NEAR SURFACE SOIL TEMPERATURE MEASUREMENTS AT RESOLUTE BAY, NORTHWEST TERRITORIES

Frank A. Cook*

During the four summers of 1950–3 diamond drilling operations were undertaken at Resolute Bay, Cornwallis Island, for the purpose of installing temperature measuring equipment in the permanently frozen ground. Several recent papers have discussed various aspects of the project. Bremner (1955) described the actual drilling, analysed the difficulties encountered and made several recommendations based on that analysis for the possible assistance of others meeting similar drilling problems. Misener (1955) reported on heat flow in the crust basing his work on deep hole readings and on the examination of the thermal properties of core samples recovered at varying depths. Misener, Bremner and Hodgson (1956) discussing the operation in general terms, combined information given by Bremner and Misener. However, apart from the general observations of Thomson and Bremner (1952), little of the temperature data itself has been reported upon.

The present paper considers the near surface soil temperature data proper, and is based upon daily routine readings taken by officers of the Meteorological Division of the Canadian Department of Transport and the Dominion Observatory of the Department of Mines and Technical Surveys. The data have been supplemented by special studies undertaken by the writer during the three summers of 1953–5 and the winter of 1953–4. So little soil temperature data are available from permafrost regions in North America that the data are published now, without waiting for the more conventional long-term averages.

The first part of the paper is concerned with routine near surface soil temperature readings from within the 6-foot overburden of frozen gravel and shattered rock overlying the limestone bedrock. This depth is subject to daily fluctuations in temperature resulting from variations in surface weather above the soil. Monthly averages for the period 1951–5 are given for depths at 4, 8, 18, and 60 inches, and the five year averages shown. At other depths, where recording elements have been installed more recently, that is, at depths of 10, 20, 25, and 35 inches, data for the two years 1954–5 have been considered. The second part of the paper is a preliminary report on a special study made in the fall of 1955 on the freeze-back in the active layer. Generalizations on soil temperature and moisture content and migration are presented based on field data. Detailed studies of the interrelationships of climate and soil with the thermal regime will be published later.

---

*McGill University-Arctic Institute-Carnegie Scholar in Geography, 1954–6.

Photo: Guy Drouin

Fig. 1. Cable installation showing thermistors at 4, 8, 18, and 60 inches.

Equipment

The installation was made in the vicinity of the former site of the joint Canadian-United States weather station some 1,000 feet inland from Resolute Bay, and on a prominent raised beach line. Here shattered rock and gravel overlie the limestone bedrock to a depth of approximately 6 feet. Many cables were installed in the course of diamond drilling operations (Bremner, 1955), but this paper is limited to the results from two cables, each with attached ceramic resistance thermometers.

The first cable, with thermometers at depths of 4, 8, 18, 39, and 60 inches below the surface, was installed during the summer of 1950 (Fig. 1). Daily readings are available from October of that year, except at the 39-inch level where readings were discontinued from June 1952 and for certain winter readings on the thermometer at the 4-inch depth, when resistance values were outside calibration curves. The second cable was installed in 1953, and readings from thermometers at depths of 10, 20, 25, and 35 inches below the surface are available from September. Both cables have sufficient lead-in to carry them to a heated building about 100 feet south of the area, where the recording equipment is installed. Individual elements on the first cable have been calibrated to a MSC Thermometer Indicator Type C2 and conversion tables prepared from microamperes to degrees Fahrenheit. Elements on the other cable have been calibrated to a standard Wheatstone bridge and conversion tables from resistance in ohms to temperature in degrees Fahrenheit prepared. While readings from the two cables do not fit exactly into the same curve, as they are placed 225 feet apart in overburden of a slightly different composition with resulting slight differences in temperature, for the purpose of this paper they are combined, as all characteristics are similar.

For the special freeze-back study additional thermistors were installed in 1955 at depths of 2, 5, 8, 11, 14, 17, and 20 inches below the surface. These thermistors were made to specifications by Industrial Instruments Inc., and calibrated separately to a standard Wheatstone bridge. On the average they offered 225 ohms resistance at 40°F and 440 ohms at 15°F, the extremes of temperatures recorded during the test. Lead-in wires were run to the heated building housing the permanent equipment, and all measurements taken there, eliminating the many problems connected with the use of a temperature-sensitive bridge in below freezing weather.

PART I. NEAR SURFACE SOIL TEMPERATURES

Data discussed includes daily, monthly, and yearly averages, and the influence of solar insolation, air temperature, and precipitation.

Daily fluctuations

Minor daily fluctuations can be seen in the active layer (Fig. 2), decreasing in amplitude with depth, until below the permafrost table at approximately 25 inches they are barely perceptible, disappearing completely at a depth of 60 inches.

