GEOGRAPHICAL BULLETIN

No. 12 1958

GEOGRAPHICAL BRANCH
Department of Mines and Technical Surveys
OTTAWA, CANADA

GEOGRAPHICAL
BULLETIN

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Available from the Queen's Printer
Ottawa, Canada

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64521-8—1½

TEMPERATURES IN PERMAFROST AT RESOLUTE, N.W.T.

Frank A. Cook

A unique opportunity to report on temperature data in permanently frozen ground in Northern Canada was presented by the program of diamond drilling in permafrost at Resolute, N.W.T., during the summers of 1950 to 1953. It was carried out jointly by the Dominion Observatory, Department of Mines and Technical Surveys; the Meteorological Division, Department of Transport; and the Associate Committee on Soil and Snow Mechanics of the National Research Council of Canada. The project was set up to determine the temperature gradient in the permafrost to depths of 1,000 feet. It also offered an opportunity to study problems connected with drilling in permafrost, and to measure heat flow in Arctic regions, a matter of considerable geophysical interest.

Several recent papers have discussed various aspects of the problem. Thomson and Bremner (1952) provided preliminary general observations from shallow-hole readings obtained in the first two years of drilling. Both short-period diurnal fluctuations and seasonal variations in temperature were observed. A minimum temperature of −13.5°C. was noted in 1950 at a depth of 50 feet, with the layer from 50 to 98 feet being nearly isothermal. Bremner (1955) discussed problems encountered in the 4 years of drilling in permafrost. Cook (1955) analysed near-surface soil and air temperatures and solar radiation for 1950-53, and the freeze-back in 1955. Misener (1955) studied the heat flow in the permafrost, arriving at certain conclusions and making certain determinations by using the divided bar method on core samples recovered during drilling operations. Misener, Bremner and Hodgson discussed the heat flow measurements and drilling problems at Resolute in general terms, combining information given by Bremner (1955) and Misener (1955). Goguel (1956) saw the thermal anomaly reported by Misener (1955) as the result of Quaternary variations in climate, basing his work on solutions for one-dimensional heat flow, with approximate corrections for the effects of latent heat. Lachenbruch (1957) offered nearby bodies of water as an explanation for the anomalously large outward earth-heat flow reported by Misener (1955).

The present paper considers Resolute permafrost temperature data in greater detail than has been attempted previously. The writer spent the period August, 1953 to September, 1954 at the Dominion Observatory

Seismic Station, Resolute, and returned in the summer of 1955 to conduct independent geomorphological field work. During these periods, considerable temperature data were accumulated. Additional data have been supplied by the Meteorological Division, Department of Transport and the United States Weather Bureau.

TEMPERATURE INVESTIGATIONS

Equipment

The equipment used to obtain the permafrost temperature data has been described previously in the literature (Bremner, 1955; Cook, 1955; Misener, 1955; Misener, et al., 1956). In brief, thermistors, temperature-sensitive elements with negative thermal coefficients that cause resistance to decrease as temperature increased, were inserted in the drilled holes at varying depths. The temperature-resistance relations at atmospheric pressure had been determined before installation, and as previous experience had shown this type of element to be stable, a degree of accuracy of better than 0.1°C. was expected. The absolute temperature, however, should probably have been decreased by a constant amount in the order of some tenths of a degree C., because the effect of pressure on the temperature-resistance relations was unknown. It is known, however, that the resistance of a thermistor changes due to changes in pressure, even though there is no change in temperature. In Resolute readings, the correction is probably the same at all depths under study, since the pressure of the freezing ice would be constant. Because the unknown correction is probably constant at all depths, the temperature gradient is probably accurate.

Data from hole 1 with recording thermistors at 5-foot intervals from 3 to 68 feet and thence at 10-foot intervals to 98 feet; and from hole 20 with recording thermistors at 50-foot intervals from 50 to 650 feet, have been used for the analysis of temperatures below 3 feet in depth. Near-surface installations at depths of 4, 8, 18 and 60 inches have been used in the discussion of the near-surface diurnal variations.

Permafrost and Temperature Gradient

Permafrost is the result of a negative heat balance at the surface of the earth, either past or present. This negative heat balance disturbs the normal positive temperature gradient due to the outward flow of heat from depths within the earth. Theoretically it can occur when the mean annual temperature at the earth's surface is 0°C. (32°F.), although, because of local conditions, it generally does not form until the mean annual temperature is several degrees lower. Whether it is the result of successive winter seasons, a relic of the last ice age, or a combination of both, has not yet been conclusively proven. Many workers believe that permafrost first appeared during the refrigeration of the earth's surface at the beginning of the Pleistocene or Ice Age, and, since that time, periods of climatic fluctuations have brought about a corresponding change in the thickness and areal extent of permafrost. However, permafrost is forming today in such places as the recently built river islands and bars in arctic regions.

Temperature gradients within the permafrost are influenced by climatic cycles. Three major cycles are involved; diurnal, seasonal, and long-term. Day to night fluctuations in both air temperature, and in the amounts of solar radiation received at the surface of the earth, cause a corresponding daily wave or fluctuation within the top 3 feet of permafrost. The amplitude of the wave-length decreases rapidly with depth, and is subject to a time lag. The yearly or seasonal cycle is similar, but the wave-length or fluctuation penetrates deeper, extending to perhaps 50 feet, while the time lag at this depth may be as much as 7 to 8 months. The long-term cycle, related to major climatic cycles of the recent past, is less well known. Long-term climatic trends should result in a gradual cooling or warming in the permafrost, changing the gradient below the zone of annual variation, and influencing the depth of permafrost. Although little quantitative data are available as yet, reports from the U.S.S.R., where permafrost has been studied in detail for many decades, indicate that such is the case.

Diurnal Variations

Thomson and Bremner (1952) and Cook (1955) have reported on diurnal variations in the top layers of permafrost at Resolute.

Minor daily fluctuations can be observed in the top 3 feet of soil, chiefly in the active layer. The range of variation, day to night, follows a sine curve damped with increasing depth. It is subject to a few hours lag with depth, increasing to about 12 hours at the permafrost table (25 inches).

These daily variations in soil temperature are due to fluctuations in the amount of solar and sky radiation received, as well as fluctuations in surface air temperature. The amplitude of the daily variation changes with the time of the year, and because radiation is a more effective agent than changing air temperature, the changes achieve their greatest range in summer. However, summer diurnal variations are much less than in non-permafrost regions to the south. Not only is there greater uniformity of the mean surface air temperature in the Resolute area, resulting from continuous daylight and relatively weak circulation prevailing in the atmosphere in summer, but totals of radiation received are less, because of the lower angle of the sun. Whereas the maximum air temperature may occur at any time within the 24-hour period, interrupting the normal diurnal rise and fall, the maximum soil temperature at near-surface levels is reached in afternoon or early evening, indicating that intensity of solar radiation and continuous sunlight have more effect on soil temperature than does air temperature.

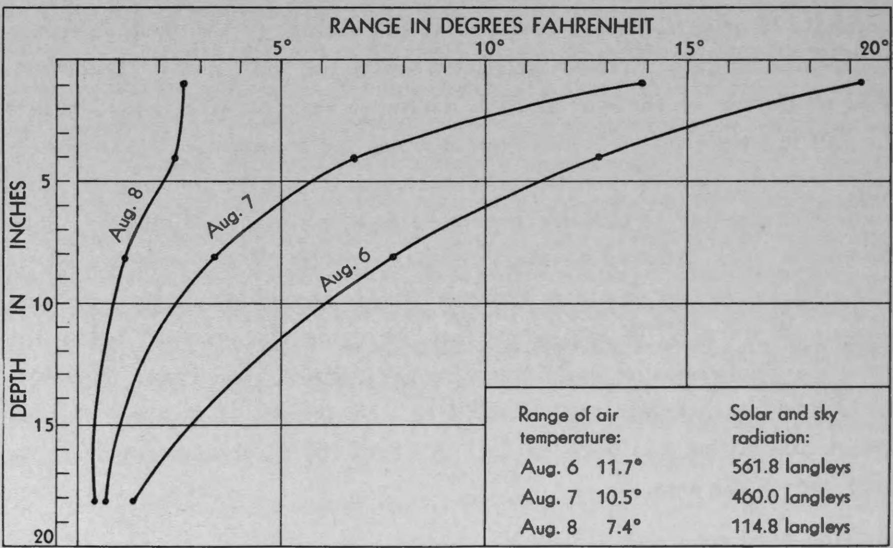

Figure 1. Range between maxima and minima at depths of 1, 4, 8 and 18 inches at Resolute, August 6-8, 1955.

The importance of radiation as a control of diurnal variations in the upper levels of permafrost is shown in Figure 1 which is compiled from data of a detailed field study by the writer at Resolute, based on 1-hourly readings at depths of 1, 4, 8 and 18 inches for the period August 6-8, 1955, inclusive.

On August 6th, a clear, calm day producing an incoming insolation reading of 561.8 langleys*, the range of the surface air temperature was 11.7°F. Larger ranges were found in the permafrost at depths of 1 and 4

* The unit of measurement of solar radiation, the langley, is the amount of radiation in gram-calories per square centimeter of horizontal surface.

Measurements of solar radiation at Resolute were supplied by the United States Weather Bureau who have installed a pyrheliometer.

inches. A range in temperature of 19.2°F. at 1 inch, was reduced to 12.8°F. at 4 inches, to 7.7°F. at 8 inches, and to 1.3°F. at the 18-inch level, at which point a lag of 8 hours was noted. Similarly, the next day when afternoon cloudiness reduced the amount of insolation received to 460 langleys, the range of surface air temperature was reduced to 10.5°F., while the range in the permafrost was reduced from 13.9°F. at 1 inch to 1.6°F. at 18 inches. On August 8th the sun was obscured by heavy fog all day, sharply reducing the amount of incoming insolation to 114.8 langleys. This reduction in incoming heat is clearly seen in the very low range of 2.5°F. for the near-surface level of 1 inch. The importance of insolation is thus indicated, for on August 6 and 7, both days of relatively high incoming radiation, the temperature range in permafrost at 1 inch exceeded that of the surface air. On the next day, August 8th, however, the range at 1 inch was reduced to about one third of the air temperature range because of sharply reduced amounts of insolation received.

In the fall, as periods of darkness lengthen each day, the effect of insolation becomes negligible, finally disappearing. Fluctuations in soil temperature then follow surface air temperature. 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 the winter and continuous darkness, any fluctuation in soil temperature tends to be the result of an unusually low minimum air temperature.

Table 1, below, based on 8-hourly readings** for the period February 11 to 13, 1956, inclusive, shows fluctuations in near-surface permafrost levels during the deep winter period. At this time of year the effect of insolation would be nil, as the sun had only returned above the horizon at Resolute the previous week. Variation here appears to be related to the minimum air temperature low for the period, of −40.6°F., which occurred on February 11th. Soil temperature at the 4-inch level dropped from 3.5°F. at 23:15 hours on February 10th, and to 1.8°F. at 23:15 hours on February 11th, after which time it rose again steadily to 2.5°F. at 11:15 hours on February 13th. Similarly, at the 8-inch level, temperature dropped from a high of 16.1°F. at 05:15 hours on February 11th, to 14.6°F. at 05:15 hours on February 12th, rising to 15.5°F. at 05:15 hours on February 13th. At 18 inches, the soil temperature dropped from 14.0°F. at 05:15 hours on February 11th, to 13.4°F. at 05:15 hours on February 12th, and rose to 13.8°F. by 11:15 hours on February 13th.

** The writer is indebted to D. Stockwell of the Dominion Observatory Seismic Station, Resolute, for taking these additional observations.

TABLE 1.—Fluctuations in Near-surface Permafrost Temperatures, Resolute, N.W.T. February 11 to 14, 1956. (8-hourly readings)

Time		Depth	4 inches	8 inches	18 inches	Surface air
CST			*(All readings in degrees Fahrenheit)*			
Feb 10:	23:15 CST	—	3.5	16.0	14.0	−25.1
Feb 11:	05:15	—	3.2	16.1	14.0	−30.9
	11:15	—	2.8	15.7	13.9	−35.7
	17:15	—	2.2	15.1	13.7	−36.4
	23:15	—	1.8	14.8	13.5	−32.2
Feb 12:	05:15	—	1.9	14.6	13.4	−25.9
	11:15	—	2.2	15.0	13.4	−27.9
	17:15	—	2.1	15.0	13.4	−30.6
	23:15	—	2.1	15.0	13.4	−25.7
Feb 13:	05:15	—	2.2	15.0	13.4	−25.2
	11:15	—	2.5	15.5	13.8	−22.0
	17:15	—	2.5	15.3	13.4	−21.2
	23:15	—	2.8	15.5	13.5	−20.8

Snow cover constant throughout period of readings. No wind. Minimum air temperature (Stevenson screen) recorded for period was −40.6°F, between 11:15 and 17:15 hours CST, February 11th.

In the winter, as in the summer, there is greater uniformity in the mean surface air temperature than in areas to the south. In the spring, with the return of day and lengthening periods of light, daily fluctuations follow surface air temperature until the season has advanced far enough for incoming radiation to be effective.

The temperature curve for the year in the active layer, plotted from daily averages, shows the following characteristics: the warm-up in spring is gradual until June, when, in response to increasingly high surface air temperatures and increased incoming radiation, the rate increases. Maximum daily fluctuations are observed in July and August. In late August, when the daily surface air temperature falls below freezing, there follows a rapid decline in all values until the soil reaches the freezing point. It remains around the freezing point for a time, as the chilling of the ground is temporarily compensated by latent heat of fusion given off by the groundwater, 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). The "zero curtain" at Resolute has been discussed in detail for the freeze-back period in the fall of 1955 (Cook, 1955, p. 244-246).

While it lasts for a very short time at 4 inches below the surface, it can exist for more than 3 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 begins again.

The mean monthly temperatures in the ground above 18 inches in depth, have their minimum temperature in February, the same month in which the minimum surface air temperatures are recorded. At depths of 20, 25 and 35 inches, it occurs in March, giving a one-month lag. The minimum temperature at 60 inches is recorded in April, showing a lag of 2 months at this depth. The maximum temperatures at 4 and 8 inches occur 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 the 35- and 60-inch levels the maximum temperatures occur in September, 2 months after the surface air temperature is attained. Only 2 months, July and August, show a mean monthly temperature above freezing in the active layer (Cook, 1955, p. 241).

As would be expected, the range of mean monthly temperature decreases with depth. There is a spring and fall overturn to depths below 60 inches. In January the coldest permafrost is at the surface, the ground becoming warmer with depth. In the summer the reverse is true for the top few feet of permafrost, with the ground becoming progressively cooler with increasing depth. The spring overturn at near-surface levels occurs in April, whereas the fall overturn generally occurs in September (Cook, 1955, p. 242).

Seasonal Variations

The data indicate seasonal fluctuations to a depth of between 50 and 60 feet. This is roughly 19 times the diurnal range of about 3 feet, very close to what would be expected theoretically. As the temperature at a given depth is proportional to the square root of the time factor, when the daily range is 3 feet, the yearly range expected would be three times the square root of 365, or approximately 57 feet.

The seasonal range can be taken roughly as the amplitude of a sine wave as it is damped with increasing depth. There is also a time lag. For example, the mean monthly maximum surface air temperature for the year occurs in July. In 1957 it was reflected in the monthly permafrost averages at 3 feet in August, at 13 feet in October, and at 23 feet in November. (Figure 2).

The seasonal range in 1955 for all depths to 98 feet is shown in Figure 3.

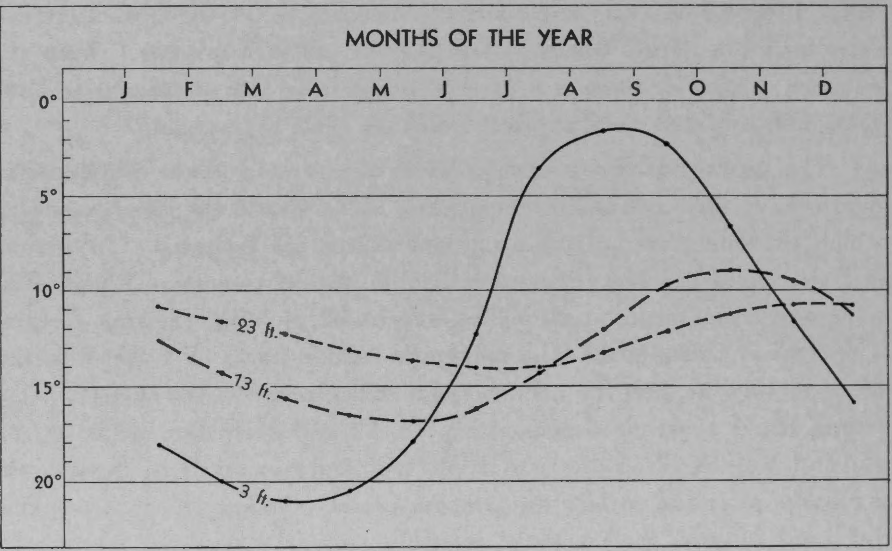

Figure 2. Seasonal range of permafrost temperatures, Resolute, at depths of 3, 13 and 23 feet; 4-year averages, 1954-1957.

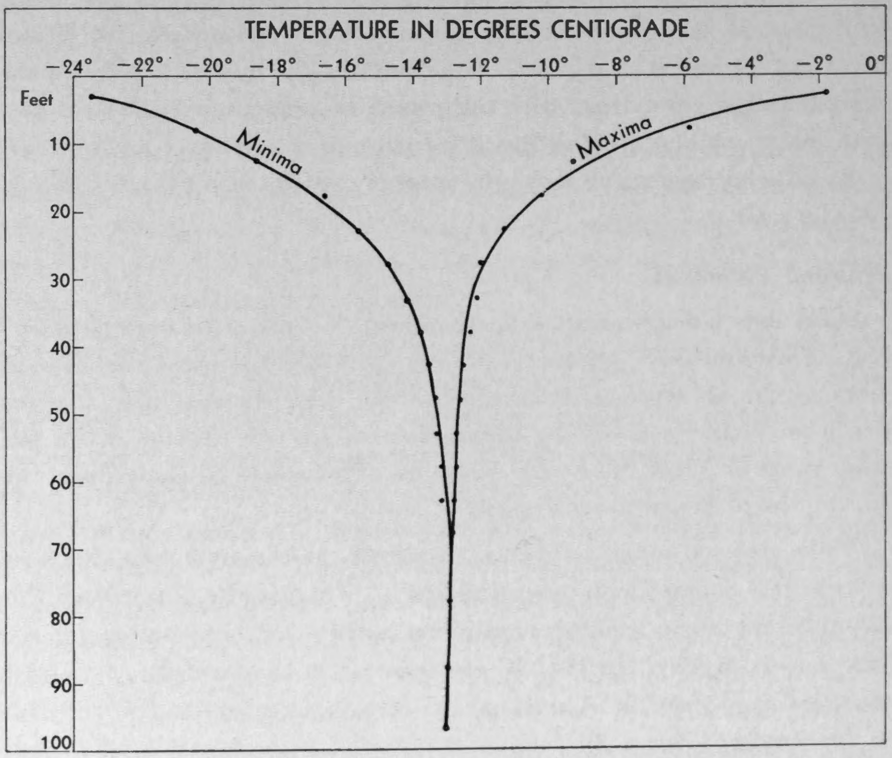

Figure 3. Amplitude of seasonal range at Resolute, as shown by maxima and minima temperature observations at depths to 98 feet, 1955 (weekly readings).

