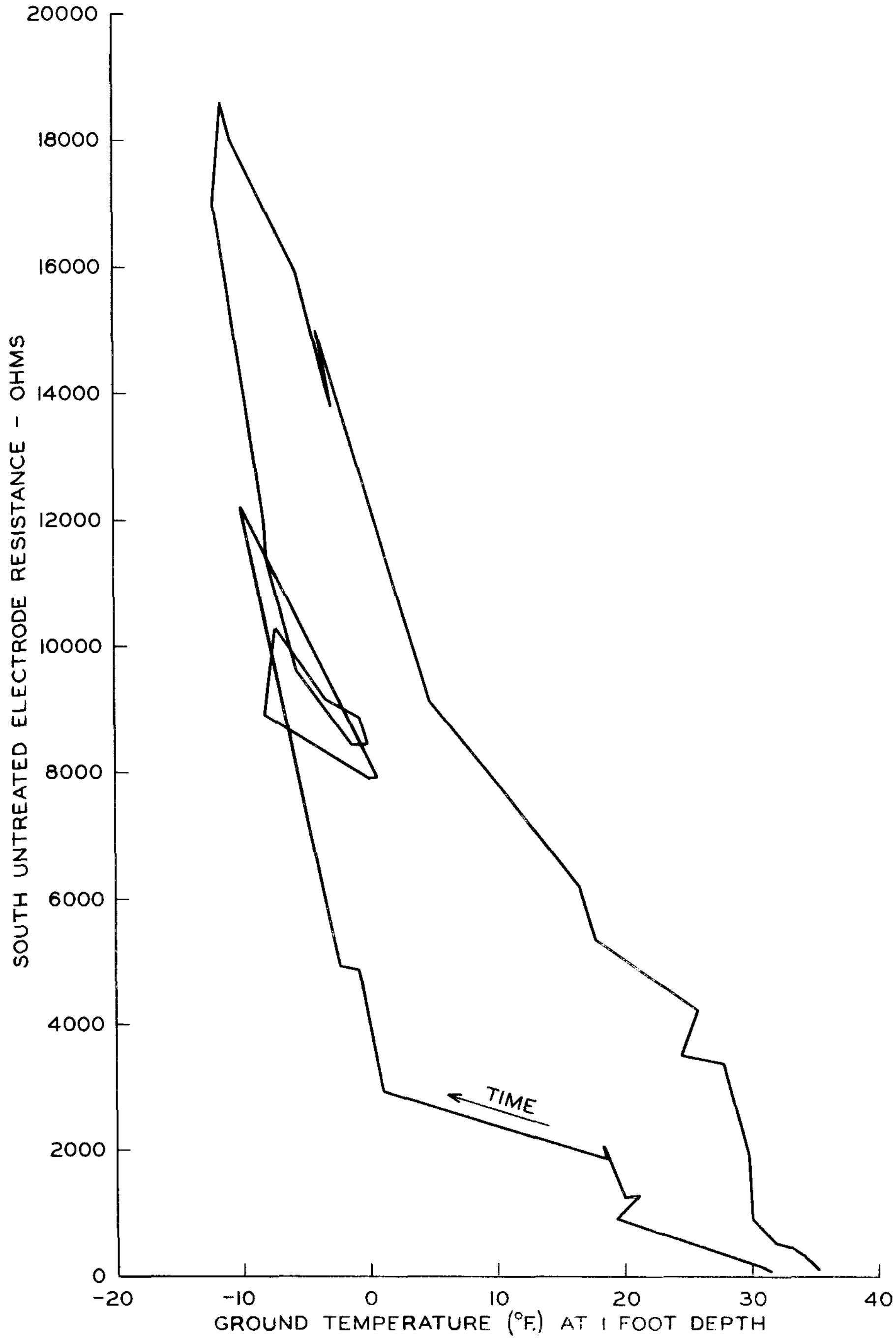

Fig. 3. Resistance-temperature Relation for Untreated South Electrode.