The amplitude of the daily variation changes with the season of the year, achieving maximum range in summer. However, summer diurnal variation is much less than in non-permafrost regions to the south. This is due to the

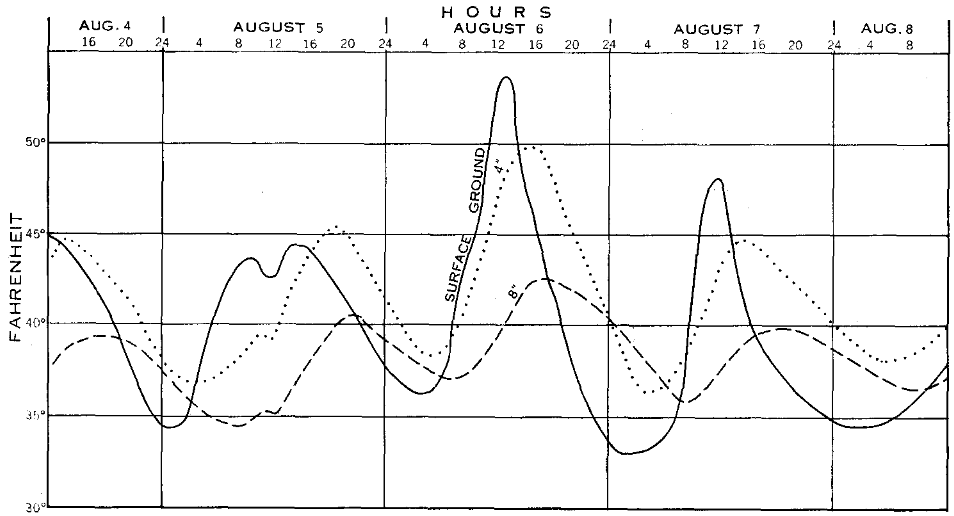

Fig. 2. Daily fluctuations in near surface ground temperature, 5–7 August 1955.

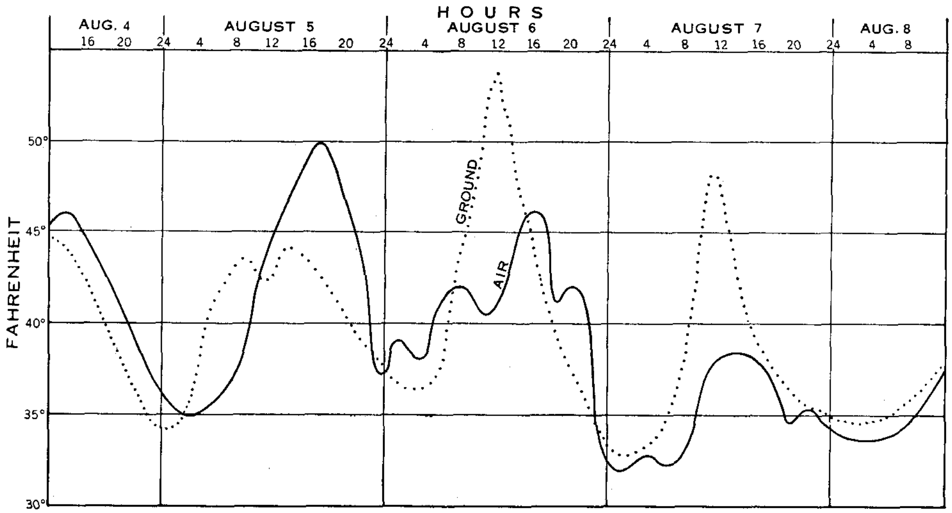

Fig. 3. Effect of insolation on surface ground temperature, 5–7 August 1955.

greater uniformity of the mean surface air temperature, resulting from continuous daylight and the relatively weak circulation prevailing at this time of year. While the maximum air temperature may occur at any time within the 24-hour period, interrupting the diurnal rise and fall found in temperate regions, the soil temperature generally reaches an early afternoon maximum; the greatest daily fluctuation in soil temperature appears to be related to the intensity of solar radiation and the continuous sunshine rather than air temperature. Several hours of sunshine, with heavy absorption of solar energy will raise the soil temperature in the top few inches of the ground appreciably higher in absolute value than the surface air temperature above the ground. This condition is shown in Figure 3 based on hourly readings for the period August 5–7, 1955. The extreme maximum air temperature for the year was recorded on August 5, a cloudy day during which surface air temperature exceeded the temperature on the surface of the ground and at all soil levels measured beneath. The next day, however, was clear and sunny, and solar radiation raised surface ground temperature, and that recorded at 4 inches below the surface, well above the maximum surface air temperature for the day.

The daily fluctuations in temperature at the ground surface level are reflected in the soil below, with a certain lag, and there is a damping of the wave with depth. Figure 2, based on data for the same period as Figure 3, illustrates these features.

In the fall, as periods of darkness lengthen each day, fluctuations in soil temperature follow surface air temperature with a daily maximum and a nightly minimum. As the season progresses and the soil freezes solidly and a cover of snow forms, variations in surface air temperature become less and less effective; during winter and continuous darkness there is little variation in soil temperature, and any fluctuation tends to be the result of an unusually low minimum temperature, rather than the influence of surface maximum air temperature. As in summer, there is great uniformity in the mean surface air temperature, and either maximum or minimum temperature may occur at any time within the 24 hours. In the spring, with return of day and lengthening periods of light, daily fluctuations again follow surface air temperature, until the season has progressed sufficiently for incoming solar radiation to be effective.