TABLE 2.—Monthly Averages of Soil Temperatures, Resolute, N.W.T., 1955, in degrees Centigrade

Depth	Month												Year	Range
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.		
3 ft.	−22.6	−23.4	−23.5	−22.6	−19.5	−12.4	− 3.3	− 1.8	− 1.9	− 6.4	−12.3	−17.0	−13.9	21.7
8 ft.	−17.8	−19.4	−20.3	−20.4	−19.5	−16.8	−10.5	− 7.6	− 5.9	− 6.5	− 9.2	−12.9	−13.9	14.5
13 ft.	−15.1	−16.8	−17.9	−18.7	−18.7	−17.9	−15.0	−12.5	−10.2	− 9.3	− 9.9	−11.8	−14.5	9.4
18 ft.	−12.8	−14.1	−15.3	−16.2	−16.7	−16.6	−15.4	−13.8	−11.7	−10.5	−10.2	−10.9	−13.7	6.5
23 ft.	−12.1	−12.9	−13.3	−14.7	−15.3	−15.6	−15.2	−14.5	−13.0	−12.0	−11.3	−11.3	−13.4	4.2
28 ft.	−12.0	−12.5	−13.0	−13.7	−14.3	−14.7	−14.8	−14.6	−13.8	−13.0	−12.5	−12.1	−13.4	2.8
33 ft.	−12.1	−12.3	−12.6	−13.1	−13.5	−13.9	−04.2	−14.2	−13.9	−13.4	−13.0	−12.6	−13.2	2.1
38 ft.	−12.3	−12.3	−12.5	−12.7	−13.1	−13.4	−13.6	−13.8	−13.8	−13.5	−13.3	−13.0	−13.1	1.5
43 ft.	−12.5	−12.5	−12.5	−12.6	−12.8	−13.0	−13.3	−13.4	−13.5	−13.5	−13.3	−13.2	−13.0	1.0
48 ft.	−12.6	−12.6	−12.6	−12.6	−12.7	−12.8	−13.1	−13.1	−13.3	−13.3	−13.3	−13.2	−12.9	.7
53 ft.	−12.8	−12.8	−12.7	−12.7	−12.8	−12.9	−13.0	−13.1	−13.2	−13.3	−13.3	−13.3	−12.9	.5
58 ft.	−12.8	−12.7	−12.7	−12.7	−12.7	−12.8	−12.8	−12.9	−13.0	−13.1	−13.1	−13.2	−12.7	.4
63 ft.	−12.8	−12.8	−12.7	−12.8	−12.8	−12.8	−12.9	−12.9	−12.9	−13.0	−13.0	−13.1	−12.6	—
68 ft.	−12.8	−12.8	−12.8	−12.8	−12.8	−12.8	−12.8	−12.9	−12.9	−13.0	−13.0	−13.1	−12.9	—
78 ft.	−12.8	−12.9	−12.9	−12.9	−12.9	−12.9	−12.9	−11.9	−12.9	−12.9	−13.0	−13.0	−12.9	—
88 ft.	−12.9	−12.9	−12.9	−12.9	−12.9	−12.9	−12.9	−12.9	−12.9	−12.9	−12.9	−13.0	−12.9	—
98 ft.	−12.9	−12.9	−12.9	−12.9	−12.9	−12.9	−13.0	−13.0	−13.0	−13.0	−13.0	−13.0	−12.95	—

Mean Monthly Surface Air Temperature in Degrees Fahrenheit

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Range
	−33.3	−23.4	−18.4	−9.5	9.1	34.4	41.9	34.4	25.1	4.6	−17.7	−26.2	1.8	75.2

The monthly maximum reached the lower limit of seasonal variation, at a depth between 50 and 60 feet, in March of the next year. Similarly, the minimum monthly mean air temperature, recorded at the surface in January, did not reach the 53-foot level in the permafrost until October, 8 months later (Table 2).

The permafrost, apart from an anomalous 13-foot reading, has practically the same mean yearly average from the permafrost table to the 98-foot level, based on the 4-year averages from 1954-1957 (Table 3). It warms up fractionally from −12.7°C. at 3 feet to −12.4°C. at 18 feet, and then cools gradually to −12.9°C. at 98 feet.

TABLE 3.—Yearly Averages of Soil Temperatures 1952-57, Resolute, N.W.T. in degrees Centigrade

Years	1952	1953	1954	1955	1956	1957	1954-57 average
Depths							
3 feet	−12.1	− 9.3	−12.1	−11.7	−13.1	−13.9	−12.7
8 feet	−11.7	− 9.2	−12.0	−11.8	−12.5	−13.9	−12.5
13 feet	−11.9	− 9.8	−12.8	−12.7	−13.0	−14.5	−13.2
18 feet	—	− 9.7	−12.0	−12.0	−12.1	−13.7	−12.4
23 feet	—	−10.1	−11.9	−12.1	−12.3	−13.4	−12.4
28 feet	−13.1	−10.7	−12.0	−12.2	−12.4	−13.4	−12.5
33 feet	−13.1	−11.5	−12.0	−12.3	−12.4	−13.2	−12.5
38 feet	−13.1	−11.9	−12.0	−12.4	−12.4	−13.1	−12.5
43 feet	−13.1	−12.1	−12.1	−12.5	−12.5	−13.0	−12.5
48 feet	−13.2	−12.2	−12.2	−12.5	−12.6	−12.9	−12.5
53 feet	−13.3	−12.4	−12.4	−12.6	−12.7	−13.0	−12.7
58 feet	−13.2	−12.4	−12.6	−12.6	−12.7	−12.9	−12.6
63 feet	−13.2	−12.6	−12.5	−12.7	−12.7	−12.8	−12.7
68 feet	−13.3	−12.8	−12.6	−12.7	−12.8	−12.9	−12.7
78 feet	−13.3	−12.9	−12.8	−12.8	−12.8	−12.9	−12.8
88 feet	−13.4	−13.0	−12.9	−12.9	−12.9	−12.9	−12.9
98 feet	−13.4	−13.0	−12.9	−12.9	−12.9	−12.9	−12.9

Long-term Variations

Misener (1955), on examination of the records of hole 1 (depths to 98 feet), noted that the temperature rose over the period from 1950 to 1954, and speculated that the heating started during the autumn of 1948. This warming trend was reversed in 1954, however, and since that time the upper few tens of feet of the permafrost have cooled appreciably (Table 4).

TABLE 4.—Cooling for Four-year Period 1954-57 at Depth, Resolute N.W.T.

3 feet	2.2°C	33 feet	.9°C
8 feet	2.1°C	38 feet	.6°C
13 feet	1.8°C	43 feet	.5°C
18 feet	1.7°C	48 feet	.4°C
23 feet	1.4°C	53 feet	.3°C
28 feet	1.2°C		

At the time of writing (April, 1958) this trend is continuing. Although Misener does not think that the rise to 1953 was a consequence of steadily rising mean surface air temperature, it is interesting to note that the mean annual air temperature did rise at Resolute from 1.5°F. in 1948 to 4.8°F. in 1952, and since that time has been falling steadily to 1.8°F. in 1957 (Table 5).

TABLE 5.—Mean Yearly Surface Air Temperature, 1948-1957. Resolute N.W.T

Year		Year	
1948	1.5°F	1953	3.2°F
1949	1.8°F	1954	3.1°F
1950	2.0°F	1955	2.5°F
1951	3.1°F	1956	.5°F
1952	4.8°F	1957	1.8°F

The minimum ground temperature below the level to which the seasonal changes penetrate, is found at approximately the 100-foot level. The temperature there was −13.2°C. in 1957, a rise of .1°C. from the previously recorded temperature in 1955. This rise probably reflected the downward movement of the warm-up recorded earlier in the upper levels. This temperature is considerably colder than the minimum of −10.6°C. reported for permafrost in Alaska by Brewer (1955). Below the 100-foot level there is a steady increase in temperature.

From 300 feet to 650 feet the curve is essentially a straight line, from which Misener determined the temperature gradient of 2.16°F. per 100 feet. This temperature gradient is much higher than the average values found in the southern part of the Canadian Shield, but compares favourably with the average value of about 2.0°F. per 100 feet found by MacCarthy in Alaska. As Misener observed, the temperature gradients in permafrost in North America appear to be higher than normal.

Through extrapolation of the temperature gradient below 300 feet, Misener puts the lower limit of permafrost at 1,280 ± 10 feet. The temperature versus depth graph is shown in Figure 4. Lachenbruch (1955) in a recent study considered that Misener's value, while being in the correct range, might be 50 to 100 feet too large, basing his argument on the assumption that nearby bodies of water have an effect on thermal gradients near the shore line in cold regions.

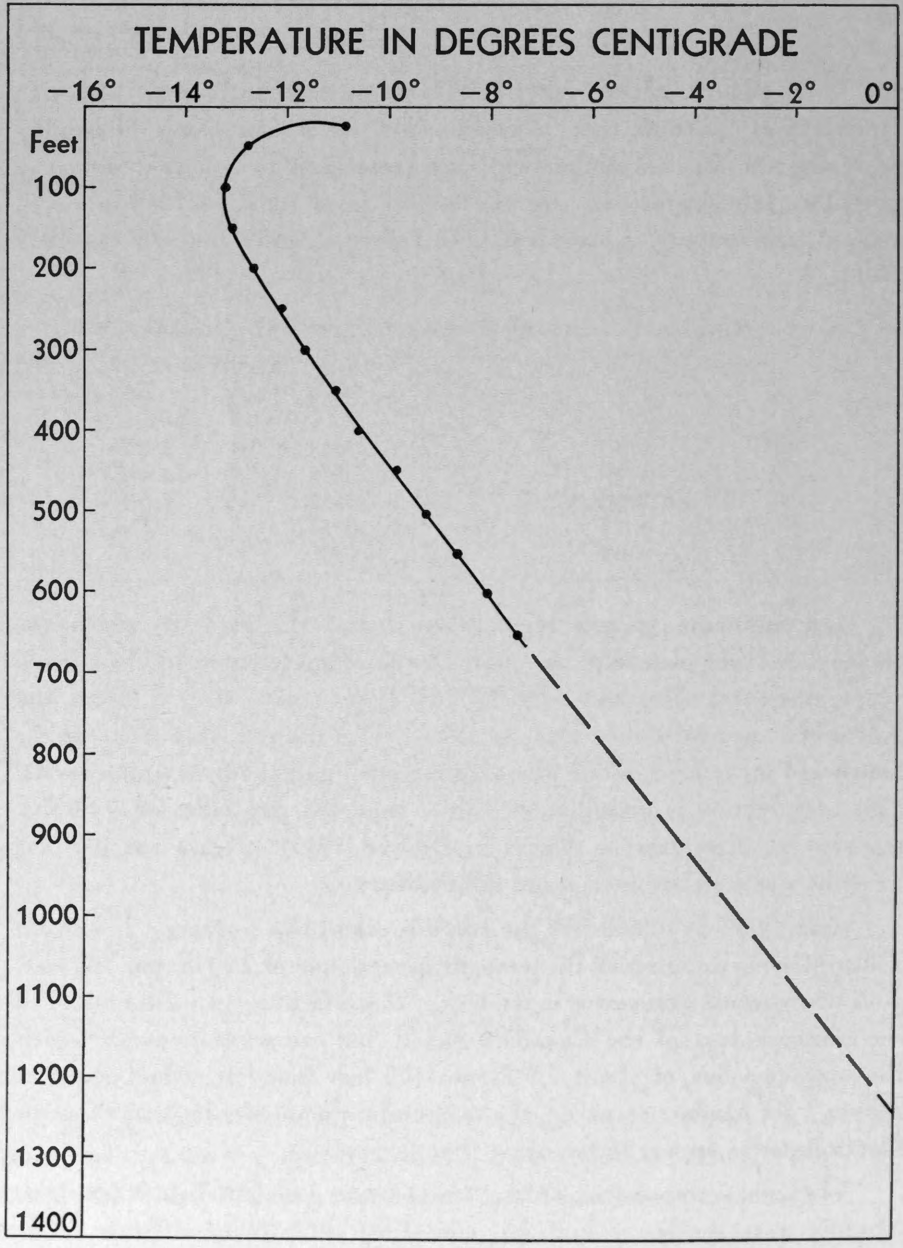

Figure 4. Thermal log of hole 20, Resolute, with extrapolation of temperature vs. depth curve to estimated bottom of permafrost (after Misener).

RÉSUMÉ

L'installation de thermomètres à résistance du type "thermistors" à différentes profondeurs et jusqu'à 650 pieds sous terre a fourni les données nécessaires à l'étude de la température du pergélisol à Resolute, Territoires du Nord-Ouest.

Les variations diurnes, observées surtout dans le mollisol, sont dues à la puissance de la radiation solaire et aux changements de température de l'air à la surface du sol.

On relève l'effet des variations saisonnières jusqu'à une profondeur de 50 ou 60 pieds, avec un décalage d'environ 8 mois. Jusqu'au niveau de 98 pieds, la température moyenne annuelle du pergélisol est à peu près la même.

Il n'existe pas encore assez de données qui permettraient une étude détaillée des variations à long terme et de leurs relations avec les cycles climatiques antérieurs. De 1950 à 1954, il y a eu tendance au réchauffement du pergélisol; depuis ce temps, par contre, les premières dizaines de pieds de profondeur se sont nettement refroidies.

La température minimum, sous le niveau atteint par les variations saisonnières, se rencontre à environ 100 pieds de profondeur. En 1957, la température atteignait à cet endroit $-13.2°C.$, certainement l'une des plus basses à être enregistrées dans le pergélisol.

Sous le niveau de 100 pieds, il y a une augmentation constante du gradient thermique, tandis qu'entre 300 et 650 pieds la courbe des températures se redresse et le gradient se stabilise alors à 2.16°F. par 100 pieds. Ce gradient thermique est beaucoup plus élevé que ceux enregistrés dans la partie sud du bouclier, mais il se compare avantageusement aux gradients déjà relevés en Alaska.

L'extrapolation du gradient thermique à Resolute situe la limite inférieure du sol gelé en permanence à 1280 pieds, $\pm$ 10.

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PHYSIOGRAPHIC REGIONS OF BOOTHIA ISTHMUS, N.W.T.

by J. Keith Fraser

Boothia Peninsula extends north from the Canadian mainland and, with Somerset Island, separates the eastern and western islands of the southern group in the Canadian Arctic Archipelago (Figure 1). The peninsula stretches 172 miles from Spence Bay at the west side of Boothia Isthmus, to Bellot Strait, the northernmost point of continental America.

Boothia Isthmus is only 17 miles across, and contains Middle Lake which, lengthwise, occupies 12 miles of this feature. A change of 50 feet in the relative level of land and sea would create an island of Boothia Peninsula that would rank ninth in size among the Canadian Arctic islands, only a little smaller than Axel Heiberg. Boothia Peninsula is in the District of Franklin, whose southern boundary lies across Boothia Isthmus from the northwest corner of Spence Bay to the westernmost coast of Lord Mayor Bay, at the head of Netsiksiuvik Inlet.

In the summer of 1953 the writer headed a Geographical Branch field party on the Boothia Peninsula. Between May and September, the party made trips by dogsled, on foot and by canoe across the isthmus and through the lakes north of Spence Bay. Observations made during these trips have been supplemented by the interpretation of air photos and form the basis for this paper.

The area covered is that adjacent to Boothia Isthmus, extending from Thom Bay and Lord Mayor Bay on the east, to Josephine Bay and Spence Bay on the west. Within this area of about 3,000 square miles, are a variety of landscapes that are related to both the Canadian Shield to the south and the plains of the Palaeozoic lowlands and islands to the west.

Discovery and Exploration

Boothia Isthmus was first visited by Europeans in 1829 when the expedition commanded by John Ross sailed south in the *Victory* along the east coasts of Somerset Island and Boothia Peninsula to Felix Harbour in Lord Mayor Bay. This expedition spent three years in the area and published a report with a map of Boothia Isthmus that remained the best published map for over 120 years. Although later explorers travelled in the general area, M'Clintock along the west coast, Rae along the west and east coasts south of the isthmus, and Amundsen through the waters west of

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Figure 1. Location Map.

Spence Bay, no further scientific exploration was done until after World War II. Missionaries, traders and members of the Royal Canadian Mounted Police travelled by dogteam along the Boothian coasts, but contributed little to the published accounts of the geography.

In 1948, the Hudson's Bay Company established a trading post at Spence Bay to replace the abandoned post at Fort Ross on Bellot Strait (Figure 2). The traders were joined the following year by the R.C.M.P. and missions were established in subsequent years. This settlement provided a base from which scientific parties were able to investigate the isthmus and adjacent areas.