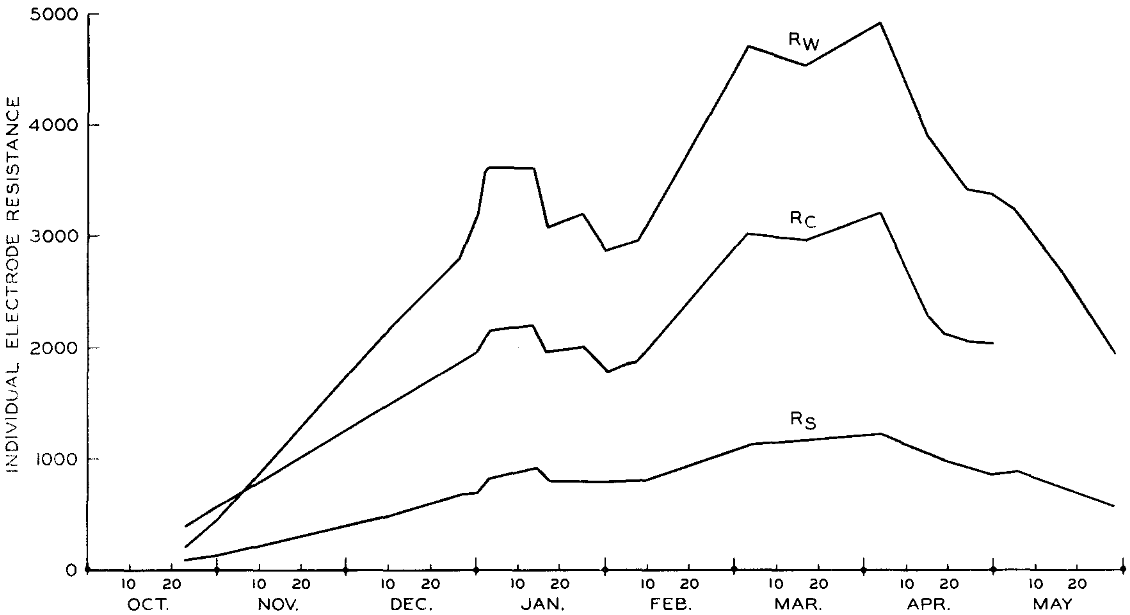

Fig. 4. Resistance of Treated Electrodes, Oct. 1956 - May 1957.

TABLE I

Resistances of Untreated Electrodes and Corresponding Ground Temperatures

	Electrode Resistances					Ground Temperature in Degrees F. at Varying Depths								
DATE	R_n	R_s	R_w	R_e	R_x	0.0'	0.5'	1.0'	2.0'	4.0'	7.0'	11.0'	16.0'	22.0'
6 Sep 1955	113	73	183			31.2°	31.3°	31.5°	30.1°	27.6°	23.6°	20.0°	16.9°	15.8°
1 Oct 1955	250	185	480			30.9	30.9	31.0	30.0	28.0	24.1	20.9	17.8	16.1
9 Oct 1955	1210	913	4690			16.1	17.5	19.3	24.9	27.1	24.1	20.9	18.0	16.7
11 Oct 1955	1790	1390	6800			20.0	20.8	21.0	23.7	26.9	24.8	21.0	18.0	16.2
12 Oct 1955	1580	1200	7150			21.0	21.1	21.2	23.5	26.2	24.2	21.0	17.8	16.3
13 Oct 1955	1580	1230	7320			21.3	21.6	21.8	23.7	26.1	24.4	21.2	18.1	16.6
14 Oct 1955	1700	1250	7750			19.8	20.6	21.1	23.1	25.8	24.2	21.2	18.0	16.5
15 Oct 1955	2060	1210	9040			18.9	19.3	20.0	22.4	25.5	24.4	21.3	18.1	16.7
17 Oct 1955	2670	2020	11600			17.0	17.6	18.4	20.8	24.9	24.4	21.4	18.1	16.7
24 Oct 1955	4350	1850	16100			18.8	18.8	18.9	19.5	22.1	23.6	21.4	18.2	16.8
9 Nov 1955	11600	2950	43700	27100	7010	-0.7	0.3	1.1	6.0	14.7	20.1	21.0	18.4	16.9
11 Nov 1955	12500	4830	48800	28000	8830	-3.4	-2.1	-0.9	4.4	13.5	19.8	21.0	18.7	17.2
12 Nov 1955	12600	4910	55900	33600	8750	-4.6	-3.3	-2.3	3.0	12.8	19.3	21.0	18.7	17.1
18 Dec 1955	28700	12200	135000	79900		-12.4	-11.1	-10.0	-5.7	2.2	9.2	15.7	17.6	17.6
21 Dec 1955	26000	7830	92900	60000	16700	0.8	0.9	0.9	1.9	3.0	8.9	15.0	17.3	17.7
25 Dec 1955	26800	7840	102000	61900	16700	-0.1	0.0	0.0	0.1	4.0	8.9	13.9	17.1	17.7
1 Jan 1956	30000	8960	140000	81100	20000	-9.1	-8.2	-8.1	-6.9	2.0	8.0	13.9	16.6	17.1
4 Jan 1956	31500	10300	143000	85000	20300	-8.8	-8.6	-7.4	-6.6	1.8	7.9	13.3	16.2	16.9
8 Jan 1956	30100	9140	116000	75300	19800	-3.7	-3.4	-3.3	-3.0	1.2	6.7	12.8	15.9	17.1
12 Jan 1956	28300	8900	101000	69200	18700	-0.7	-0.7	-0.7	-0.4	1.6	6.3	12.3	15.4	17.1
15 Jan 1956	26300	8450	94800	65100	17700	-0.1	-0.1	-0.1	0.0	2.7	6.5	11.9	15.2	17.1
17 Jan 1956	26400	8410	103000	68300	18000	-1.9	-1.4	-1.2	-1.1	2.9	6.1	11.9	14.9	17.0
20 Jan 1956	29000	9610	124000	79100	20600	-6.8	-6.0	-5.9	-5.9	1.9	6.7	11.5	14.9	17.1
25 Jan 1956	32600	11400	138000	92300	22800	-8.9	-8.0	-8.0	-8.2	-0.8	5.8	10.9	14.5	16.8
9 Feb 1956	34000	12000	145000	97400	24250	-9.2	-8.5	-8.3	-9.2	-1.6	4.1	9.6	13.2	16.2