The temperature curve for the year plotted from daily averages shows the following characteristics; the warm up in spring is gradual until June, when in response to increasingly high surface temperatures and increased incoming radiation, the rate increases. Maximum daily fluctuations are observed in July and August. In late August, when daily surface air temperatures fall below freezing, there follows a rapid decline in all values until the soil temperature reaches the freezing point. Here it remains for a period of time as the chilling of the ground is temporarily compensated by latent heat of fusion given off by the ground-water until it has turned to ice. This break in the slope of the curve along the 32°F line has been called by Sumgin the "zero curtain" (Muller, 1947, p. 17), it is discussed more fully in the second part of this paper. Table 1 shows that while the "zero curtain" lasts for a very short period of time at 4 inches below the surface, it can exist for more than three weeks just above the permafrost table. With the advance of winter there is a gradual decrease in soil temperatures until the winter low is reached, at which point the cycle starts again.

Table 1. Active layer zero curtain at Resolute Bay, 1951–5.

Depth in inches	*Duration in days*				
	1951	*1952*	*1953*	*1954*	*1955*
4	–	–	–	–	–
8	21	12	10	12	11
10	NR[1]	NR	12	16	12
18	30	23	17	19	15
20	NR	NR	19	23	16

[1] NR–No record.

Monthly averages

The mean monthly temperatures in the ground for the period 1951–5, as shown in Table 2, indicate that in the active layer, at depths of 4, 8, 10, and 18 inches below the surface, the minimum temperature occurs in February, the same month in which minimum air temperature is recorded. At depths of 20, 25, and 35 inches it occurs in March, giving a lag of one month. The minimum temperature at 60 inches is recorded in April, showing a lag of two months at this depth. The maximum temperature at 4 and 8 inches occurs in July, as does the maximum air temperature at the surface. One month lag is noted at depths of 10, 18, 20, and 25 inches, while at 35 and 60 inches below the surface the maximum occurs in September, two months after the maximum air temperature is attained. Only two months, July and August, show a mean monthly temperature above freezing in the active layer.

The range of mean monthly temperatures decreases with depth; in 1954 it was 56.3°F at 8 inches, 49.4° at 18 inches, 40.2° at 25 inches, and 37.2° at 60 inches.

Figure 4 shows that there is a spring and fall overturn to depths below 60 inches. In January the coldest temperature is at the top, the ground warming progressively with depth. In 1954, the January mean temperature at 8 inches was -15.5°F, -14.2° at 10 inches, -11.8° at 18 inches, -7.4° at 20 inches, -5.7° at 25 inches, -4.0° at 35 inches, and -3.9°F at 60 inches below the surface. In summer the reverse is true, the warmest temperature is at the surface, the ground cooling progressively with depth. In 1954, the July mean temperature at 4 inches was 42.6°F, 37.4° at 8 inches, 33.7° at 10 inches, 32.7° at 18 inches, 32.5° at 20 inches, 29.8° at 25 inches, 26.7° at 35 inches, and 22.9°F at a depth of 60 inches.

Table 2. Monthly and yearly averages of near surface soil temperatures, 1951–5.