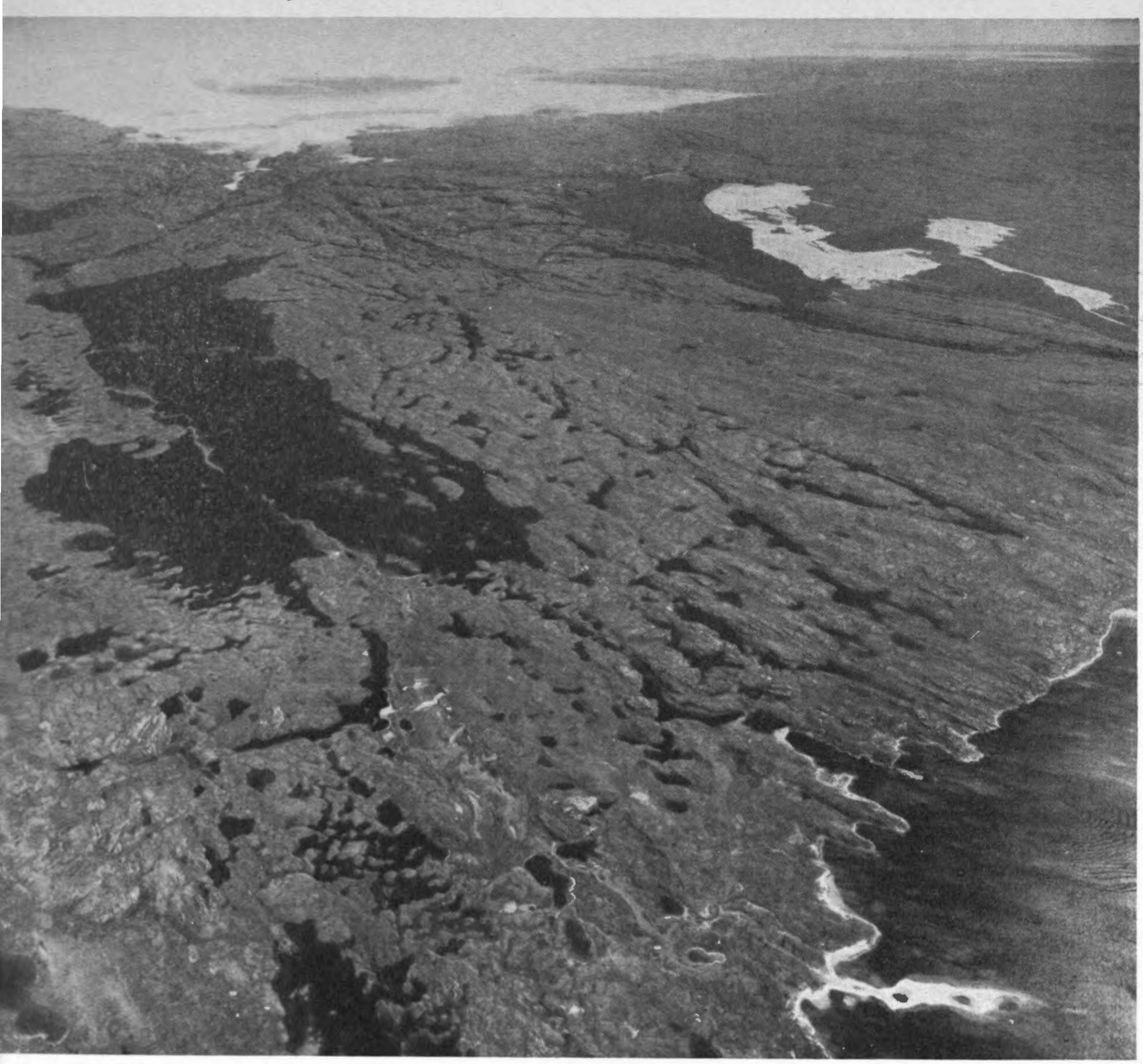

Figure 2. Boothia Isthmus, looking east, with Lord Mayor Bay in the distance, Middle Lake, and Spence Bay where the settlement is located. (RCAF Photo)

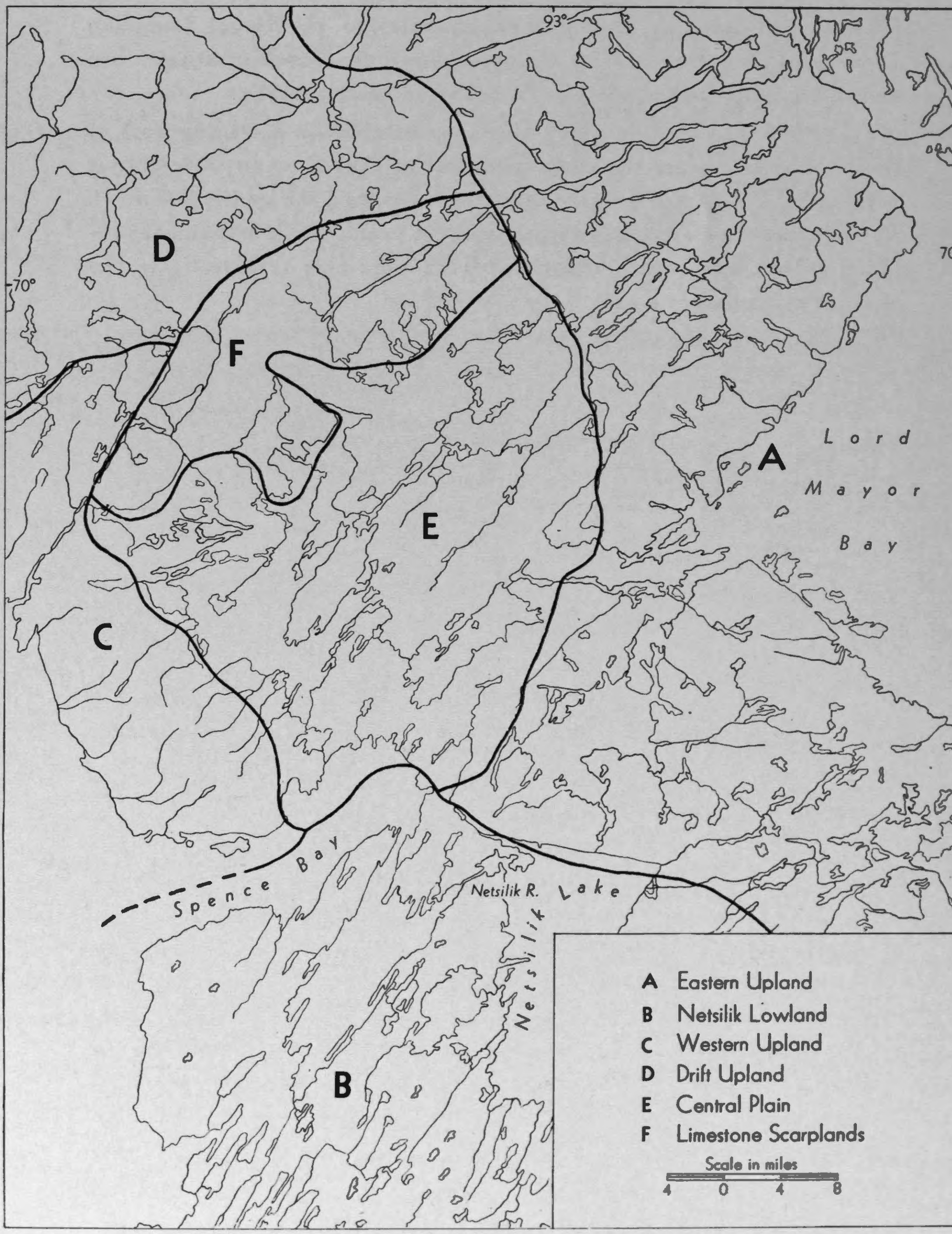

Figure 3. Physiographic regions of Boothia Isthmus.

Physiographic Regions

Boothia Peninsula is composed of a central ridge of Archaean rocks rising to nearly 2,000 feet in central Boothia and flanked on both coasts by overlapping Palaeozoic sediments. These younger rocks extend no farther south than Josephine Bay on the west coast and the vicinity of Agnew River on the east coast, except for outliers which occur inland north of the isthmus. Limestones probably underlie the low terrain south of Spence Bay and most of the central plain which separates the Archaean uplands extending along both coasts of the isthmus area.

The Pleistocene ice sheet covered the whole of Boothia Peninsula and left a discontinuous mantle of drift in the form of drumlins, outwash, eskers and associated moraine. These deposits are more significant in the area surrounding the isthmus than in the northern part of the peninsula where most of the surface is bare rock upland. Postglacial submergence and emergence resulted in the formation of marine strands at elevations of at least 700 feet.

Six main physiographic regions may be recognized in the area (Figure 3).

A. Eastern Upland
B. Netsilik Lowland
C. Western Upland
D. Drift Upland
E. Central Plain
F. Limestone Scarplands

A. EASTERN UPLAND

The whole of the east coast in the area under discussion is formed of rugged gneissic hills rising in places over 1,000 feet above the sea. The Eastern Upland extends to the west until it is terminated by several linear fault scarps overlooking the Central Plain (Figure 4) and the Netsilik Lowland. Elevations increase northwards, from the summit of the Netsilik scarp at about 450 feet to the hills near Kogaluktok Falls in Thom Bay which rise a little over 1,000 feet. The whole region is extremely rugged, and cut by joint and fault valleys which control the drainage. The linear configuration of the coasts, valleys and west-facing scarps indicates that the Eastern Upland is composed of a group of old fault blocks which are further dissected by numerous secondary joints (Figure 6).

Evidence of glaciation is shown by the polished and grooved upland surface and by scattered limestone erratics perched on heights well above present sea level. Postglacial marine action almost completely washed drift from the hills into the sea and the valleys. Emerged beaches occur at elevations up to at least 500 feet, but are seldom as well developed as on the

Figure 4. Looking east towards Thom and Lord Mayor bays over part of the Eastern Upland. Krusenstern Lake occupies a tectonic valley in the central part of the photograph and is bordered by part of the drumlinized Central Plain in the foreground. (RCAF Photo)

sedimentary formations elsewhere on the isthmus. In Netsiksiuvik Inlet, on the largest island, a flight of strands, formed mainly of finely comminuted crystalline rubble, rise nearly 200 feet above the sea. Near the summit of the island and on the hills on the north side of lower Sagvak Inlet, fine-grained materials containing marine shells exist in pockets.

Marine terraces occur near the rapids in Sagvak Inlet and appear to be at three definite levels—35, 60 and 175 feet above sea level. The predominant component is coarse crystalline gravel with much sand, and the

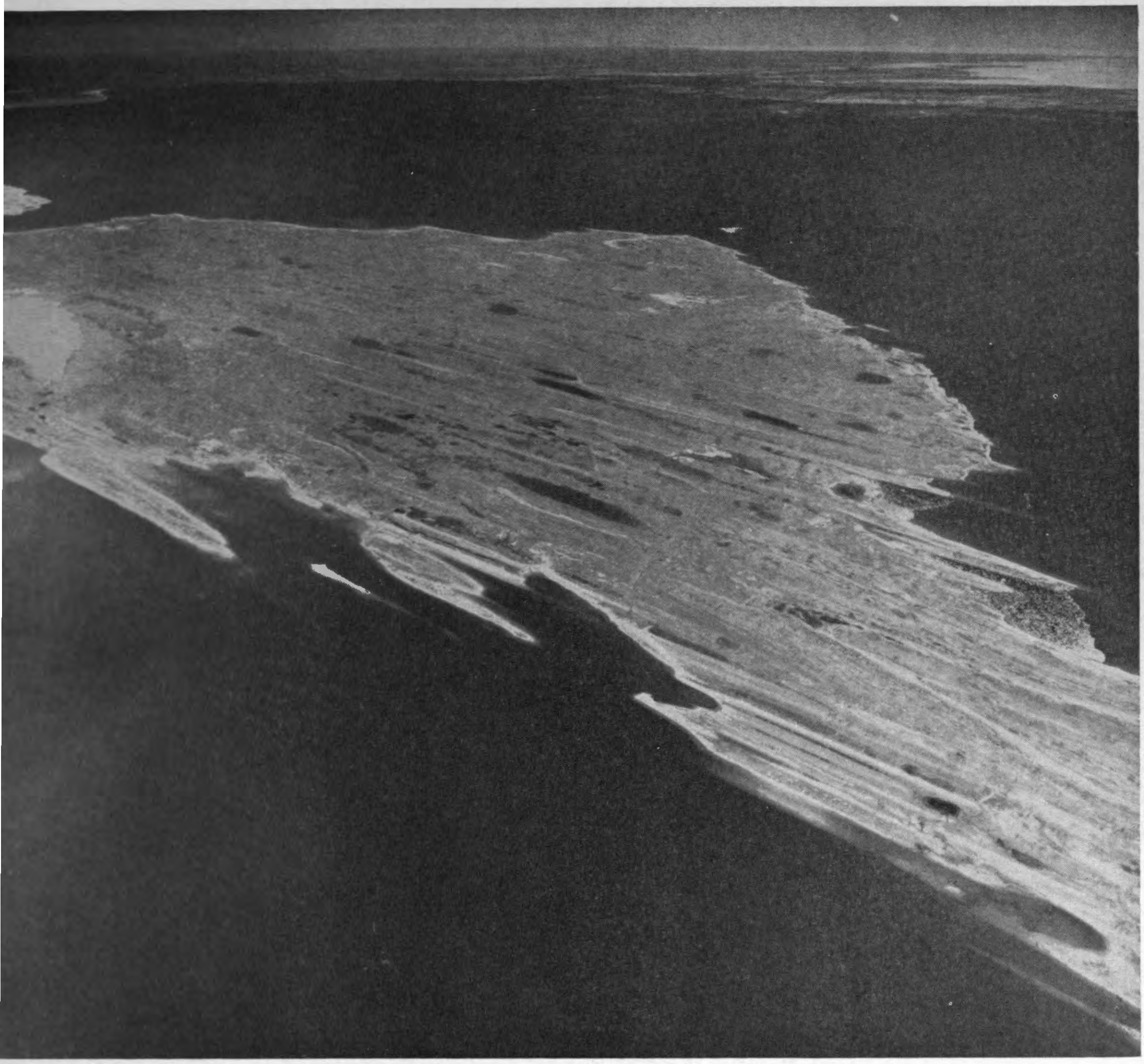

Figure 5. Part of the Netsilik Lowland between Willersted Inlet and Spence Bay, looking west. Note the low relief and strong drumlinization. (RCAF Photo)

terraces are well formed and well preserved. Only at the mouth of Lord Lindsay River do comparable terraces exist anywhere on the east coast. Inland, along the south shore of Krusenstern Lake, terraces were observed at 150 and 180 feet.

The waters of Krusenstern Lake enter Thom Bay at Kogaluktok Falls, 43 feet in height. These falls begin by boulder rapids at the exit of the lake, thence passing through a winding gorge at one point only 20 feet across and falling over two cataracts of 10 to 15 feet in height, after which the water issues from the gorge and flows over a boulder and cobble bed for

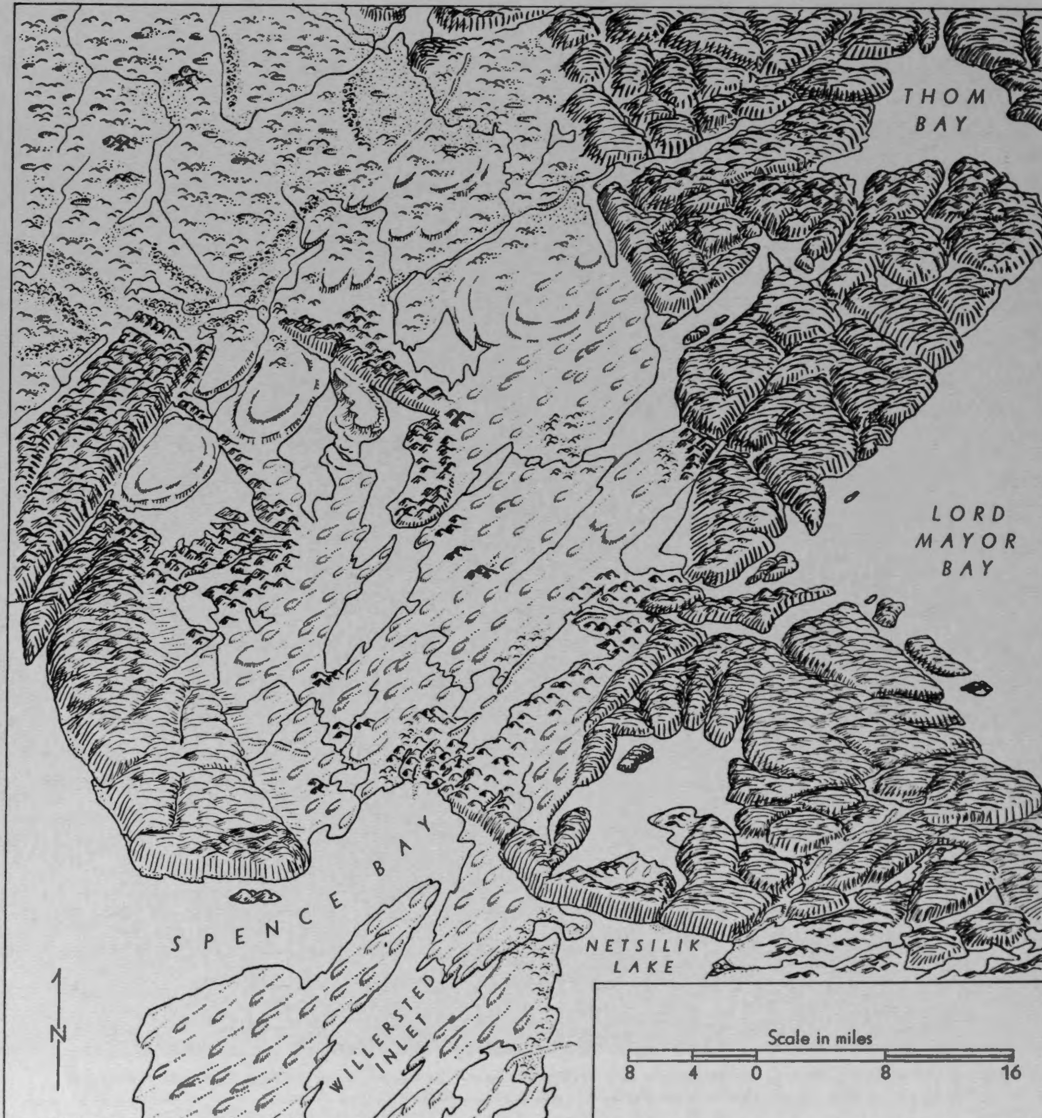

Figure 6. Physiographic diagram of Boothia Isthmus and adjacent areas.

several hundred yards to the sea. The gorge sides are 20 to 30 feet in height and formed of a reddish granite gneiss. Most of the surrounding country rock is gneiss and hard schist.