TABLE

Resistances of Untreated Electrodes

Electrode Resistances

DATE	R_n	R_s	R_w	R_e	R_x
21 Feb 1956	45100	17000	184000	129000	33100
4 Mar 1956	48900	18600	194000	141000	36200
9 Mar 1956	48100	18000	186000	139000	36200
18 Mar 1956	42800	15900	144000	112000	31000
1 Apr 1956	38800	13800	126000	101000	28700
8 Apr 1956	41100	15000	142000	114000	31900
22 Apr 1956	36700	10900	87600	72000	22400
26 Apr 1956	29200	9100	78200	62600	19500
1 May 1956	23700	7780	62700	49400	15400
6 May 1956	18700	6200	50800	38600	12300
14 May 1956	18000	5340	46900	37700	11700
22 May 1956	13600	4270	33900	27700	8550
30 May 1956	12300	3450	31700	26400	7900
4 Jun 1956	12100	3380	29000	24200	7540
6 Jun 1956	8940	1940	18400	13500	4940
8 Jun 1956	4950	1280	9320	8240	3240
10 Jun 1956	3050	970	6600	5000	1640
12 Jun 1956	2850	925	6100	4990	1640
14 Jun 1956	2520	836	4450	3860	1400
19 Jun 1956	1100	569	1400	1960	780
23 Jun 1956	854	488	1040	1650	650
27 Jun 1956	687	414	790	1380	553
4 Jul 1956	447	281	472	984	416
15 Jul 1956	213	146	293	706	257
25 Jul 1956	154	116	223	582	171

I (Cont'd)

and Corresponding Ground Temperatures

Ground Temperature in Degrees F. at Varying Depths

0.0'	0.5'	1.0'	2.0'	4.0'	7.0'	11.0'	16.0'	22.0'
-12.2°	-12.0°	-12.0°	-13.2°	- 5.1°	1.8°	8.4°	12.1°	15.8°
-11.8	-11.3	-11.3	-12.1	- 6.1	0.1	6.8	11.4	15.3
-11.2	-10.8	-10.6	-11.1	- 6.1	- 0.3	6.3	11.0	15.0
- 5.6	- 5.5	- 5.5	- 6.0	- 4.2	- 0.9	5.3	10.0	14.4
- 3.3	- 3.2	- 3.0	- 3.2	- 1.6	0.9	4.2	8.0	13.7
- 4.4	- 4.1	- 4.0	- 3.9	- 1.3	1.3	5.3	8.9	13.6
3.0	2.5	2.1	2.0	1.4	2.1	5.1	8.4	13.0
5.3	5.0	4.9	3.6	2.9	3.0	5.4	8.5	12.7
11.4	10.8	10.3	8.3	5.3	4.2	5.4	8.3	12.7
26.1	25.1	16.9	15.8	9.0	5.1	5.9	8.5	12.8
18.9	18.8	17.9	12.0	11.9	8.0	6.0	8.3	12.1
26.3	25.9	25.6	21.6	16.2	11.1	9.2	8.7	12.2
25.6	24.6	24.5	22.3	18.6	13.7	10.8	9.9	12.2
29.1	28.0	27.8	23.2	19.1	14.2	11.2	10.2	12.3
30.9	30.0	29.8	24.8	19.6	14.8	11.8	10.7	12.3
31.0	30.0	29.9	24.9	19.9	14.9	12.0	10.8	12.2
31.0	30.1	30.0	25.1	20.0	14.8	12.3	10.9	12.1
31.1	30.1	30.0	25.2	20.2	14.9	12.2	10.8	12.2
31.2	30.3	30.2	25.4	20.3	15.2	12.2	10.9	12.1
33.0	31.0	30.1	27.0	22.0	16.0	13.1	11.3	12.4
33.1	32.0	31.9	27.9	22.8	16.7	13.2	11.4	12.3
36.2	34.0	33.0	28.0	22.5	16.2	14.0	11.9	11.5
35.9	34.8	34.2	28.2	24.1	19.0	15.1	12.8	12.9
35.5	34.8	34.3	29.8	25.0	20.0	16.0	13.0	12.9
40.6	38.4	33.2	30.1	24.8	21.2	17.3	12.4	10.2