Year	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
4 inches													
1951	−16.4	−20.4	−17.9	−10.5	3.7	28.6	44.1	37.5	30.3	12.5	−9.5	−19.8	5.2
1952	−21.0	−27.7	−24.3	−11.5	14.5	45.6	44.2	44.3	26.8	14.1	3.6	−3.7	8.7
1953				−2.5	5.9	17.4	40.2	38.8	30.3	13.9	−1.5	−10.2	
1954				−12.7	2.9	22.8	42.6	41.7	31.5	16.1	2.4	−6.8	
1955	−11.5	−17.3	−16.2	−10.5	1.4	23.1	39.0	37.4	28.7	19.5	0.2	−10.3	7.0
1951–55 Av.				−9.5	5.7	27.5	42.0	39.9	29.5	15.2	−2.4	−10.2	
8 inches													
1951	−14.4	−18.2	−17.0	−10.8	2.7	24.3	37.2	34.6	29.2	13.4	−7.8	−21.2	4.3
1952	−24.0	−25.2	−23.1	−11.0	11.5	37.2	38.3	35.2	26.2	14.5	4.6	−4.6	6.6
1953	−16.7	−17.5	−16.4	−3.9	9.5	15.9	35.4	35.1	29.2	15.2	−4.1	−9.3	6.1
1954	−15.6	−20.0	−17.4	−13.0	1.3	19.1	37.4	36.9	31.0	16.8	2.9	−6.3	6.1
1955	−11.6	−18.4	−17.1	−10.9	0.4	19.9	36.1	34.4	28.5	19.2	0.9	−9.5	6.0
1951–55 Av.	−16.5	−19.9	−18.2	−9.9	5.1	23.3	36.9	35.2	28.8	15.8	−0.8	−10.2	5.8
10 inches													
1954	−14.2	−15.3	−14.0	−10.9	1.8	17.0	33.7	35.4	30.4	15.4	−0.2	−6.0	6.1
1955	−10.6	−18.8	−18.9	−11.3	−0.6	17.8	32.3	33.3	27.7	19.1	0.9	−5.7	5.4
18 inches													
1951	−10.9	−15.4	−15.2	−10.1	1.1	20.0	32.5	32.6	29.9	16.5	−2.6	−15.3	5.2
1952	−19.7	−21.9	−22.1	−12.6	7.6	26.2	33.8	32.8	27.9	16.5	6.6	−1.1	6.2
1953	−10.5	−12.3	−14.7	−4.4	3.8	13.2	29.2	32.9	31.5	16.9	2.8	−5.2	7.0
1954	−11.8	−15.4	−15.0	−12.1	0.0	15.7	32.7	34.0	31.7	18.8	6.2	−2.3	6.9
1955	−7.7	−14.1	−14.9	−10.1	0.8	16.0	32.1	33.1	29.9	20.3	1.8	−6.2	6.7
1951–55 Av.	−12.1	−15.8	−16.4	−9.9	2.7	18.2	31.7	32.9	30.2	17.8	3.0	−6.0	6.4
20 inches													
1954	−7.5	−9.5	−10.2	−9.4	−1.0	13.6	32.5	34.1	31.5	18.7	7.2	1.5	8.5
1955	−3.0	−8.9	−9.2	−6.9	−1.1	12.8	30.9	32.7	29.1	20.3	11.2	2.7	9.2
25 inches													
1954	−5.7	−8.1	−8.8	−8.2	−1.5	11.4	29.8	31.7	31.3	21.0	13.0	5.8	9.3
1955	0.1	−5.7	−7.3	−6.0	−0.9	11.6	28.8	31.3	28.8	21.3	13.7	4.3	10.0
35 inches													
1954	−4.4	−6.9	−7.9	−7.8	−1.8	9.2	26.7	30.0	30.3	21.7	13.9	7.0	9.2
1955	1.3	−4.4	−6.4	−5.6	−1.1	9.4	25.9	29.7	28.3	21.5	14.8	5.6	10.7
60 inches													
1951	−3.7	−8.7	−10.9	−8.1	−2.3	8.7	20.0	25.5	26.7	20.2	7.0	−5.1	5.8
1952	−12.2	−13.9	−15.9	−13.2	−4.1	15.3	24.1	26.6	26.3	19.0	11.8	3.3	5.6
1953	−3.6	−8.3	−9.6	−5.0	−1.2	7.4	19.9	25.8	26.8	20.4	10.5	3.3	7.2
1954	−3.9	−7.6	−9.3	−9.5	−2.9	6.3	22.9	26.2	27.7	22.0	12.6	5.8	7.5
1955	−0.3	−5.7	−8.9	−7.5	−2.2	7.1	21.6	26.4	27.1	21.7	13.3	2.2	7.9
1951–55 Av.	−4.7	−8.8	−10.9	−8.7	−2.5	9.0	21.7	26.1	26.9	20.7	11.0	1.9	6.8

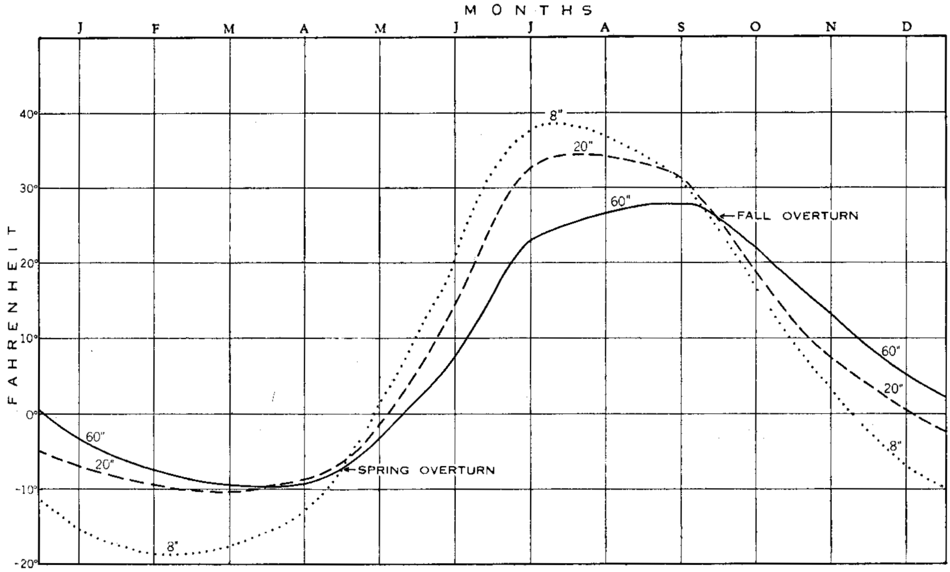

Fig. 4. Spring and fall overturn to depths of 8, 20, and 60 inches, 1954.