Between its mouth and Lord Lindsay Lake, Lord Lindsay River flows through a narrow valley with boulder and gravel terraces and steep talus slopes. This was a preglacial valley blocked by drift which the river reoccupied by cutting through the drift and redepositing it at and near the present mouth as a delta. Further uplift resulted in the river dissecting its delta in several stages, leaving several well-developed terraces at its mouth. Upstream the river has incised to the bedrock basement over which it flows in a succession of boulder rapids. The lower part of the river is tidal for about a mile.

The coastlands of the Eastern Upland, having been more exposed to the sea during postglacial uplift, have been more strongly washed of glacial deposits than the inland or western areas. The northeast-moving ice sheet deposited more drift on the western side of the upland than on the eastern. Accordingly, although all the higher summits are bare rock, the valleys and slopes around Lord Lindsay lake, east of Angmaluktok Lake and Pangnikto Lake have a relatively deep cover of unconsolidated material. Most of this is till, partly reworked and admixed with marine deposits, and the slopes exhibit strong evidence of continuing soil flow towards the valley floors.

B. NETSILIK LOWLAND

The border of the Eastern Upland is sharply marked southeast of Spence Bay by a remarkably straight fault scarp which forms the northern shore of Netsilik Lake (Figure 6). The upland rises nearly 500 feet above the lake and is in strong contrast to the drumlinized lowland which surrounds Willersted Inlet and forms the west shore of Netsilik Lake.

The Netsilik Lowland is characterized by drumlinoid forms which give to the area a ribbed or fluted character and control both the drainage and the configuration of the lakes and coastline (Figure 5). The drumlinoid trend runs a little north of northeast, and the entrance to Willersted Inlet parallels this trend. These hills seldom exceed 100 feet in the northern part of the lowland, although an examination of air photographs shows that the land is higher towards the south end of Netsilik Lake. Although not shown on the accompanying map, the Netsilik Lowland extends south and southwest to Shepherd Bay, its eastern boundary running from the south end of Netsilik Lake nearly to the mouth of the Murchison River.

It is likely that the lowland is underlain by limestones of Middle or Upper Palaeozoic age, similar to those occurring on King William Island. Although no exposures appear on air photos in that part of the lowland shown on Figure 3, low scarps are visible near Acland Point south of Shepherd Bay.

Drumlinoid forms created during a period of ice advance are responsible for the linear character of the lowland, but other features result from the stage of ice retreat. Several eskers and associated deposits occur near

Netsilik Lake. The drumlinoid drift material was reworked by wave and current action in the postglacial seas, and short flights of strands were left on the sides of the drumlinoid forms.

Netsilik Lake receives the waters of Lady Melville Lake, Pangnikto Lake and a large watershed surrounding these lakes. Lady Melville Lake drains through a system of small lakes and streams to enter Netsilik Lake at its northeast corner where it has formed a moderately large delta. Pangnikto Lake waters have cut through the Netsilik scarp along the north side of the lake. In this section there are numerous short rapids before the river cascades to the lake in its lower extremity. The Netsilik River is a short stream with boulder rapids. The watershed of Netsilik Lake on the south lies within 2 miles of Shepherd Bay.

C. WESTERN UPLAND

An upland of Archaean rocks rises on the west side of the isthmus to between 800 and 900 feet above the sea. It forms the coast between Cape Isabella and Josephine Bay, is bounded on the east by the Central Plain and the Limestone Scarplands, and on the north grades into the Drift Upland. As in the case of the Eastern Upland, the Western Upland is composed of a group of fault blocks, cut by faults and joints as exemplified by the deep ria-like inlet of Josephine Bay and the linear margins of the upland.

The southern part of the Western Upland (Figure 7) is composed mainly of grey and reddish granite, whereas north of the Garry Lakes the terrain has a gneissic foliation (Figure 8). The upland surface is bare of overburden near Cape Isabella and north of Artists Bay, but the central area differs in having a relatively deep mantle of limestone till which has been reworked first by wave action and subsequently by wind. Through this overburden protrude crystalline rocks. Active soil stripes occur on the slopes.

Lakes are small and scarce. The small streams have incised their valleys through the till and are controlled by the underlying bedrock topography. The drainage pattern is symmetrical, as the height of land occurs along the centre of the upland. Around Josephine Bay, the drainage is strongly controlled by the gneissic structure.

It is believed that the till was deposited on the Western Upland summit by northeast-moving ice which came from King William Island, incorporating in its passage much limestone material. On meeting the topographic

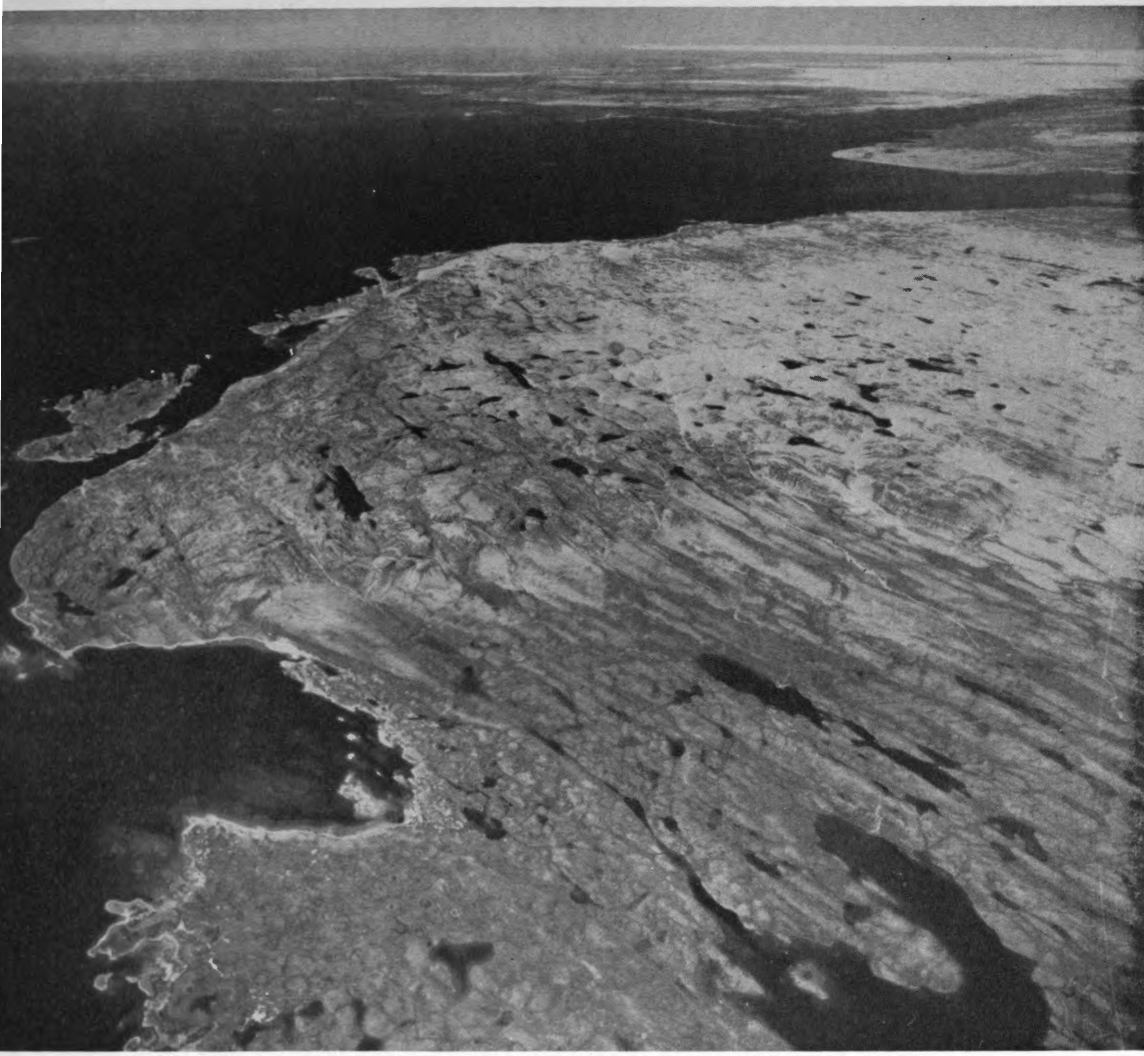

Figure 7. Looking west over the Western Upland, showing Cape Isabella and the drift-mantled upland, with part of the Central Plain and Redfish Lake in the foreground. (RCAF Photo)

barrier of the Western Upland, much of this englacial drift was left on the summit, after which the ice continued to move to the northeast across the central plain where more loose material and softer rocks were available to supply more drift. The comparatively bare surface near Cape Isabella is presumed to be due to the rift forming Spence Bay which lay in the path of the ice sheet and in which material was left. The absence of drift on the upland near Josephine Bay is less easily explained, but it is possible that the deposits were removed by postglacial wave action to a greater extent than on the central part of the Western Upland.

Figure 8. View west towards Josephine Bay, showing the Limestone Scarplands along the northern shores of Kangikjuke Lake (foreground), and Lake Hansteen (background). (RCAF Photo)

Following a postglacial uplift, but preceding a later marine submergence, evidence suggests that prevailing winds from the northeast brought fine material from the Central Plain and reworked the drift on the upland. The direction of these winds is clearly shown by thin deposits on the plain and the presence of unconsolidated material on the east-facing slopes of rock exposures and valleys on the upland.

The drift-mantled upland is almost desert-like in its aspect. Good drainage, wind action and soil movement have not allowed plants to become well established, so that the more exposed slopes and upland surfaces have only scattered pads of avens and poppy. No other area on the isthmus is so barren with the exception of the localized dunes near Tukingayak Lake. Even the bare rock areas of the Eastern Upland have considerable vegetation in the valleys.

Through the Western Upland, the Garry River drains the waters of Lake Hansteen and three smaller unnamed lakes to the north. At the outlet of Lake Hansteen, the river begins by flowing over a series of boulder rapids for more than a mile before cascading over Garry Falls, 40 feet in height, after which it enters the upper Garry Lake across a small delta. The upper and lower Garry lakes are divided by short bouldery rapids formed by the stream cutting through reworked moraine. Cliffs of granite gneiss form the shores of the lakes along much of their length with large cones of coarse talus leading to the water's edge. Where the Garry River leaves the lower lake, it has cut through marine and river terraces and enters the head of Josephine Bay in a small delta.

Flanking the coast of the Western Upland from Cape Isabella to about 8 miles past Imilik Island are flights of strands which have been breached by the small streams originating on the upland. Swamp and small lagoons are contained behind the lower strands and the terrain rises abruptly from steep cliffs and talus cones to the upland granite surface. Below the cliffs and cones are broad drainage swales, triangular in plan, the apex heading towards the cliffs.

D. DRIFT UPLAND

North of the Western Upland and the Limestone Scarplands lies a large area of glacial and glacio-fluviatile deposits through which protrude scattered exposures of crystalline rock. The area rises steadily to the northwest, attaining an elevation of more than 1,200 feet above the sea. A deranged and more intricate drainage system, with several moderately-sized lakes, differs from the structurally-controlled drainage systems of the eastern and western uplands or the drumlin controlled drainage of the lowland plains. Eskers and outwash indicate that this region was affected by the waning ice sheet to a greater degree than any of the other regions. Innumerable small lakes occur in the pitted outwash and moraine.

Several features which resemble end moraines lie in this physiographic region. They run generally north-south and are associated with sheets of pitted and dissected outwash along their eastern border. They may indicate stages of the retreating ice front which contained proglacial lakes between the ice and the Eastern Upland.

Areas of sand dunes originating from proglacial deltas occur at Sanagak and Tukingayuk lakes. Here Lord Lindsay River enters these lakes and has cut through the delta deposits in winding braided channels. Dunes and ventifacts indicate a prevailing northeast wind. Most of the dunes at Tukingayuk Lake are colonized and stabilized by clumps of wild rye grass.

The eskers, which have a northeast-southwest to east-west trend conforming to the trend of other eskers in the area, are all embankment eskers; no multiple eskers occur on the isthmus.

The glacial deposits left on this area of higher elevation were apparently undisturbed by postglacial sea action. Although no upper marine limit was recognized anywhere on the isthmus, occurrences of marine shells and silts at approximately 600 feet both on the Eastern and Western Uplands indicate an emergence of at least that amount. The absence of marine strands in the Drift Upland, where much loose material is available from which strands might be formed, indicates non-submergence.

The Drift Upland adjoins partially concealed outcrops of limestone and dolomite to the south, and the deposits thin out to the north where the Archaean basement rocks again reappear through the overburden. Streams traversing the area rise in the bare rock plateau in central Boothia Peninsula. Longer rivers and the absence of large lakes help to differentiate this region from the others.

E. CENTRAL PLAIN

Confined between the Eastern and Western Uplands and the Limestone Scarplands is a lowland which rises little more than 275 feet above the sea. This plain is characterized by strongly drumlinized terrain and the presence of large lakes. Although a definite physiographic region in itself, part of its borders indicate a transition from it to the adjacent regions.

Over most of the area lies a mantle of drift which mainly conceals the underlying bedrock. However, crystalline rock knobs protrude through the drift in three main areas, the Lake Hansteen ridges, the Lake Jekyll ridges and the Middle Lake ridges (Figure 2). Some of these hills rise several hundred feet above the Central Plain but have been included with the plain rather than with the associated uplands because of lower relief and the presence of much drift intermingled with the rock knobs. Elsewhere on the plain there are other much smaller and scattered exposures of rock knobs, which indicate both the relatively thin mantle of drift and the strength of the underlying bedrock relief.

Small separated outliers of Palaeozoic limestones related to the scarplands to the north also occur in several places on the Central Plain. Their low southwest-facing scarps indicate a gentle northeasterly dip. In several instances they are almost indistinguishable from the adjacent drumlin forms, having been moulded as crag-and-tail landforms and the rock exposures partly or completely concealed by drift and subsequent soil movement.

The drumlinization of the Central Plain varies in its development from place to place. The topography and drainage system in the area north of Spence Bay result from strong drumlinization. In the Angmaluktok Lake area, where the terrain is more broadly rolling, drumlin formation is less evident. Drumlins occur again between Krusenstern and Tukingayuk lakes, but this drumlin field is separated from that to the southwest by an area of non-lineated moraine, possibly ablation moraine. Somewhat similar features occur along the north shore of Middle Lake and near Spence Bay west of, and intermingled with, the Middle Lake ridges. Here the features are associated with an intermittent embankment esker which leads along the north shore of the lake, winds through the western end of the Middle Lake ridges and finally terminates as a sandspit in Spence Bay. There is a short, low esker-like feature northwest of Redfish Lake, apparently well modified by postglacial sea action. Arcuate parallel ridges associated with the Middle Lake esker may mark either short successive pauses of the ice front or crevasse fillings at the time of the formation of the esker.

Strands occur on the drumlin slopes and on the Middle Lake esker, as well as along the shores of the larger lakes where the terrain is favourable for their formation. Marine shells occur widely throughout the Central Plain, especially in non-sorted soil circles which characterize the summits of the drumlins. Large collections of shells were observed in several scattered localities in the Middle Lake ridges.

Between the Middle Lake ridges and the Eastern Upland at Pangnikto Lake is a part of the Central Plain which lies at a somewhat higher elevation. The drumlin forms in this area have the same orientation as the rest of the drumlins on the isthmus. This area grades into the rock knobs of the Middle Lake ridges to the north and is rather abruptly terminated to the southeast by the rocky ridges along the shores of Pangnikto Lake. Drainage is less effectively controlled than on the lowland northwest of Spence Bay, but the long drumlin forms are similar in local elevation and form.

F. LIMESTONE SCARPLANDS

North of the central plain lie flat-topped hills composed of limestones and dolomites presumably of late Palaeozoic age (Figure 8). They are the remnants of sediments deposited in the depression between the Western and Eastern Uplands and have been strongly eroded by rivers in preglacial time so that only isolated or semi-isolated outliers remained before the onset of the last glaciation. The ice sheet moving across them from the southwest undoubtedly removed additional bedrock and redistributed it in drift towards the north and northeast. The sediments appear to have a gentle dip to the northeast, the angle being partly obscured by drift left in the lee of the hills.

Steep cliffs of limestone occur along the northeast side of Kangikjuke Lake, where the level top of the mesa is about 500 feet above the lake. A steep slope of coarse talus blocks mantles much of this cliff, leaving only the upper 10 to 20 feet as a true rock face. A thin cover of till and material formed *in situ* covers the summit. Lower portions of the formation are almost completely concealed by till near the outlet of Kangikjuke Lake.

North of Lake Hansteen, a rounded hill of limestone rises gently from the lake and is terminated on the west by a rift containing a long narrow lake, the west shore of which is formed by a fault scarp of gneiss. Low outcrops of limestone, thinly laminated and almost horizontally bedded, occur around the hill, and are parallel to or in many cases coincident with emerged beaches. An area of exposed limestone occurs on the summit.

Smaller outliers with low cliffs occur north of Kangikjuke Lake where buttes with south-facing exposures occur. These hills have comparatively level summits and are separated by broad valleys occupied by small streams. The outliers are covered by drift except for small level exposures of limestone shattered *in situ* on the summits and a series of discontinuously exposed beds along the sides of the hills. Other exposures of limestone occur in low hills west of Tukingayuk Lake.

There are three isolated outliers on the Central Plain. One is just north of Redfish Lake where no actual rock exposures were observed. A small sedimentary remnant lies 5 miles west of the south end of Lake Jekyll and some low hills near Angmalukto Lake are interpreted from air photographs as mantled limestone outliers.