TABLE I (Cont'd)

Resistances of Untreated Electrodes and Corresponding Ground Temperatures

Electrode Resistances						Ground Temperature in Degress F. at Varying Depths								
DATE	R_n	R_s	R_w	R_e	R_x	0.0'	0.5'	1.0'	2.0'	4.0'	7.0'	11.0'	16.0'	22.0'
4 Aug 1956	113	77	167	297	106	35.1°	33.5°	35.2°	30.1°	26.0°	17.0°	18.0°	15.0°	14.0°
8 Aug 1956	109	72	158	275	101	37.6	35.0	31.1	30.1	27.2	15.0	14.0	14.1	14.2
12 Aug 1956	112	78	170	332	106	30.0	31.0	31.1	29.5	27.1	22.0	16.1	14.1	14.9
15 Aug 1956	119	80	178	374	111	27.2	32.0	31.6	30.1	25.0	19.8	18.3	15.8	13.9
19 Aug 1956	117	83	166	379	111	29.9	29.9	29.5	30.1	27.6	19.2	18.4	14.0	15.2
26 Aug 1956	122	89	182	448	118	28.8	31.8	29.4	24.5	23.0	23.2	15.3	13.1	10.3
9 Sep 1956	147	134	208	636	182									
23 Sep 1956	171	147	221	734	223									
30 Sep 1956	215	173	255	864	275									
16 Oct 1956	749	610	2030	4900	1030									
28 Oct 1956	3820	1510	10100	13600	3960									
11 Nov 1956	8760	2920	19800	24200	6790									
25 Nov 1956	16300	5250	35100	40800	11600									
2 Dec 1956	16900	5290	37100	41300	12300									
16 Dec 1956	19700	6660	46600	50500	15700									
25 Dec 1956	21000	6950	48000	51400	16500									
1 Jan 1957	28300	10300	72000	73600	24600									

TABLE II

Treated Electrode Resistances

Date	R_w	R_c	R_s	R_{oiw}	R_{oic}	R_{iiw}
23 Oct 1956	215	419	102	224		
1 Nov 1956	455	570	130	512		
10 Dec 1956	2160	1480	494	2220	3520	
27 Dec 1956	2800	1770	670	3170	4200	
31 Dec 1956	3150	1950	686	3890	4570	
2 Jan 1957	3580	2070	794	4670	5170	
3 Jan 1957	3690	2160	831	4700	5350	
14 Jan 1957	3600	2200	925	3910	5120	
17 Jan 1957	3090	1960	788	3010	4250	
26 Jan 1957	3200	2000	800	3280	4400	
1 Feb 1957	2870	1780	777	2950	3910	11.7
8 Feb 1957	2950	1890	795	3240	4250	
3 Mar 1957	4710	3040	1140	5370	7050	15.5
17 Mar 1957	4540	2980	1180	5200	6850	14.5
4 Apr 1957	4920	3200	1220	5450	7250	19.8
15 Apr 1957	3940	2300	1050	3880	5100	12.5
19 Apr 1957	3670	2130	1000	3560	4620	11.0
25 Apr 1957	3440	2060	907	3370	4450	13.0
30 Apr 1957	3390	2040	862	3325	4390	12.0
6 May 1957	3250	4950*	900	3200		11.0
16 May 1957	2690	4010*	794	2600		10.0
29 May 1957	1943	2606*	570	1675		9.0

* Line to outer loop of electrode broken.