The mean annual soil temperature increases from the surface to the permafrost table, where it starts to decrease again. The mean annual surface temperature for 1954 was 3.1°F, increasing to 6.1° at 8 inches, 6.9° at 18 inches, 8.5° at 20 inches, and 9.3°F at 25 inches, the approximate level of the permafrost table. Below this level it decreased to 9.2°F at 35 inches and to 7.5° at 60 inches below the surface.

Precipitation

The effect of rainfall seems negligible; it adds little to the moisture content of the soil, a factor affecting soil temperature. Normally rainfall only dampens the actual ground surface, the moisture content of the soil being derived from melting permafrost within the soil itself. The average annual rainfall, falling in July, August and September, is less than 3 inches, with individual showers being light and of low intensity. In 1954, 16 days of measurable rain gave the year's total liquid precipitation of 2.71 inches. Of this total, 12 days gave less than 0.2 inches each, while one day, August 29, gave 0.97 inches, or one-third the total for the year.

While the total annual snowfall is also light, averaging about 25 inches, it does have the effect of decreasing any variation due to fluctuations in surface air temperature. Some snow cover is present from about the beginning of September to the end of May; it is not possible to give depths at any one time because the snow is constantly moving, being blown about almost continuously. No regular measurements have been taken at the time of routine readings.

No routine measurements of soil-water in the active layer, or of the height of the water table were taken.

PART II. FREEZE-BACK IN THE ACTIVE LAYER, 1955

A knowledge of the thermal regime of the active layer in permafrost is basic to an understanding of many problems in the study of periglacial phenomena. This is especially true for the study of patterned ground, as the majority of hypotheses relating to its development are built around the action of frost in the soil.

Of special interest is the manner in which the freeze-back occurs in the fall; it is considered by many to be the most important part of the freeze-thaw cycle. It is a phase, however, on which there is practically no quantitative field data. Throughout the summer and fall of 1955 the writer studied the thermal regime in the active layer at Resolute Bay in an integral soil temperature–soil analysis–climatic data study. During August and September a special study was conducted on the freeze-back and this part of the present paper is a preliminary presentation of some generalizations based on field data for that period.

Use of the permanent installation in shattered rock and gravel, combined with an additional vertical section installed in a nearby pocket of clay in which several immature stone polygons were developing, allowed the recording of temperature gradients in two different materials. This is of great significance in patterned ground study where differential freezing and pressures play so important a part.

Measurements

Readings were taken at four-hourly intervals for the period August 28–October 1, this time interval providing sufficient data to give a complete picture of soil temperatures during the freeze-back period.

The start of the freeze-back, August 28, coincided with the drop of the daily maximum air temperature below the freezing point. At Resolute Bay once the daily maximum air temperature falls below freezing it continues to drop steadily each day, and does not rise again that season. An examination of existing records reveals that this has occurred each year since the establishment of the weather station in 1947.

Before August 28 there were daily fluctuations in temperature in both the shattered rock and the clay pocket, the wave being damped and subjected to a lag with depth. The shattered rock and gravel showed a greater wave amplitude than the clay owing to its greater conductivity. Once the soil temperature reached freezing point, daily fluctuations ceased for the period of the zero curtain, the period of time necessary for the turning of the water content into ice. After the soil became solidly frozen daily fluctuations started again, but with smaller amplitudes than previously, due to the lateness of the season and the presence of a light snow cover. Fluctuations ceased when the snow cover in the area reached a depth of 6–8 inches.

Zero curtain

The data shows the condition called by Sumgin "the zero curtain" (Muller, 1947, p. 17). As already stated the lowering of temperature in moist ground does not proceed at a uniform rate, as the penetration of cold is retarded by the moisture content of the soil. The loss of heat is temporarily compensated by latent heat of fusion given off until all water is turned to ice. This is aided by the hydrostatic pressure developing in the unfrozen material which lowers the freezing point of the soil. The hydrostatic pressure develops due to downward squeezing between the advancing frost line and the permafrost table, and to the increase in volume of the moisture as the temperature of the water itself is lowered. The maximum zero curtain occurs just above the permafrost table where the water is unable to escape. The depth and duration of the zero curtain is controlled by several factors such as available moisture, the thermal properties of the soil, and weather conditions.