The more outstanding outliers are associated with Archaean ridges that appear to have partially protected the remnants from final erosion,

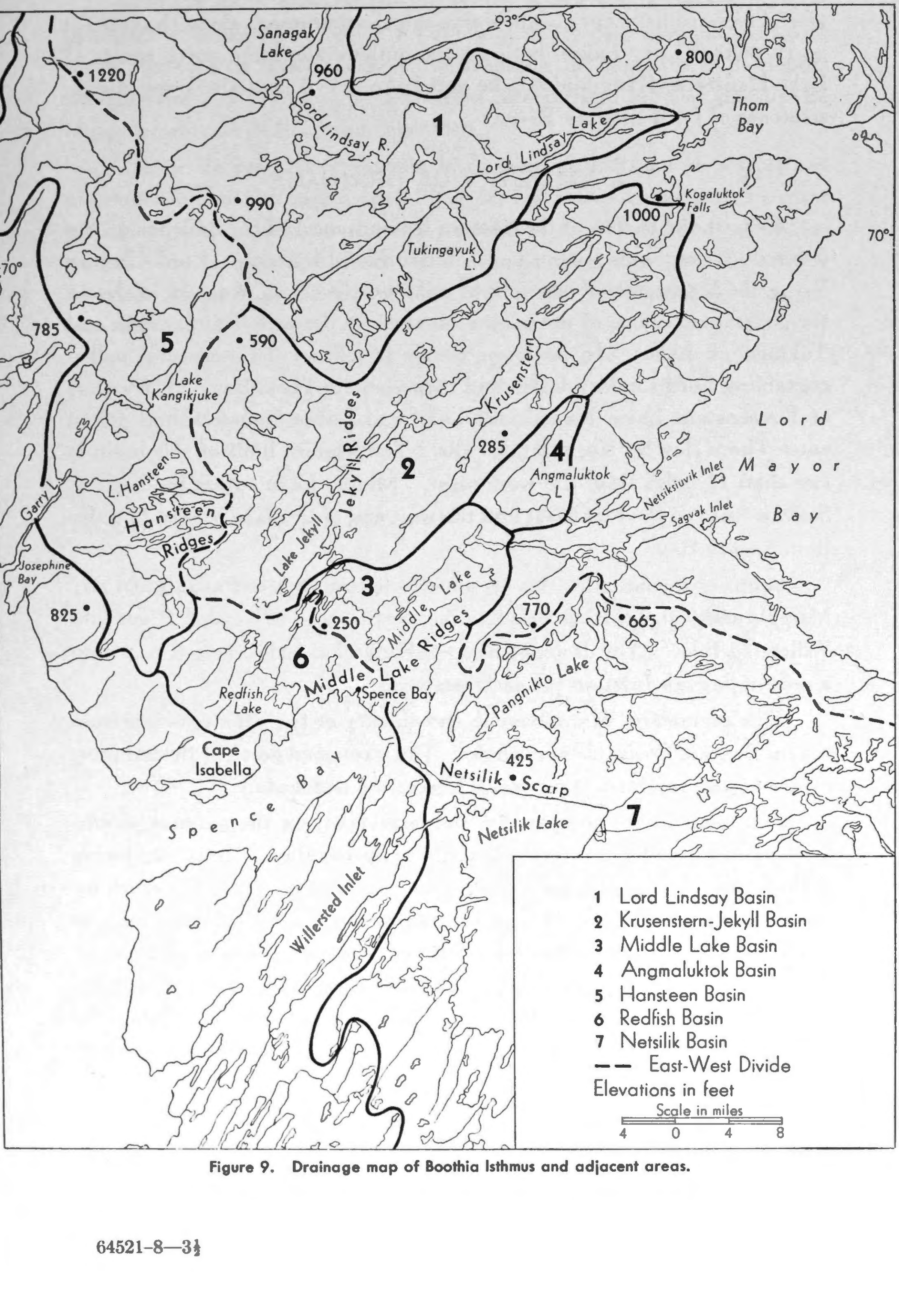

Figure 9. Drainage map of Boothia Isthmus and adjacent areas.

whereas the uplands have been stripped of any Palaeozoic mantle. Preglacial streams have cut channels through the limestones along the contact north of the Garry Lakes, between the outliers along the north coasts of Lake Hansteen, Kangikjuke Lake and Lake Jekyll, and along the middle stretches of Lord Lindsay River.

ASYMMETRY OF DRAINAGE

Despite the barrier of the Eastern Upland, most of the drainage on the isthmus is eastwards to the Gulf of Boothia (Figure 9). Lord Lindsay River, the headwaters of which lie 65 miles northwest of its mouth in almost the geographic centre of the peninsula, receives the waters of Sanagak and Tukingayak Lakes. In its lower course it follows the structural valley containing Lord Lindsay Lake, and thence enters Thom Bay. The waters of Krusenstern Lake, Kangikjuke Lake and Lakes Hansteen and Jekyll enter Thom Bay by Kogaluktok Falls. The western limit of this basin is less than 12 miles from the west coast. Middle Lake enters the head of Sagvak Inlet on the east coast and the west end of this lake is only 2½ miles from Spence Bay.

South of the isthmus, this asymmetry is reversed, as Pangnikto, Lady Melville and Netsilik lakes drain to the west by way of Netsilik River into Willersted Inlet. The drainage basin of Pangnikto Lake extends to within a mile of Sagvak Inlet on the east coast.

This asymmetry of drainage in the vicinity of the isthmus differs from that of Boothia Peninsula as a whole. The watershed north of the isthmus, by actual measurement, practically bisects the peninsula.

According to the topography, the large lakes on the isthmus should discharge their waters across the lowland to Spence Bay. However, during deglaciation, proglacial lakes appear to have been confined on the south by the ice sheet, so that outlets were created to the east by reoccupying preglacial valleys. These outlets were retained following the disappearance of the ice and the subsequent uplift. The hard crystalline rocks forming the Eastern Upland could not have been incised by postglacial streams in preference to the lower and more easily eroded terrain north of Spence Bay.

RÉSUMÉ

En 1953, une équipe de la Direction de la géographie a fait une étude détaillée de la physiographie de l'isthme de Boothia, qui relie la presqu'île du même nom à la terre ferme.

Au cours de la dernière glaciation, les glaces ont recouvert toute la péninsule et laissé sur la région à l'étude quantité de matériaux glaciaires qu'on trouve sous forme d'eskers, de drumlins, de moraines et de dépôts pro-glaciaires. Ces formes de déposition caractérisent le relief glaciaire de la partie centrale de l'Arctique canadien.

L'étude de ces formes suggère la division de l'isthme en six régions physiographiques: les roches cristallines des élévations qui longent les côtes est et ouest, les plaines de drumlins au nord et au sud de Spence Bay, les hauteurs de la partie septentrionale de l'isthme composées surtout de moraines de fond, et finalement les avant-buttes de calcaire de la partie centrale.


Location of Map Area
KEEWATIN
Hudson Bay
SASKATCHEWAN
Churchill River
MANITOBA
ONTARIO
Closed Black Spruce Forest
Closed Mixed Spruce Birch Forest
Open Pine Forest (Seral)
Open Pine Forest with Spruce (Seral)
Young Birch-Willow Scrub
Closed Pine Forest on Sand
Open Pine Forest on Outcrop
Mature Birchwood on Peat Ridges
Muskeg
Open Bog
Aquatic Vegetation
Scale in Miles
0 1/4 1/2 3/4 1
MACBRIDE LAKE
MACBRIDE RIVER
99°55′
99°50′
56°50′
56°50′
99°55′
99°50′

A VEGETATION MAP FROM THE SOUTHERN SPRUCE FOREST ZONE OF MANITOBA

J. C. RITCHIE*

INTRODUCTION

In a recent article, Küchler (1956) has stressed that the compilation of any vegetation map should be preceded by a careful consideration of its designated purposes. The aims of the present map are as follows: to present the results of a survey of a small area in northern Manitoba which is believed to be representative of a large part of the boreal vegetation of this region; to point out any association of particular communities with features of physiography; and to indicate with some precision, the characteristics of the particular vegetation zone. In addition to presenting the map, this article attempts to demonstrate how the various plant cover types might be identified on aerial photographs, and to explore the limitations and prerequisites of vegetation mapping from the interpretation of aerial photographs.

Several vegetation maps for boreal regions of North America have been produced which have objectives similar to this one. Examples are the maps of Drummond (1950), Gadbois and McKay (1954), and Hare and Taylor (1956). In these cases, and in the present study, the data for the maps have been drawn both from field surveys and from the interpretation of aerial photographs. As Küchler (1953) points out, there is an acute need for extended vegetation mapping on this continent, particularly the northern zones—the boreal, the subarctic and the arctic. Many regions are accessible only with difficulty, and the uniformity of vegetation over large areas makes extended field work more difficult to justify. Hare (1950) has already stressed the desirability of securing more accurate information about the zonation of northern vegetation and considerable progress is being made in this direction in the areas east of the Ontario-Manitoba boundary. However, little has been established so far about the vast boreal regions which lie to the west of Hudson Bay. Of necessity, many areas cannot be visited by field parties and some degree of certainty must be established regarding the applicability of particular systems of aerial photograph interpretation. The McGill University group have developed

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various "keys" for the interpretation of photographs and they have found that these have some general, reliable application in regions of Labrador-Ungava (Drummond, 1950 and Blake, 1953). In the northwest, Raup and Denny (1950), and Stone (1948) have established working keys for the interpretation of aerial photographs in terms of both vegetation, and terrain types.

For northern Manitoba, the writer is attempting to compile two types of map: the first is a detailed map, of the physiognomic-floristic type, covering a small area at a scale not less than 1:100,000; the second, which is exclusively physiognomic, is designed to show the main vegetation types by which the major zones of Manitoba might be delimited with reasonable accuracy. For the first, detailed field work is essential by a competent botanist in much of the area to be mapped. For the second, it is necessary merely to recognize a few main physiognomic types; for example, the McGill group have used the "cover types," (1) bare rocks, (2) lichen woodlands, (3) closed-crown forests, and (4) bog and muskeg (Hare and Taylor, 1956).

METHODS AND RESULTS

During the summer of 1955 the author accompanied a field party of the Manitoba Geological Survey in the MacBride Lake–Barrington River region of northwest Manitoba. From preliminary scrutiny of aerial photographs, a selection was made of representative sites for particular study. Reports on the floristics and vegetation have been published (Ritchie, 1956 a, 1956 b), and these provide the basis for the present map. In the field and subsequently in the laboratory, it was possible to identify on the photographs, the main community types in the area. This control was used to determine the plant cover of areas which had not been visited; about 50 per cent of the present map area was not actually surveyed in the field. Viewed under a pocket stereoscope, the various types of vegetation were outlined in pencil on the photographs. The outlines were then transferred by pantograph to a base map (provided by L. C. Kilburn, then in the service of the Mines Branch of the Manitoba Government) and necessary corrections due to photographic distortion, were made by visual estimation. For details of community structure and composition the reader is referred to an earlier publication (Ritchie, 1956 b). There it was shown that the area of these studies lies within the Southern Spruce Forest Zone, which is characterized by the prevalence on mesic sites of a closed black spruce forest, with a dense carpet of mosses forming the ground vegetation.

The following physiognomic-floristic types have been recognized:

Closed black spruce forest—A mature forest found on moderately well drained (mesic) sites, consisting of a closed stand of trees of black spruce (*Picea mariana*), with a continuous ground cover of mosses, chiefly *Pleurozium schreberi, Hylocomium splendens, Ptilium crista-castrensis* and species of *Dicranum*.

Mixed black spruce—white birch forest—A closed forest of well grown trees of black spruce and white birch (*Betula papyrifera* var. *neoalaskana*) with scattered individuals of jackpine (*Pinus banksiana*). There are usually shrub strata of willows and alder, a field layer of low shrubs and herbs, and a discontinuous ground cover of mosses and lichens. This type is seral and is confined to mesic sites.

Open pine forest—A seral type, it is found on mesic sites and consists of an open stand, dominated by jackpine associated with white birch, willows and alder. The ground vegetation is a heath with lichens and scattered herbs.

Open pine forest with spruce—A distinct variant of the above type consisting of the same species as the open pine forest, but with scattered individuals and clumps of black spruce which form a particular pattern on the photographs.

Young birch-willow scrub—The earliest seral type after fire, with woody vegetation. It occurs on mesic sites and comprises a dense growth of young white birch trees associated with various species of willow and with alder.

Closed pine forest on sand—Found on eskers and sandplains and appears to be an edaphic climax. It consists of a stand of jackpine, with sparse ground vegetation of prostrate shrubs, lichens and bryophytes.

Open pine forest on outcrop—An open stand of jackpine, found on areas of outcropping bedrock. The rock surfaces are usually covered with a mat of lichens.

Mature birchwood—A special and localized type, made up of a closed stand dominated solely by white birch. It occurs on certain peculiar ridges of peat, usually associated with shallow lakes, and must be regarded as a unit which is not typical of this forest zone in general. It is described and discussed in greater detail elsewhere (Ritchie, 1956 b).

Muskeg—This term is applied in the sense of Hustich (1949). It is an open stand dominated solely by small spruce, growing on peat substrata dominated by species of *Sphagnum*, associated with various ericoid shrubs and a few willow species.

Open bog—A treeless community, dominated here by sedges rooted in a mat of mosses—chiefly species of *Sphagnum, Drepanocladus, Tomenthypnum* and *Meesia.*

Aquatic vegetation—This community of floating-leaved and emergent aquatic plants is usually found as peripheral stands in shallow lakes and ponds; its chief components being species of water-lily (*Nuphar*), pondweed (*Potamogeton*) and wapato (*Sagittaria*).

Mixed white spruce-poplar forest—Not shown on the accompanying vegetation map but occurs elsewhere in the general region, and should be taken into account in any interpretation of photographs of this zone. This community, which is described in an earlier account (Ritchie, 1956 b), consists of a mixed stand of aspen poplar, balsam poplar and white spruce, occurring on local deposits of alluvial soil. This type of forest is rare in the area.

The final identification of these units on the photographs, requires the use of photographic data—i.e. the tone, texture and stereoscopic appearance—and also information concerning the landforms or physiographic units with which a particular vegetation unit is associated. Undoubtedly, any decision about a particular segment of vegetation as seen under the stereoscope, is strengthened by existing knowledge of the range of substrata within which the community in question occurs, provided it is possible to identify these substratum types. It should be stressed that this is no rule of thumb, but merely ancillary guiding data which might aid identification. For example, in the vegetation zone under consideration, ridges of outcropping bedrock invariably bear an open stand of jackpine; this knowledge is of value in establishing a degree of certainty in interpretation, provided the photographic characteristics are discernible. If the basic ecological relationships of the vegetation of the area have been ascertained, physiography can lend support to any decision based on purely photographic appearance.

A summary is provided in Table 1, of the photographic and physiographic features, detected by scrutiny of aerial photographs, which are associated with those physiognomic-floristic units into which the vegetation of the map area has been classified. Of the vegetation types found on till slopes and ridges, four are seral; that is, four types (with several intermediates) can be recognized which are at different stages in the recovery from the effects of forest fires. From the writer's experience in northern Manitoba, it is clear, at least in this region west of Hudson Bay, that any adequate mapping from photographs must take into account that much of

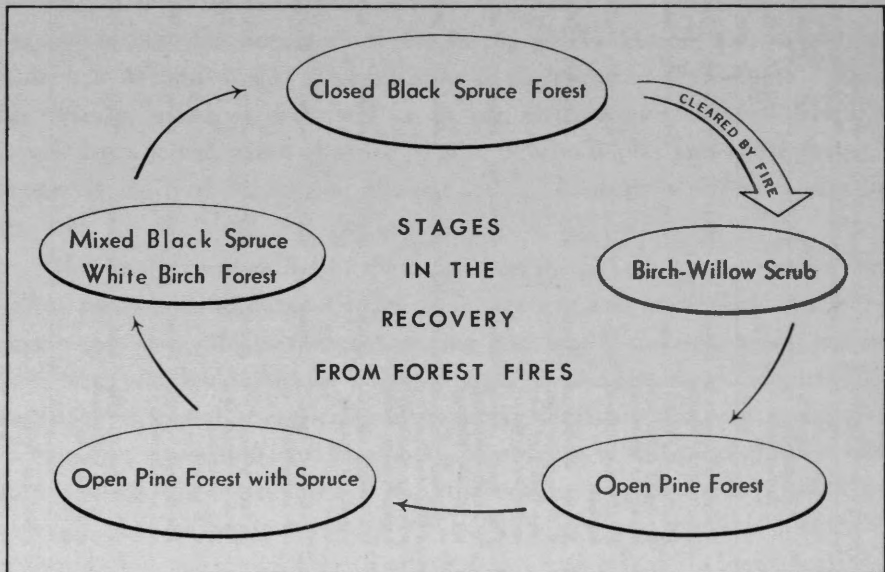
TABLE 1

A Summary of the Photographic Characteristics and Associated Physiographic Features of the Vegetation Types

Vegetation Type	Tone	Texture	Stereoscopic Appearance	Xeric		Mesic		Hydric	
				Rock	Sand	Upland Till	Bottomland Alluvium	Lake	Peat Deposits
Closed black spruce forest	Darkest tones, dark grey to black	Even stippling	Individual trees visible; tall and slender	absent	rarely	commonly	absent	absent	absent
Closed mixed spruce-birch forest	Even dark grey with light spots (birches)	Diffuse matrix, coarse stippling	Medium-size trees; scattered individual crowns of white birch	absent	rarely	commonly	absent	absent	absent
Open pine forest (seral)	Even light grey	Very fine, almost diffuse stippling	Small trees, diffuse outlines	absent	rarely	commonly	absent	absent	absent
Open pine forest with spruce	Even light grey with patches of dark grey	Fine stippling with small areas of coarse stippling	As for above but with groups and individuals of black spruce apparent	absent	rarely	commonly	absent	absent	absent
Closed pine forest on sand	Medium grey	Faintly stippled	Flat crown surface in which individuals are not conspicuous	absent	exclusively	absent	absent	absent	absent
Open pine forest on outcrop	Light grey on white	Finely stippled darker patches on smooth, lighter background	Individual trees with diffuse outlines; structure and relief of bedrock often visible	exclusively	absent	absent	absent	absent	absent
Mature birchwood*	Medium grey with light spots	Smooth surface with fluffy appearance	Undulating crown surface of merging trees	absent	rarely	absent	absent	absent	commonly
Muskeg	Light grey	Diffuse background with coarse stippling	Small trees; light, flat background	absent	absent	absent	absent	absent	exclusively
Open bog	Lighter grey	Smooth surface	Surface without features, except in rare, cases of strängmoor	absent	absent	absent	absent	absent	exclusively
Aquatic vegetation	White grey on black of open water	Smooth surface	Featureless; margins and islands often reniform	absent	absent	absent	absent	exclusively	absent
Mixed white spruce-poplar forest**	Dark grey	Coarse stippling	Tallest trees; spires of spruce and crowns of poplar clearly visible	absent	absent	rarely	commonly	absent	absent

*Apparently not of widespread occurrence in the boreal forest as a whole (see text)

** While not present in the map area this important type occurs in the general region (see text) the vegetation is subseral and that the proportion of mature or climax stands is very small. For example, in the Forest-Tundra zone of Manitoba, there are vast areas of "false", anthropogenic tundra, and any vegetation map which fails to recognize their status and origin, is of little use to the plant geographer. Thus, to secure a proper understanding of a vegetation map in this area, the outlines of subseral stages, at least on mesic sites, must be established. For the present area, the findings reported earlier (Ritchie, 1956 b) might be summarized here as follows:



In the light of this information, the differences which can be detected between the areas southwest, directly south, southeast, and north of MacBride Lake can be interpreted in terms of fire history. The area to the southwest has been subject to the least disturbance by fire; but the region north of the lake shows evidence of considerable fire disturbance in the recent past. These suggestions are borne out by the field studies. The regeneration cycle outlined above seems to be reliable, with minor variations, in the boreal zone of northwest North America as a whole (Lutz, 1956).