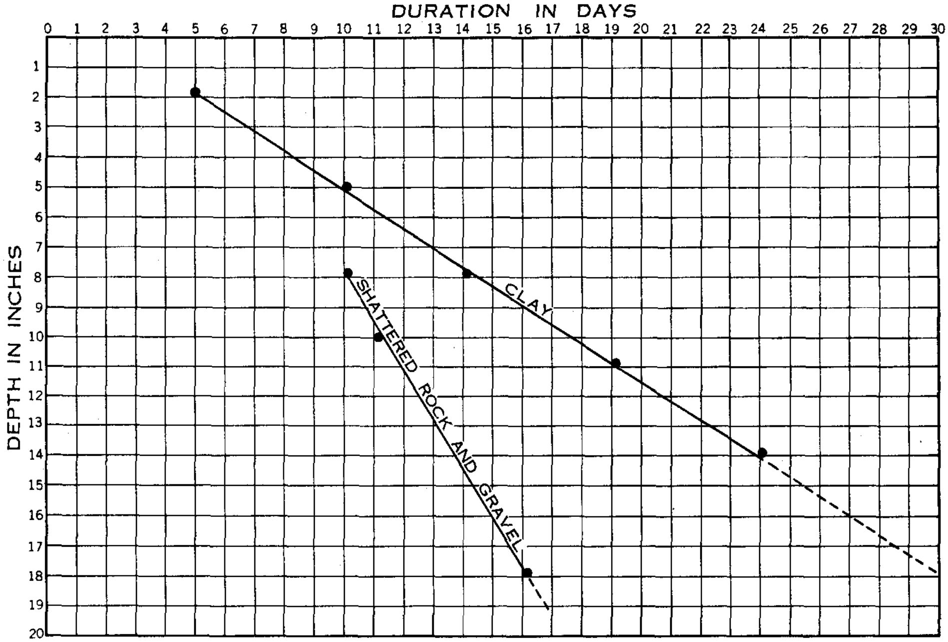

Fig. 5. Zero curtain at Resolute Bay, 1955.

Figure 5 shows the zero curtain in both the shattered rock and gravel and the clay for 1955. The clay shows a longer zero curtain than the shattered rock and gravel, partly due to its greater moisture content. At 8 inches in the shattered rock and gravel the zero curtain effect lasted 10 days, while in the clay at the same depth it was prolonged to 14 days. At 15 inches a 14-day zero curtain in the shattered rock and gravel was prolonged to 25 days in the clay. The interval between the zero curtain at equivalent depths increased with depth to the permafrost table. The implications to patterned ground study of this differential freezing with associated pressures are important and will be discussed in a later paper.

		Clay							*Shattered rock and gravel*								*Surface air °F. daily*	
Date	*Depth*	*2"*	*5"*	*8"*	*11"*	*14"*	*17"*	*20"*	*Sfc.*	*4"*	*8"*	*10"*	*18"*	*20"*	*25"*	*35"*	*Max.*	*Min.*
Aug. 28		32.6	32.7	32.2	32.2	32.1	32.1	32.1	32.5	33.6	32.6	32.2	32.2	32.2	31.6	30.0	34.0	32.2
29		33.9	33.5	32.8	32.4	32.3	32.2	32.1	33.6	33.5	33.4	32.6	32.4	32.5	31.4	30.1	35.5	32.2
30		32.4	32.7	32.4	32.4	32.4	32.2	32.1	31.8	33.2	32.6	32.5	32.5	32.3	31.4	30.0	33.6	30.2
31		31.4	31.6	31.7	31.7	31.8	31.8	31.9	31.3	32.4	31.9	31.8	31.8	31.8	31.3	30.0	31.5	28.9
Sept. 1		31.3	31.4	31.5	31.5	31.5	31.6	31.7	31.3	32.5	31.9	31.8	31.8	31.7	31.3	30.0	31.4	28.6
2		31.2	31.3	31.4	31.4	31.5	31.6	31.7	31.2	32.3	31.5	31.8	31.5	31.6	31.3	30.0	31.7	28.0
3		31.2	31.3	31.4	31.4	31.5	31.6	31.7	30.4	32.5	31.9	31.7	31.8	31.6	31.3	30.0	30.8	25.7
4		31.1	31.3	31.4	31.4	31.5	31.6	31.7	30.7	32.4	31.9	31.7	31.9	31.6	31.3	30.0	28.6	25.2
5		30.4	31.2	31.4	31.4	31.5	31.6	31.7	29.5	32.2	31.7	31.7	31.7	31.6	31.3	30.0	28.4	21.9
6		30.4	31.1	31.4	31.4	31.5	31.6	31.7	30.5	32.2	31.8	31.7	31.7	31.7	31.2	30.0	29.1	25.0
7		30.6	31.0	31.3	31.4	31.5	31.6	31.7	31.3	32.4	31.8	31.6	31.8	31.7	31.2	30.0	30.1	26.4
8		30.6	31.0	31.3	31.3	31.4	31.5	31.7	31.0	32.3	31.6	31.6	31.6	31.6	31.1	30.0	32.0	24.7
9		30.6	31.0	31.2	31.3	31.4	31.5	31.6	29.5	32.3	31.6	31.5	31.6	31.6	31.1	29.9	31.2	25.0
10		30.3	30.8	31.2	31.3	31.4	31.5	31.6	28.4	31.7	31.6	31.3	31.8	31.6	31.1	29.8	27.2	17.9
11		30.1	30.6	31.1	31.3	31.4	31.5	31.6	28.3	31.0	30.8	30.6	31.5	31.6	30.9	29.8	25.8	20.0
12		29.8	30.4	31.1	31.2	31.4	31.4	31.6	28.9	30.3	30.0	29.5	31.5	31.6	30.8	29.7	23.8	20.0
13		29.2	30.0	31.0	31.2	31.4	31.4	31.6	26.9	29.4	29.4	28.6	31.4	31.5	30.7	29.7	25.3	19.6
14		28.6	29.5	30.7	31.2	31.4	31.4	31.6	26.0	28.2	28.9	27.4	31.3	31.2	30.2	29.3	25.0	14.7
15		27.5	28.7	30.2	31.2	31.4	31.4	31.6	25.8	26.8	27.9	26.1	31.2	30.5	29.4	28.8	22.9	11.3
16		28.8	29.3	30.2	31.1	31.4	31.4	31.6	27.8	28.5	28.4	26.0	30.7	29.7	28.7	28.4	27.4	19.4
17		29.3	29.7	30.3	31.0	31.4	31.4	31.6	29.0	29.4	28.9	26.4	30.4	29.0	28.3	28.0	28.6	22.1
18		30.0	30.2	30.5	31.0	31.4	31.4	31.5	30.2	30.5	29.7	27.0	30.3	28.8	28.2	27.9	31.4	27.5
19		29.9	30.2	30.6	31.0	31.4	31.4	31.5	29.4	30.1	29.5	27.3	30.1	28.6	28.2	27.9	29.9	23.8
20		29.8	30.3	30.6	30.9	31.3	31.4	31.5	28.8	29.9	29.4	27.4	29.9	28.4	28.0	27.5	30.4	22.0
21		29.7	30.0	30.4	30.9	31.2	31.4	31.4	27.9	28.5	28.0	26.6	29.5	27.9	27.6	27.3	24.7	16.9
22		29.9	30.2	30.5	30.8	31.2	31.3	31.3	28.5	28.6	27.8	26.3	29.0	27.4	27.3	27.0	25.4	22.6
23		29.3	29.8	30.4	30.8	31.1	31.3	31.3	25.6	25.9	26.0	25.1	28.5	26.9	26.9	26.6	22.2	14.1
24		29.6	29.8	30.1	30.6	31.0	31.1	31.2	27.5	26.1	25.4	24.3	27.6	26.0	26.2	26.1	19.9	14.0
25		28.1	29.6	30.0	30.5	30.8	31.0	31.0	26.1	25.9	25.2	24.5	27.0	25.7	25.9	25.9	24.7	19.8
26		28.6	29.1	29.3	30.2	30.6	30.8	30.8	25.7	25.1	24.5	24.0	26.4	25.3	25.5	25.6	24.1	18.2