In conclusion, it is suggested that there are three important requirements for vegetation mapping in this part of Canada. These are, (1) thorough ground control secured by intensive field studies of the plant communities in question, (2) a knowledge of the degree of association between vegetation type and physiography, and (3) an understanding of the seral relationships of the vegetation.

Acknowledgment is made to the National Research Council of Canada for support of these investigations.

RÉSUMÉ

L'auteur présente ici les résultats d'une étude de la végétation faite dans une petite région du nord du Manitoba en 1955; le but est de démontrer les possibilités d'identifier, à l'aide de photographies aériennes, les différents groupes de plantes qui composent le couvert végétal. A la suite du travail sur le terrain et de l'examen minutieux des photographies aériennes, il a préparé une carte de la végétation de cette région; une copie accompagne l'article. Cette carte représente les onze types physionomiques de la flore identifiés ainsi que leur répartition.

L'auteur fait de plus un court exposé des méthodes d'identification employées et présente, sous forme de tableau, un abrégé des caractéristiques photographiques et physiographiques accompagnant les types de végétation illustrés sur la carte.

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GLACIAL GEOMORPHOLOGY OF THE TORNGAT MOUNTAINS, NORTHERN LABRADOR

by J. D. IVES*

The Torngat Mountains of Northern Labrador are Eastern Canada's nearest mainland counterpart of the Norwegian fiord landscape. Situated between latitudes 58° and 60° N., they rise precipitously from the sea and culminate in heights exceeding 5,000 feet between Kangalaksiorvik and Saglek fiords. The comparison with coastal Norway is by no means superficial, and problems of a similar nature face both geomorphologists and botanists in the two areas. The Norwegian mountains have received much careful attention, and their role in the glaciations of Northwest Europe has long been recognized. The role of the Torngat Mountains, however, and even that of Labrador-Ungava as a whole, is little known and the weight of hypothesis greatly over-balances that of the field evidence.

During the summer of 1955 the writer worked within a 50-mile radius of Schefferville (Knob Lake), approximately the geographic centre of the peninsula. Particular attention was given to the problems associated with the deglaciation of the area and it became evident that these problems must be regarded on regional and not on local proportions and that the work should eventually be extended to a consideration of Labrador-Ungava as a whole. Work in the Schefferville area convinced the writer that the detailed study of a number of carefully selected areas would greatly facilitate the approach to these problems. It was envisaged that by working first in the extreme northeast of Labrador-Ungava, and later, in chosen localities between the northeast coast and the geographic centre, it might be possible to outline the successive stages of wasting of the last ice sheet, from the first indication of thinning on the northeast coast, to what may prove to be the final stages of stagnation in the geographic centre.

Thus the Torngat Mountains became the scene of two summers' field work; a report on the 1956 work has already been published (Ives, 1957 & 1958-in press), whereas the 1957 work forms the basis of the present paper. Study of a large number of air photographs led to the choice of the Koroksoak (Korok River)-Nakvak watershed area between the Ungava Bay and Atlantic drainage in the southern Torngat Mountains as a locality likely to repay detailed field investigation. The watershed lies about 30

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Figure 1. General map of the survey area.

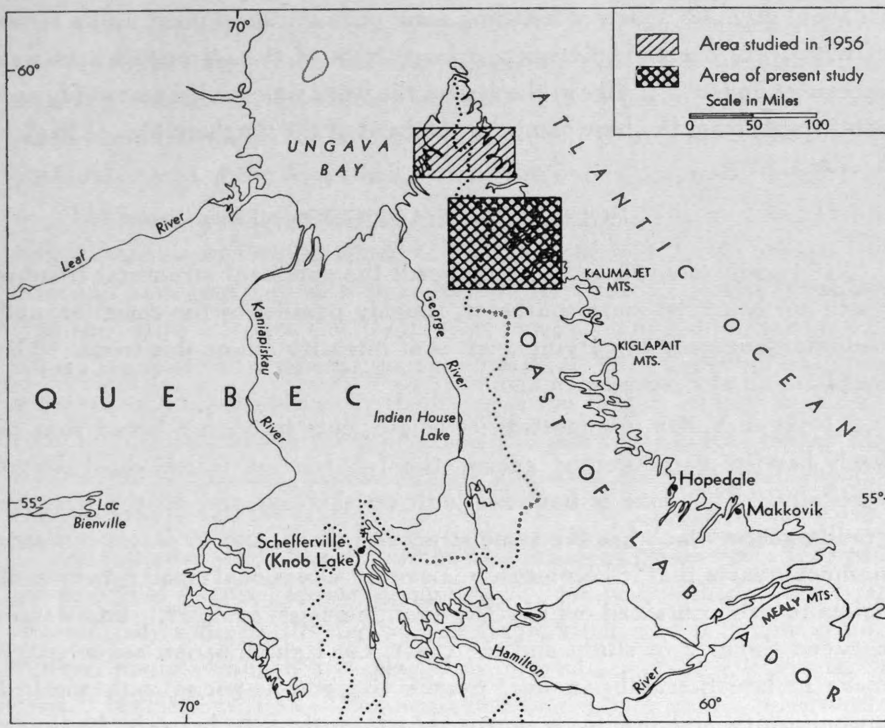

Figure 2. Location map.

miles west-northwest of the head of Saglek Fiord in latitude 58° 30 N. Here the main summit area, exceeding 3,500 feet, is pierced by a major trough, the col of which stands at 1,050 feet above sea level. From the col the floor of the trough falls away very gently eastwards and carries the small Nakvak Brook to Saglek Fiord. Eighteen miles east of the col the brook enters a lake, which for convenience will be referred to as "Nakvak Lake", about 3 miles long, which was the most suitable landing place for a float plane and was therefore selected as the site for the base camp. Westwards from the col, the land drops relatively steeply into the valley of the Koroksoak River, the lower stream of which flows westwards in a deep trough, entering Ungava Bay immediately north of the George River estuary. The upper section of the main stream swings northwards from the col, then east again, and drains a valley parallel to Nakvak Brook for more than 25 miles, with its headwaters within a few miles of Ramah Bay on the Atlantic coast.

A major tributary enters the Koroksoak from the southeast, immediately below the col. It drains a broad U-shaped valley of considerable length, the upper part of which contains a lake which was used as a landing site for establishing a food and fuel cache. This cache and the base camp lie about 30 miles apart, so by using main camps at each point and a series of temporary camps in between, a large tract of the watershed area was accessible on foot. Later in the season the work was carried eastwards and southwards from the base camp, to the head of the northern arm of Saglek Fiord.

GEOLOGICAL BACKGROUND

Between Nachvak and Hebron fiords the dominant structural trend is north-northwest to south-southeast, roughly parallel to the coastline, and metamorphic zones of varying degrees of intensity follow this trend. The rocks are all of Precambrian age.

Nakvak Valley, for most of its length, cuts through a broad zone of finely-banded garnetiferous gneiss, the foliation of which dips almost vertically. This zone is bounded both on the east and on the west by granite-gneiss which has the same structural trend, and in places contains so much quartz that it becomes a quartzite. Occasional small synclines of dolomite are contained within the granite-gneiss complex. Eastwards, between the area of study and the coast, the Ramah series, sedimentary rocks of late Precambrian age, overlie the granite-gneiss with marked unconformity and occupy a narrow north-south zone between Nachvak and Saglek fiords. The entire area is cut by two series of basic dykes which are particularly conspicuous in the coastal area. Major faults follow the structural trend, although a second set, at right angles to the first, is readily apparent in the topography.

TOPOGRAPHY

The southern Torngat Mountains, in the vicinity of Saglek Fiord, are much less dissected than the mountains further north, and alpine forms are almost entirely lacking. Throughout the mountains, however, the degree of dissection decreases westwards from the coast (Odell, 1933). The entire area may be described as the uplifted and dissected rim of the Labrador-Ungava plateau.

The highest land of the southern section probably rises to 5,000 feet above sea level near the head of Saglek Fiord, and from this area westwards, large sections of the plateau surface have been preserved, giving an overall regional slope down towards the west. On the Koroksoak-Nakvak watershed, 30 miles west of the head of the fiord, the summit surface barely exceeds 3,500 feet, and from there the surface continues to fall gradually towards Ungava Bay without any perceptible break.

About the head of the fiord, cirque development has reached a stage of late youth, and very rarely do individual cirques coalesce, but merely form separate scallops in the plateau surface. Further west, cirques become smaller and less numerous, and their floors lie at greater altitudes until, on the Quebec side of the watershed, cirques are only very poorly developed.

The most distinctive feature of the topography, however, is a parallel series of U-shaped troughs which cut through the highland in an east-west direction and, together with their equally impressive transection valleys, split the entire area into a series of great blocks. The Koroksoak-Nakvak trough is one of the most conspicuous with its col less than 1,100 feet above sea level Other troughs enter the heads of the various arms of Saglek and Hebron fiords, although generally their cols are considerably higher than that of the Koroksoak-Nakvak trough, and some fade out gradually into the general level of the plateau.

In this area, where the summit surface is so well preserved, a very good impression of the pre-Pleistocene topography can be obtained. The surface is essentially rolling with slight to moderate relief, and is cut by shallow valleys, many of which are completely dry and bear no relation to the present drainage pattern. Remnants of a broad, open valley, preserved as benches high above the floor of the Koroksoak-Nakvak trough, slope gently downwards to the west from a point near the present head of Saglek Fiord. A detailed analysis of these features is not possible without accurate maps, but it may be tentatively suggested that regional uplift in late Tertiary times occurred in two stages (Thompson, 1954). The first stage resulted in relatively little vertical movement and created a regional slope towards the west from the present coastal area, into which long consequent streams eroded shallow valleys. At this stage it would appear that the Ungava Bay depression was already in existence. Further uplift on a much larger scale resulted in excessive rejuvenation and the formation of deep gorges and valleys by the Atlantic slope streams. This movement was probably accompanied by widespread block faulting (Tanner, 1944, p. 161), giving zones of weakness which the rejuvenated streams utilized, so that the high-level valleys of the first cycle are frequently discordant with the second cycle valleys. The second cycle reached a stage of late youth to early maturity in the eastern section and the watershed had migrated a considerable distance from the Atlantic coast, prior to the onset of the Pleistocene glaciations.

The present topography, particularly along the troughs and in the east, owes its character to the modification of the pre-Pleistocene forms

Figure 3. In the eastern sector the summit surface of the Torngat is deeply dissected. This view shows sections of the surface which have been preserved and possibly tilted slightly in relation to each other. (2 August, 1957).

during at least two, and possibly three, glacial and interglacial cycles. However, in the west, tributary valleys are frequently V-shaped, and except in the major valleys, large scale topographic evidence of glaciation is lacking. It is unlikely that the summit surface has been more than slightly modified during the successive glacial and interglacial cycles. Little can be said about the early glaciations until more evidence is available; the following discussion is restricted to the more recent phases of glaciation.

PLEISTOCENE GEOMORPHOLOGY AND GEOLOGY OF NAKVAK VALLEY

Nakvak Valley forms the eastern section of the Koroksoak-Nakvak trough, and as it is representative of the eastern sections of the troughs of the southern Torngat Mountains, it will be described in some detail.

From the col at 1,050 feet, the valley floor slopes very gently eastwards, falling scarcely 200 feet in the 18 miles between the col and Nakvak Lake. No soundings were made, but the lake is probably deep and shoals rapidly at its eastern end where the present stream has cut a shallow notch through a rock bar. Downstream from the lake, the valley floor slopes more steeply, falling 400 feet in 3 miles before a final section of gentle gradient is reached. The present stream descends this step through a series of rock gorges and waterfalls, hugging the south side of the broad valley floor. A broad, shallow depression, now dry, on the north side of the valley probably represents an earlier course of the stream before the most recent glacial interference. Lake shorelines, a few feet above the present level of Nakvak Lake, indicate that this old course was used as recently as late-glacial time.

The valley floor varies in width between 2 and 4 miles. Its course is gently curving and the basal remnants of several truncated spurs, project as low, glacially-scoured rock ridges, far into the valley floor (Cotton, 1941). Upstream of Nakvak Lake, almost as far as the col, the valley floor is remarkably flat, and carries a deep fill of fluvio-glacial outwash, in places pitted with kettle holes and dissected into terraces. It is unlikely that the terraces were cut by the present stream, which flows sluggishly through a series of small lakes, but rather by a more vigorous stream of late-glacial times, which was supplied by the discharge across the col at 1,050 feet of water from an ice-dammed lake held in the upper part of the Koroksoak Valley (*see* below). The watershed area on the col is a broad, flat zone of marsh, about 3 miles square.

On the concave sides of the major curves in the course of the trough, the slopes rise quite gently from the floor to summits 2,000 to 3,000 feet higher, whereas the convex sides are drastically over-steepened, and rise as precipitous crags for more than 1,000 to 2,000 feet, before levelling off again. Fluvio-glacial and glacial material has been deposited thickly on the gentler slopes, and appears to have been only slightly affected by subsequent mass movement, so that significant erosional and constructural features have been preserved. Figure 4 shows a schematic vertical section from valley floor to summits in the vicinity of Nakvak Lake. The upper slopes, except on steep inclines, are mantled with a deep cover of angular, frost-shattered blocks of bedrock (mountain-top detritus or *felsenmeer*), which is so well developed that the underlying bedrock structures are completely masked. Patterned ground (Washburn, 1956) is widespread, and a periglacial cycle of erosion (Peltier, 1950) has reached a stage of late youth on the gentler slopes. Occasional glacial erratics are found in the mountain-top detritus and, corroborating the 1956 field work (Ives, 1957), erratics were found on several of the higher summits. To find unequivocal erratics requires prolonged searching, and it is not difficult to understand why it has been frequently concluded that the upper surfaces were never glaciated (Daly, 1902; Bell, 1884; Coleman, 1921; Douglas, 1953). Between 2,700 and 2,300 feet, the mountain-top detritus is replaced by glacially-scoured bedrock. Perched blocks are abundant in this zone, and occasional kames, terraces, and sections of lateral moraines are to be found in favoured places; striations have not been preserved. The bedrock, especially in the zone of garnetiferous gneiss, is in the early stages of disintegration, although over wide areas it is comparatively sound. The dividing zone between mountain-top detritus above, and glaciated bedrock below, is interpreted as the trimline of a former outlet glacier.

At an altitude of 2,300 feet, north of Nakvak Lake, the bedrock abruptly gives way to a broad kame terrace which slopes down towards the east, and below this, the lower slopes are completely masked with glacial and fluvio-glacial deposits. For 300 to 400 feet below the main kame terrace, short segments of kame terraces and individual kames are present. The superficial material on the lower slopes is dissected by a flight of terraces which slopes eastwards and is continuous down to, and across the valley floor. The terraces merge into channels further downslope, where the gradient is less steep, and where the fill is probably deeper. The terraces and channels are interpreted as a sequence of marginal drainage features, formed by melt-water flowing between the valley side and a melting lobe of ice (Mannerfelt, 1945; Schytt, 1956).

The eastward slope of the channels and terraces indicates that, at the time of their formation, the surface of the ice also fell towards the east, although not necessarily at the same gradient (Mannerfelt, 1949, pp. 197-8). Generally, the individual channel and terrace sections only range from 200 to 1,000 yards in length, but occasionally channels can be traced for upwards of 1½ miles. They are broken by steeply sloping gullies (sub-glacial chutes), which follow the greatest slope (Mannerfelt, 1949, p. 197).

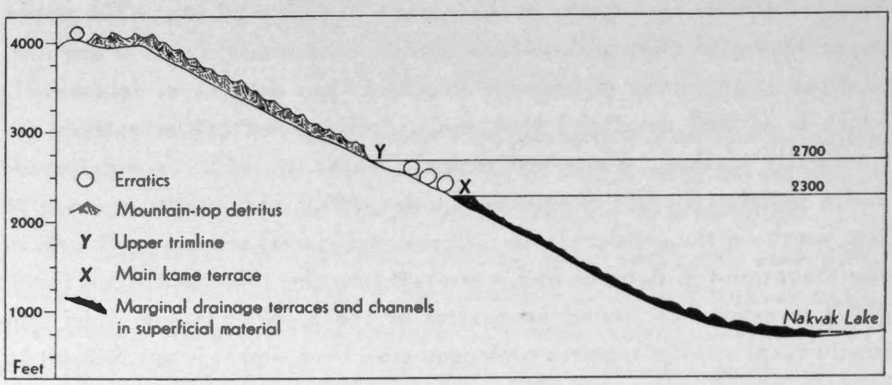

Figure 4. Vertical section in vicinity of Nakvak Lake.

The most conspicuous feature in the whole vertical section (X in Figure 4), is the broad kame terrace. The kame terrace complex can be traced along the north side of Nakvak Valley for the greater part of its length. One 15-mile section, extending eastwards from the lake, was examined in detail. A profile was constructed along this section by pace and altimeter methods. This section is continuous except for minor breaks where ribs of bedrock extend into the main valley or where tributary streams cut gorges through it. Long sections of the terrace are remarkably broad and uniform, and the general slope varies between 60 and 90 feet per mile. Occasional kettle holes pit the outer edge, and in some sections the surface of the terrace slopes into the hillside.

Several tributary valleys enter the main valley from the north, forming deep re-entrants in the general slope. The terrace curves into the re-entrants and on the downstream side of each, its slope is reversed, implying that a lobe of ice, sloping down from the surface of the trunk glacier, had plugged the mouths of the tributary valleys. Invariably, at the mouths of these valleys, the terrace is gradually replaced on the gentler slopes by a morainic ridge which in places exceeds 60 feet in height. In some tributary valleys, small lakes are dammed against the lateral moraine; whereas in others, laminated silts and clays, and a gorge through the moraine, indicate the existence of former lakes. Abandoned shorelines above the present lakes suggest that when the trunk glacier was thicker, presumably up to 400 to 450 feet thicker where it coincided with the upper trimline, the lakes were correspondingly higher.