Table 3. Daily averages of soil temperatures for period of freeze-back, 1955.

Photo: Guy Drouin

Fig. 6. Excavation in frozen clay, September 12, showing segregation and growth of ice lenses.

Penetration of the 32°F freezing line

Table 3 shows that the 32°F line proceeded downward from the surface as most of the heat was lost to the atmosphere through conduction and radiation. Latterly the permafrost table advanced upward, as trapped heat was lost into the permafrost below.

The 32°F temperature line advanced more quickly in the shattered rock and gravel than in the clay. Excavation to the permafrost table was attempted weekly and notes taken on the condition of the soils. On September 5 the clay had frozen to a depth of 2½ inches, while the shattered rock and gravel had frozen solidly to a depth of 4 inches. At this time ice was also appearing on nearby freshwater lakes and the permafrost table had risen ¾ inch. On September 12 the clay was solidly frozen to a depth of 5 inches and in the top 3 inches ice lenses were beginning to form and there were stratified layers of clay and clear ice approximately 0.04 inches in depth. The permafrost table had advanced upward by one inch, and the enclosed material in the unfrozen clay pocket looked and felt mealy in texture. The shattered rock and gravel was frozen to a depth of 12 inches, and although no lenses had formed in this material, some of the individual particles were encased in ice. By September 19, the last day on which it was possible to excavate, the clay was solidly frozen down to 10 inches, with considerable ice segregation in the top 6 inches, ice lenses of clear ice being between 0.04 and 0.08 inches in depth, as shown in Figure 6. The permafrost table had advanced upward to 20 inches below the surface, and the shattered rock and gravel was frozen solidly.

No heaving of the surface of the clay was apparent to the eye, but precise instrumental measurements were not taken. However, as Haley and Kaplar have shown (1952, pp. 264–5), heaving may be negligible when reduction in the volume of soil below is equal to volume of water removed, because sufficient tensile force develops in the pore water in the process of ice segregation to consolidate the soil.

Table 4. Percentage moisture content of soil during freeze-back, 1955.