At its eastern end, the kame terrace-lateral moraine complex fades out on steep, rocky slopes; whereas westwards, it becomes increasingly intermittent and eventually passes above the level of the confining walls as the watershed is approached.

On the south side of the valley, steep slopes and the occurrence of glacial diffluence valleys, have proved less favourable for the preservation of such features. However, sections of kame terrace and lateral moraine were found in several localities and they correspond in height to the similar feature on the opposite side of the valley.

Review of the air photographs and examination on foot and by plane, with one landing to measure altitude, revealed that many of the major troughs carry extensive remnants of lateral moraines and kame terraces at altitudes corresponding to the Nakvak Valley complex described above.

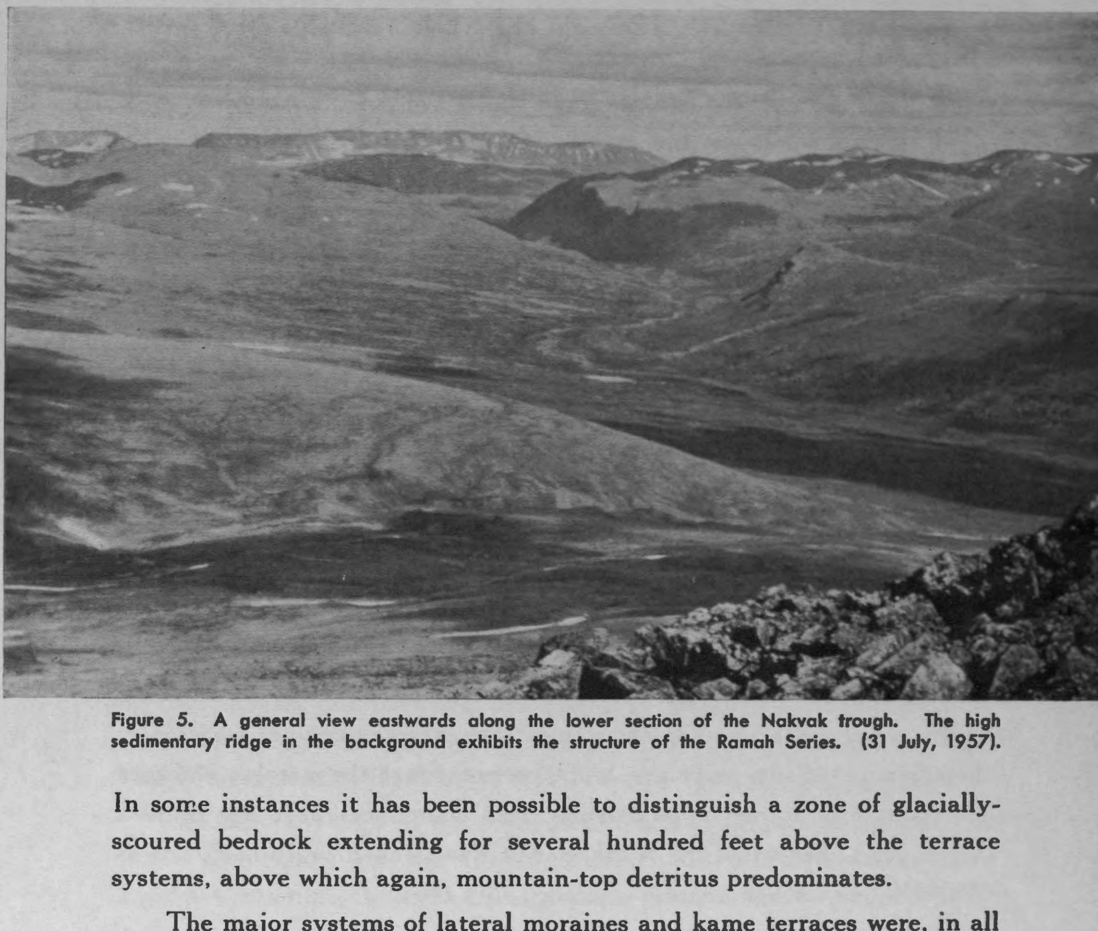

Figure 5. A general view eastwards along the lower section of the Nakvak trough. The high sedimentary ridge in the background exhibits the structure of the Ramah Series. (31 July, 1957).

In some instances it has been possible to distinguish a zone of glacially-scoured bedrock extending for several hundred feet above the terrace systems, above which again, mountain-top detritus predominates.

The major systems of lateral moraines and kame terraces were, in all probability, formed contemporaneously at a stage when the troughs of the southern Torngat Mountains contained thick tongues of ice which were, in fact, eastward-flowing outlet glaciers of the continental ice sheet lying to the west of the watershed.

Based on the above correlation, it appears likely that the zones of glacially-scoured bedrock above the kame terrace complexes were also formed when the same outlet glaciers were thinning from their maximum stand at the upper trimline. During this interval, the speed of flow of the glaciers was sufficient to ensure that erosion predominated over deposition.

Following the main kame terrace-lateral moraine stage it is reasonable to suggest that the speed of flow slackened, that the ice became passive and finally stagnant, allowing the formation of the marginal drainage terraces and channels, and that it eventually melted in situ, leaving the 'dead-ice topography' in the valley bottoms.

The succession of events represents the withdrawal of glacier ice from its local and temporary maximum stand, to its final dissipation as stagnant masses on the valley floors. The presence of erratics on the high summits, and of the maturely developed mountain-top detritus on the upper slopes, combine to indicate that, prior to this maximum, glacier ice over-topped even the highest summits, and that this event considerably ante-dated the outlet glacier stage. The restriction of mountain-top detritus to the upper slopes, recorded earlier (Ives, 1957), led to the partial anticipation of this conclusion, although in the Kangalaksiorvik-Abloviak area, no sharp dividing line, marked by lateral moraines and kame terraces, or even a trimline, could be readily detected. Evidence presented below has therefore led to the modification of the original hypothesis, and the conclusion anticipated here is that the glaciation responsible for the inundation of the highest summits was separated from the outlet glacier stage by an interglacial of considerable intensity.

PLEISTOCENE GEOMORPHOLOGY AND GEOLOGY OF "SHORELINE VALLEY"

In contrast to the eastern section of the Koroksoak-Nakvak trough, the western section contains neither lateral moraines nor kame terraces, and it appears that here, the continental ice sheet which fed the outlet glaciers, actually over-topped most of the higher summits. The Koroksoak section of the trough, therefore, remained as a major channel of ice movement until late glacial times, although its main southbank headstream, here referred to as the "Shoreline Valley", appears to have remained largely ice-free at the maximum of the final glaciation (the outlet glacier stage), and to have contained a large lake which was dammed laterally against the trunk glacier in the Koroksoak-Nakvak trough.

A remarkably well preserved shoreline of the former lake contours the upper slopes of the valley for many miles. This shoreline and related features were examined from the main camp situated at the outlet of the present lake (Figure 1). The altitude of the present lake is 1,736 feet above sea level. The valley is broad and U-shaped and has been glaciated at some time in the past. The pronounced shoreline of the former ice-dammed lake lies 640 feet above the surface of the present lake or 2,376 feet above sea level, implying a minimum depth of 640 feet in this vicinity and a depth of almost 1,000 feet further down-valley.

Opposite the lake outlet, a deep gorge enters from the south almost at grade with the main valley floor; where it enters Shoreline Valley it exceeds

800 feet in depth. The high shoreline enters the gorge, and the former lake presumably penetrated as a long arm for several miles. Six miles south of the present lake, the floor of the gorge rises above the level of the high shoreline, and immediately north of this, a secondary gorge enters the first from the west, carrying today only a very small stream. This gorge drains a series of broad upland valleys containing long sections of abandoned shorelines which contour the hillslopes at an altitude of several hundred feet above the main shoreline. Presumably these remnants represent part of the shores of an extensive system of former lakes which drained, by way of the gorge, into the ice-dammed lake of Shoreline Valley. This system of higher lakes was not examined on foot, although sections of shoreline could be traced through binoculars from a neighbouring summit. They extended many miles to the south and west.

The shoreline of the former lake at 2,376 feet in Shoreline Valley can be traced to within 5 miles of the confluence with the Koroksoak River. Smaller lakes were dammed against the main trunk glacier to higher levels both to the east and west of Shoreline valley, and spilled into the main lake over ice-free cols. Perched deltas indicate the positions of some of these spill-ways. The actual outlet of the main lake was not traced in the field, as it could not be reached on foot in the time available. However, there is every reason to believe that the overflow at the maximum level was across the high col between Shoreline Valley and the valley which drains into the northern arm of Saglek Fiord.

The distribution of mountain-top detritus on the upper surfaces bears the same relation to the high shoreline as to the upper glacial trimline in the eastern section of the Koroksoak-Nakvak trough. Moreover, by expanding the profile of the upper trimline to the watershed area, the high lake stage may be correlated with the glacial stage responsible for the formation of the trimline.

Less well preserved remnants of other shorelines were found 350 to 400 feet below the 2,376-foot shoreline, but further down-slope no other shorelines were found except those within 50 feet of the valley floor and the present lake level. Lower shoreline sections up to 400 feet below the high shoreline indicate thinning of the damming glacier and possibly represent the thinning from the upper trimline to the main kame terrace-lateral moraine stage in Nakvak Valley. When the lake level fell below the col at 2,376 feet, subsequent overflow was lateral across spurs in the lower part of Shoreline Valley and thence across the present watershed area and eastwards along the margin of the containing glacier.

It is assumed that the presence of the immense volume of lake water in Shoreline Valley prevented, thermally and dynamically, the entry of glacier ice from the Koroksoak Valley (Thorarinsson, 1939-1953; Glen, 1954), and that at the maximum stage, the ice dam must have been about 1,200 to 1,500 feet thick. With loss of volume due to the lowering of the dam, the ice tongue, meeting less resistance, penetrated a further 5 to 6 miles up the valley to form a high terminal moraine with a maximum height of 180 feet. The fact that the moraine lies 5 miles upstream of the most northwesterly remnant of the high shoreline, supports the suggestion that the tongue of ice which built the moraine entered the valley after the formation of the shoreline and after the level of the lake had fallen considerably. Lower shorelines are truncated successively upstream of the high shoreline.

Three separate, lateral overflow gorges, marking successively lower levels of the lake, were identified. The lowest gorge was abandoned when the glacier ice had thinned to expose the Koroksoak-Nakvak col. Following this stage, a lake was dammed in the main Koroksoak Valley to the height of the col at 1,050 feet, over which it drained into Nakvak Brook and Saglek Fiord. Remnants of a shoreline and perched deltas at the same level as the col were traced westwards along the Koroksoak Valley. Examination of air photographs of the lower Koroksoak Valley revealed a second shoreline some 400 to 500 feet below this, which may indicate a later ice-dammed lake or mark the upper limit of the post-glacial marine transgression in this area.

SIGNIFICANCE OF THE ICE-DAMMED LAKES

The ice-dammed lake in Shoreline Valley is correlated with the maximum of the final glaciation (the outlet-glacier stage), which is probably the equivalent of the "classical" Wisconsin maximum (Flint, 1957, p. 341) of central North America. The former existence of the system of ice-dammed lakes is critical for distinguishing between the high-level glacial maximum, which left erratics on the highest summits (here referred to as the Torngat glaciation), and the outlet-glacier stage (designated the Koroksoak glaciation).

Evidence in the Kangalaksiorvik-Abloviak area (Ives, 1957), only permits the assumption of a long interval of time between glaciation of the high summits and the outlet-glacier stage, to allow for the formation of the mountain-top detritus on the upper slopes and the final sharpening of the cirques. There it is implied that the surface of the continental ice sheet had gradually lowered from above the highest summits, to the level of the

Figure 6. A complex of easterly-sloping glacial drainage channels and sub-glacial and fluvio-glacial deposits characteristic of the eastern sections of many of the Torngat troughs. (8 Sept. 57).

Figure 7. Gorge occupied during the final stages of lateral overflow from the main glacial lake in "Shoreline Valley". (13 August, 1957).

upper glacial trimline (outlet-glacier stage). However, in the light of the evidence presented above, this hypothesis needs modification; simple lowering of the surface of the ice sheet from the higher to the lower level did not occur, for had it done so, Shoreline Valley would have remained choked with ice and no system of ice-dammed lakes of such proportions could have formed. It is suggested, therefore, that following the emergence of the high summits, thinning continued until the entire Torngat area had become ice-free, at least as far as the main valleys and troughs are concerned. Following this interval, there occurred a resurgence of ice from the west. Thick ice-tongues penetrated the troughs and passed over the low cols into the heads of the Atlantic fiords, as the outlet glaciers of the continental ice sheet to the west. The outlet glaciers blocked the mouths of the tributary valleys where melt-water and rain accumulated to form the series of ice-dammed lakes. The accumulation of water in the lakes was sufficiently rapid to maintain itself against the encroaching ice, for had this not occurred, lobes of glacier ice would have penetrated far up Shoreline Valley, over the col at 2,376 feet, and into the valley leading to the northern arm of Saglek Fiord.

It is therefore proposed that the Torngat and Koroksoak glaciations were separated by an interglacial. Lake shorelines beneath the thresholds of cirques, and a general consideration of the extent of local ice during the interglacial, imply that temperature and precipitation were possibly similar to that of today, with patches of permanent ice and perennial snowbanks occurring in sheltered places. Several patches of ice were found at the heads of small tributary valleys in mid-August, which interrupted the continuity of the high shoreline. The fact that similar valleys, ice-free today, contain sections of the shoreline at 2,376 feet, indicates that little more ice existed when the shoreline was formed, than is found today.

It is possible that this period of deglaciation affected the entire area of Labrador-Ungava, and it is tentatively correlated with an interval between two recent glaciations recognizable in the Knob Lake area of central Labrador-Ungava.

DATE OF THE TORNGAT GLACIATION

The late-Pleistocene scheme of glaciation proposed above for the Torngat Mountains, implies that the final (Koroksoak) glaciation was preceded by an interglacial and that this in turn followed a much more extensive glaciation (Torngat), which over-topped the highest summits. Although no direct evidence is available, some discussion on the possible date of the Torngat glaciation is pertinent. There appear to be two possible dates. If the scheme of four glacial stages, now well established in central North America, is considered in its simplest form, then the Torngat glaciation may be correlated with the Illinoian glaciation, and the succeeding interglacial with the Sangamon interglacial, although this correlation would be difficult to establish because of the great distance which separates this area from the better known areas to the south. However, if a cycle of climatic fluctuations on a world-wide scale occurred during the Pleistocene, synchronous fluctuations may be expected in the Torngat Mountains. Also, it is improbable that the two glaciations represent substages of the final glaciation, the "classical" Wisconsin. There is evidence accumulating from detailed study of the drift sheets of central North America, that a glaciation of considerable extent occurred in post-Sangamon time, but antedated the "classical" Wisconsin (Flint, 1957, pp. 341-2 & 358). In the light of this, the second alternative for the age of the Torngat glaciation is that it represents the equivalent of the post-Sangamon and pre-"classical" Wisconsin glaciation.

The presence of unweathered erratics on the high summits of the Torngat Mountains, taken in conjunction with similar finds in the Shickshock Mountains (Flint, Demorest and Washburn, 1942), suggests the possibility that these rocks have not survived the long Sangamon interglacial and therefore are more recent. Unweathered erratics in a cold climate cannot be taken as evidence of post-Sangamon age (Flint, personal communication); yet the length of time required for the destruction of erratics by frost-shattering, must also be considered, and on this score it seems improbable that the erratics in question are of great age. As the absolute age of the erratics cannot be ascertained, the Torngat glaciations cannot yet be correlated with glaciations outside Labrador-Ungava.

The following scheme is therefore proposed, the age of the individual phases being strictly relative:

1. Torngat glaciation.

   Inundation of the highest summits at the maximum stage, with the ice margin at the seaward edge of the continental shelf.

2. Interglacial.

   Probably little more ice and perennial snow in the Torngat area than today. This interglacial saw the disappearance of continental ice from most, if not the whole, of Labrador-Ungava.

3. Koroksoak glaciation.
   (a) maximum—
   the continental ice sheet covered most of Labrador-Ungava and the local ice-divide lay well to the west of the present watershed, with large outlet glaciers passing through the coastal mountains towards the Atlantic. The glaciers reached the level of the upper trimline, above which large areas remained ice-free, and probably sheltered coastal areas also. Ice-dammed lakes stood at their maximum level and spilled into the Atlantic drainage.
   (b) kame terrace-lateral moraine stage—
   the outlet glaciers had thinned 400-450 feet from their maximum stand at the upper trimline.
   (c) dissipation of the outlet glaciers—
   melting was at first gradual and then very rapid with the formation of flights of marginal drainage terraces and channels in the eastern sections of the troughs. Lakes trapped between the continental ice sheet and the watershed, gradually drained. The outlet glaciers were eventually reduced to stagnant remnants which melted in situ.

FINAL STAGES OF THE LAST GLACIATION IN THE TORNGAT MOUNTAINS

Evidence already presented (Ives, 1957) shows that, following the withdrawal of the continental ice sheet from the Torngat Mountains, local glaciers reached only very limited dimensions. Now that it has been possible to propose two recent glaciations in this area it is reasonable to suppose that cirque development was vigorous throughout the maximum of the final glaciation, a conjecture consistent with the greater cirque development near the Atlantic coast, in which direction the continental ice sheet diminished in thickness. Since the writing of the earlier paper (Ives, 1957), occasional sets of terminal and lateral moraines, from the basins of large coalescing cirques, have been detected north-northwest of the head of Nachvak Fiord. This implies that once the continental ice sheet had withdrawn sufficiently to the west of the present watershed, occasional westerly-flowing, valley glaciers were reconstituted, but only in localities especially favourable for accumulation and supply. With this modification, the earlier statement, that cirque glaciers generally did not over-spill their thresholds in late glacial time, appears correct.

The final stage of glaciation recognizable in the Torngat Mountains is the existence of a large mass of ice over the eastern part, at least, of the present site of Ungava Bay, which dammed up lakes in the western Torngat valleys such as the Koroksoak and the Abloviak. Thus it is reiterated that the Labrador-Ungava plateau has played a much more significant role in the accumulation and dispersal of ice than have the coastal mountains of Labrador.