	Clay					*Shattered rock and gravel*				
Depth in inches	*Date* *Aug. 22*	*Aug. 29*	*Sept. 5*	*Sept. 12*	*Sept. 19*	*Aug. 22*	*Aug. 29*	*Sept. 5*	*Sept. 12*	*Sept. 19*
3	16	17	24	32	34	9	9	10	11	11
6	15	15	18	23	25	8	8	9	10	10
9	14	15	15	12	18	8	8	7	8	9
12	14	14	14	12	14	8	8	7	6	7
18	15	15	12	8	7	8	8	7	6	6
24	17	17	18	18	18	8	8	7	6	6
Average	15.1	15.5	16.7	16.7	16.9	8.1	8.1	7.8	7.8	8.1

Moisture content and migration

During the weekly excavations samples of soil were taken for the purpose of studying moisture content by dry weight. Sampling was done at 3 inch intervals to a depth of 12 inches, and at 18 and 24 inches, the latter depth being approximately the permafrost table. The samples were oven-dried to remove moisture. On August 29, as shown in Table 4, the profile from surface to the permafrost table revealed that the moisture content was distributed rather evenly throughout the soil, although slightly higher percentages were noted at both the ground surface and at the actual permafrost table. The shattered rock and gravel averaged 8.1 per cent moisture content by dry weight, while the clay averaged 15.5 per cent. The difference in moisture content was caused by the difference in particle size, the fine-particled clay being able to retain considerably more water than the coarse-particled gravel.

On September 5 the moisture content of the clay in the top 3 inches had increased by 50 per cent, while that of shattered rock and gravel showed little change. This situation was intensified on September 12, when moisture content in the top 3 inches of clay stood 100 per cent above the amount recorded before freezing began, and considerable increases were noted at 6 and 9 inches as the freezing isotherm progressed downward. Again the shattered rock and gravel showed little change. On September 19 there was a further slight increase in moisture content of the clay in the top layers.

Thus the data show considerable moisture migration in the clay pocket, and little moisture migration in the shattered rock and gravel. The different behaviour appears to be related to differences in structure between the two soils, coarse-grained soils being unable to draw and hold water, while the fine-grained soil can not only hold greater amounts of moisture, but can also draw moisture from great distances. As Taber has shown (1929; 1930) in the laboratory, freezing of the ground in the clay pocket proceeded in the early stages as in an open system, moisture migrating upward to be available to the ice lenses forming parallel to the freezing surface. The moisture content of the lower layers was reduced accordingly. In the latter stage, freezing probably proceeded as in a closed system, with both the downward freezing surface and the advancing permafrost table attracting some moisture.

The writer wishes to acknowledge the manual assistance given by individual members of the staff of the Ionosphere Station of the Telecommunications Division of the Canadian Department of Transport, as well as laboratory, work-shop and congenial living accommodation made available at that station. He is indebted to the staff of Resolute Bay joint Canadian-U.S. weather station for their enthusiastic support in supplying climatic data and equipment as requested, and to Mr. Andrew Thomson of the Meteorological Division of the Canadian Department of Transport for permission to use the routine soil temperature data. The Royal Canadian Air Force supplied air transportation to and from Resolute Bay on several occasions. The writer is grateful for the continuing interest in the project of Dr. John Hodgson of the Dominion Observatory; to Professor J. Ross Mackay of the University of British Columbia for invaluable advice in the earlier stages of his research; and to Professor J. Brian Bird of McGill University under whose direction the field project of 1955 was conducted. Finally, he is indebted to the McGill University-Arctic Institute-Carnegie Program for a grant covering field work for the summer of 1955.

References

Bremner, P. C. 1955. "Diamond drilling in permafrost at Resolute Bay, Northwest Territories". *Publ. Dom. Obs.* Vol. 16, pp. 264–390.

Haley, James F., and Chester W. Kaplar. 1952. "Cold-room studies of frost action in soils". *Highway Res. Bd. Spec. Rep. No.* 2, pp. 246–67.

Misener, A. D. 1955. "Heat flow and depth of permafrost at Resolute Bay, Cornwallis Island, N.W.T., Canada". *Trans. Amer. Geophys. Un.* Vol. 36, pp. 1055–60.

Misener, A. D., P. C. Bremner, and J. H. Hodgson. 1956. "Heat flow measurements in permafrost at Resolute Bay, Northwest Territories". *J. Roy. Astronom. Soc.* Vol. 50, pp. 14–24. (Also issued in *Contr. Dom. Obs. Ottawa*, Vol. 1, No. 19).

Muller, S. W. 1947. 'Permafrost of permanently frozen ground and related engineering problems'. Ann Arbor: ix + 231 pp.

Taber, S. 1929. "Frost heaving". *J. Geol.* Vol. 37, No. 5, pp. 428–461.

1930. "The mechanics of frost heaving". *J. Geol.* Vol. 38, pp. 303–317.

Thomson, A., and P. C. Bremner. 1952. "Permafrost drilling and soil-temperature measurements at Resolute, Cornwallis Island, Canada". *Nature*, Vol. 170, No. 4330, Oct. 25, pp. 705–6.