Precipitation is slight in the Torngat Mountains today, and the snow-line is high when compared with the annual temperatures. Thus, with the presence of a large mass of ice on the plateau between the mountains and the moisture-bearing winds during the glacial periods, this incidence of "precipitation starvation" may well have been accentuated. On the other hand, the relatively heavy snowfall on the plateau, and especially on the Laurentian scarp, would also have been accentuated during glacial periods by the increased topographic barrier afforded by the presence of an ice cap. This factor would operate well into late glacial time, for it seems certain that large masses of ice remained to the west and southwest of the Torngat Mountains after the mountains themselves had been released from the grip of the continental ice sheet.

RELATIVE AGE OF THE MOUNTAIN-TOP DETRITUS

The restriction of mountain-top detritus to the areas which remained ice-free during the Koroksoak glaciation, implies that its formation antedates that glaciation, and that a long period of time is therefore necessary for the deep-splitting of bedrock. Where bedrock is exposed below the limits of the Koroksoak glaciation, frost-shattering has cracked up the surface only to a limited degree, and although occasional blocks have been heaved out of position, the original glaciated pavement is still clearly recognizable. Glacial striations are rarely preserved, although coarser grooves are to be found and the surface forms always contrast strongly with the upper slopes which remained ice-free during the Koroksoak glaciation. It is suggested, therefore, that the mountain-top detritus dates from late in the Torngat glaciation when thinning of the ice had exposed the upper surfaces to frost-action. Detritus which may have formed somewhat later at lower elevations has been swept away during the final glaciation. The optimum time for the development of the mountain-top detritus was probably during the height of the Koroksoak glaciation, but it is believed that the entire period from the initial uncovering of the upper summits, to the present, has been necessary for its mature development.

Figure 8. Maturely developed mountain-top detritus which is a conspicuous feature of the upland surfaces in the Torngat Mountains. (16 August, 1957).

Further field work is necessary before areas occupied by mountain-top detritus can be interpreted indisputably as having been ice-free during the final glaciation, but it is anticipated, that if detailed knowledge of the distribution of mountain-top detritus in Labrador-Ungava can be obtained, it will yield much information concerning conditions during the final glaciation.

THE NUNATAK HYPOTHESIS

The problems associated with the recognition and delimitation of nunataks, or ice-free areas, fall as much within the fields of botany and zoology as within those of geography and geology. As the two lines of approach to the solution of these problems should be pursued, ideally, side by side, it might be worth while at this point, to outline briefly the development of the nunatak hypothesis and to relate to it the botanical implications of the present work.

The presence of American plants in restricted areas of northern Scandinavia, led to the formulation of the classical nunatak hypothesis (Blytt, 1881, and later authors, cf. Dahl, 1955), as the only plausible explanation of the occurrence of a number of species which could not have followed the retreating ice northwards because they have never been found in more southerly districts; later, geologists confirmed that ice-free areas had persisted in some localities of Norway during the maximum glaciation (cf. Tanner, 1937, and earlier). The discovery of a number of so-called Cordilleran plants in isolated areas of northeastern North America, and arctic plants on isolated mountains farther south, led to the acceptance of a similar explanation for North America (Fernald, 1925; Hultén, 1937); and this in turn strongly influenced Coleman (1920, 1921, 1922, 1926) in his discussions on the extent of the Pleistocene ice sheets. The hypothesis suggested that plants survived the last glacial period on mountain summits which projected above the ice sheets at their maximum extent (nunataks). In this way, the discordance of present-day flora (relic flora) in isolated areas, with that of the surrounding areas, has been explained. The original hypothesis has been subsequently modified to suggest that many of the plants survived the glacial maximum in low-lying coastal areas which were protected from glacial inundation in various ways, and that during late- and post-glacial climatic amelioration, these plants migrated into neighbouring mountain areas where they are frequently found today (Nordhagen, 1935; Abbe, 1938; Dahl, 1955).

The application of the same hypothesis to Iceland has been discussed by biologists and geologists and there is little doubt that a considerable part of the present flora and fauna of this Atlantic island has survived on nunataks and on the adjacent continental shelf during glacial periods.

Dahl (1955) has recently presented a review of the evidence associated with the nunatak hypothesis, and has done much to explain the frequently opposing views of the geomorphologists and geologists, on the one hand, and the botanists and zoologists, on the other. Rousseau (1933, 1953), however, after extensive botanical surveys in the Lake Mistassini region and in the interior of Ungava, takes a different stand in reviewing the problem of the relic flora of Quebec and Labrador. He suggests that the Cordilleran plants might have reached their present position, either by migrating during late glacial and post-glacial times, or by conservation on nunataks. In a personal communication he states that either method, or preferably both, could be responsible for the actual plant distribution. Several other botanists have also suggested variations of the migration hypothesis (Hooker, 1862; Porsild, 1922; Abbe, 1938).

At the maximum of the Koroksoak (i.e. most recent) glaciation in the Torngat Mountains, large areas of higher land remained ice-free, and coastal areas, including parts of the now submerged continental shelf, were also probably ice-free, and would thus provide refuges for hardy plants which may have migrated into northern Labrador-Ungava during the preceding interglacial. It is considered that the Torngat glaciation, when at its maximum, would not provide suitable conditions for plant refuges, and that the entire land area, except possibly precipitous coastal crags (Dahl, 1946), was inundated by the continental ice. One cannot ignore phytogeographic evidence for the survival of the arctic flora north of the ice sheets, from where plants could disperse southwards (Hultén, 1937; Löve & Löve, 1957); for migration from refuges in the Arctic Archipelago in post-glacial time, has probably occurred on a large scale. The possibilities of refuges for plant and animal life throughout the entire glacial period in the eastern parts of Labrador are, however, less evident. Much more geological and biological work is needed in northeastern Labrador-Ungava in general, and in the Torngat Mountains in particular, before definite conclusions can be drawn on the possible survival of biota in these regions in coastal or nunatak areas.

CONCLUSIONS

Although absolute dating and correlation with other areas cannot be attempted at present, it is postulated that the Torngat Mountains have experienced two recent glaciations separated by an interglacial; the final glaciation, the Koroksoak, being much less extensive than the Torngat glaciation which preceeded it. Based on this theory, it is proposed that the initiation of the mountain-top detritus ante-dated the Koroksoak glaciation, and that the deep, frost-shattered mantle is only to be found in those areas which remained ice-free throughout that glaciation.

During the final stages of the Koroksoak glaciation the ice thinned and withdrew westwards from the Labrador coast, damming lakes against the higher land to the east as it did so, and although cirque glaciers and some small valley glaciers were reconstituted at this time, the Torngat area became virtually ice-free, long before the disintegration of the main mass of the ice which lay to the west and southwest.

The scheme of glaciation and deglaciation postulated for the Torngat Mountains has certain general applications to Labrador-Ungava as a whole, and although anything approaching final solution remains for the future, it is perhaps not too premature to examine in outline, some of these applications and to relate them to the scattered field evidence now available.

That the Torngat Mountains have been influenced by two recent glaciations, separated by an interglacial, suggests that Labrador-Ungava as a whole, has probably been subjected to the same fluctuations, and it might be useful to consider this possibility in any attempt to interpret the glacial landforms of the peninsula, although wide regional differences must be anticipated. Also, it must be considered that glacial maxima in different areas were not necessarily contemporaneous.

It is postulated that southwards from Hebron, conditions at the maximum of the final glaciation (Koroksoak) may well have become increasingly severe; that is, the land was beset by a greater thickness of ice in that direction. The distribution of mountain-top detritus throughout Labrador-Ungava, and particularly its presence or absence on the higher land along the coasts and on the outermost islands, should prove a useful indicator of the maximum extent of the Koroksoak glaciation (for comparison with Norway, *see* Dahl, 1946, 1954 and 1955).

Field studies in the vicinity of Hopedale and Makkovik during the early summers of 1956 and 1957 revealed that the final ice sheet had submerged even the highest summits in these areas, and that the general regional movement of ice had been towards the northeast. Summits between 1,200 and 2,000 feet near the coast, were formed of bare, unweathered, or slightly weathered rock, much of which retained well preserved striations, crescentic fractures, and even chatter marks. Mountain-top detritus was entirely lacking and frost-splitting rare; summit conditions contrasted sharply with those in the Torngat Mountains, although difference in altitude is a significant factor. Furthermore, the presence of mountain-top detritus on the summit (3,007 ft. Port Manvers Run) of Mount Thoresby (E. P. Wheeler, personal communication) indicates that this summit remained as a nunatak throughout the final glaciation and adds strength to the hypothesis that the presence of mountain-top detritus may be taken as an indication of the existence of nunataks. It appears that the nearby Kiglapait Mountains were completely over-ridden at the maximum of the final glaciation (A. Morse, personal communication).

Some tentative conclusions may now be put forward concerning the thinning and final disappearance of the last ice sheet. It appears that the ice withdrew from the Labrador coast to the west of the height of land. The works of A. P. Low (1896), V. Tanner (1944), scattered information in the literature, and in particular observations made by Dr. E. P. Wheeler, (when taken in conjunction with the work in the Torngat) suggests that late in glacial time large bodies of water were dammed by ice throughout the uplands. Prichard (1911), writing of Indian House Lake, describes a "beach of clear gravel elevated at a height of 700 feet (by aneroid) above the present level of the lake", and gives credit to his colleague, Hardy, for comparing it with the 'parallel roads' of Glen Roy in Scotland. These scattered observations, added to those made in the Torngat area, imply that a large mass of ice existed far inland long after the coastal zone had become ice-free. Whether at this stage the ice constituted a large active ice sheet, or scattered masses of stagnant ice, cannot at present be deduced.

It is concluded that ice remained in the vicinity of the George and Koroksoak river mouths after the Torngat Mountains had become ice-free, and at this time also, a large mass of ice remained on the plateau. Marine transgression would rapidly break up the ice in the Ungava Bay area, so that the ice cover on the plateau probably remained much longer.

A very late, and possibly a final stage is recognizable in the Knob Lake area of the central plateau (Ives, 1956b). Within a 50-mile radius of Knob Lake, glacial drainage terraces and channels, and direct overflows and abandoned lake shorelines indicate that, once the ice had thinned below the summits of the highest ridges, a complex pattern of ice-dammed lakes and drainage, marginal to, and beneath the remaining ice masses, was formed, and that the remnants of the ice sheet melted in situ as detached pieces.

The Kivivic Lake area, 25 miles northwest of Knob Lake, marks the dividing zone between flights of glacial drainage channels which slope away from the lake area to the north and south respectively, indicating that this area represents the site of one of the final remnants of stagnant ice. Similar conclusions can be drawn for parallel valleys towards the northeast, and on a regional scale, this pattern appears to have been repeated many times.

These general proposals concerning the deglaciation of Labrador-Ungava, although somewhat tentative, indicate that future work may eventually lead to an understanding of the role played by this vast area in the glaciations of North America. It is hoped that the present paper will provoke sufficient interest to accelerate the solution of these problems which are basic to a full understanding of the landscape of a large part of the Canadian mainland.

ACKNOWLEDGMENTS

The work was made possible by a grant from the Banting Fund, administered by the Arctic Institute of North America, and transportation from Goose Bay to and from northern Labrador by the British Newfoundland Exploration Company.

The writer is particularly indebted to Professor R. F. Flint, and to the following for valuable suggestions and assistance: Professor J. B. Bird, Dr. Askell Love, Dr. Jacques Rousseau, Dr. E. P. Wheeler.

RÉSUMÉ

On connaît peu le rôle joué par les monts Torngat lors de la glaciation de l'Ungava et du Labrador. En 1957, l'auteur étudia en détail la géomorphologie glaciaire du bassin hydrographique des rivières Koroksoak et Nakvak; cette région est située entre la baie d'Ungava et le versant Atlantique, dans la partie sud des monts Torngat. L'examen d'un grand nombre de photographies aériennes avait révélé que des travaux intensifs sur le terrain y seraient du plus haut intérêt.

L'étude morphologique a révélé l'existence d'un grand nombre de formes de glaciation qui ont permis d'établir ainsi qu'il suit la marche des événements lors des phases tardives de la dernière glaciation régionale.

1. La glaciation Torngat: à son stade maximum, celle-ci recouvrait les plus hauts sommets et s'avancait jusqu'à la bordure externe de la plate-forme continentale.
2. Un interglaciaire: au cours de cette période, la calotte continentale se retirant presque complètement de l'Ungava-Labrador, les conditions dans les Torngat étaient sensiblement les mêmes qu'aujourd'hui.
3. La glaciation Koroksoak: la calotte continentale recouvrait alors la majeure partie de l'Ungava-Labrador. Le centre d'accumulation était localisé à l'ouest de la ligne actuelle de partage des eaux et des langues émissaires traversaient la chaîne côtière en direction de l'Atlantique. Des réseaux de lacs de barrage glaciaires se déversaient vers l'Atlantique.

Les lacs de barrage glaciaires localisés dans les vallées du secteur ouest des monts Torngat, dans la vallée de la Koroksoak par exemple, indiquent qu'au cours du stade avancé de la glaciation d'importants champs de glace subsistaient dans la partie est de la baie d'Ungava. Le plateau Ungava-

Labrador a donc joué un rôle beaucoup plus important que les Torngat comme centre d'accumulation et de dispersion des glaces. De grandes étendues de glace demeurèrent à l'ouest et au sud-ouest des Torngat bien après le déglacement des montagnes.

On peut voir une phase encore plus récente dans la région du lac Knob, sur le plateau central. A moins de 50 milles de cet endroit, on note des terrasses et des chenaux d'écoulement pro-glaciaires, des lignes d'anciens rivages et des traces de débordement glaciaire qui indiquent que lorsque les glaciers de cette période eurent partiellement fondu et atteint des niveaux inférieurs aux sommets les plus élevés, il se forma un réseau complexe de lacs de barrage glaciaires et de chenaux pro-glaciaires et sous-glaciaires, de sorte que les restes de la calotte fondirent sur place en pièces détachées. La région du lac Kivivic, située à 25 milles au nord-ouest du lac Knob, est le point de départ d'un grand nombre de chenaux glaciaires d'orientation nord-sud, et indique l'emplacement de l'un des derniers culots de glace.

L'auteur conclut qu'une connaissance de la répartition du matériel non déplacé des sommets ainsi que des organismes vivants qui auraient pu survivre sur les nunataks existant au cours de la glaciation Koroksoak fournirait des données additionnelles sur les traits caractéristiques de la dernière glaciation.

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ESKIMO STONE STRUCTURES

J. Keith FRASER

The vast expanses of the Canadian Arctic give the impression of an almost complete lack of occupance, yet everywhere there is evidence of nomadic occupation by the Eskimo or his predecessors. In country lacking timber, the inhabitants have relied on other materials for construction; rocks, for example, have been put to many uses, and with these the Eskimo has left evidence of his way of life. The manner of his camping and hunting, as well as his burial grounds are revealed. The various arrangements of the rocks often show the kind of occupation followed, or indicate the type of local animal hunted.

This paper describes some of the common stone groupings that may be found in the Canadian Arctic. Some are quite common and may indicate nothing more than an occasional nomadic visit. Others, however, especially when associated with a local resource or occupation, indicate a more permanent residence.

Tent rings are the most common feature and may occur almost anywhere, although they are most numerous where seasonal camps are located at advantageous sites. When found in association with various other rock groupings, they indicate the predominant livelihood of that area. Tent rings associated with a row of rocks standing on end, or one or two on top of another (called by the Eskimo "inuksuk"), are evidence of a present or former caribou hunting country. Should the tent rings be found in association with fish weirs, fish drying racks, or caches, a fishing economy is evidenced.

Some of the structures or groupings are of an ancient culture predating the present Eskimo, and called by them, the "Tunit" people. The Tunit were a sea-faring people and built their homes by the sea, either in groups of two or three, or occasionally in large settlements of thirty or more.

TENT RINGS

The tent ring is a circular arrangement of moderately sized stones used to hold down the edge of a skin tent, or in recent times, a canvas tent. The rings vary from 4 to about 20 feet in diameter, and their number indicates the number of families that have used the campsite. They are commonly found on hill summits which offer better drainage, good observation points, and are windswept of snow. During late spring when sled travel is still possible on sea ice, the tents are sited on the beaches. This photo shows several rings near the shore of Ferguson Lake, Victoria Island.

RELIC STONE HOUSES

Scattered across the Arctic there is evidence of a culture predating the present Eskimo, and known to them as the Tunit people. They built sunken houses with stone walls, roofed with whalebone and covered with skins. The ruins are found in small clusters or in larger groups along ridge slopes close to the sea. The illustration shows a Tunit house at the head of Petersen Bay, King William Island. The figure (left) stands in the doorway.

GRAVES

The Eskimo began burying the dead only after the arrival of missionaries. As the ground is frozen for most of the year it was practical to leave the body on top of the ground for disposal by animals. Often, the body was encircled by small stones, whose arrangement indicated the size of the deceased. This illustration shows a child's grave. The stone groupings are more often found singly rather than in burial grounds, as the natives did not transport the bodies any distance.

INUKSUKS

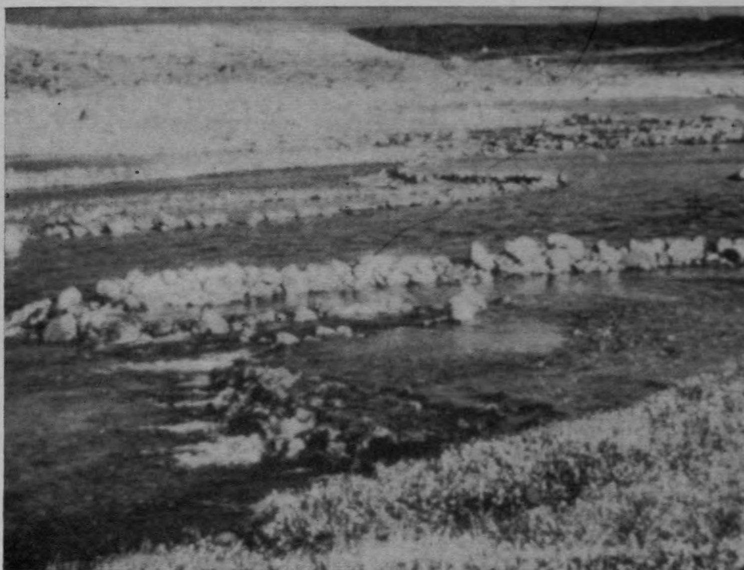
Inuksuks, rocks standing on end or one on top of another, are indicators of former caribou hunting country. They are usually found along ridges, and from the valley below they appear like people standing. During a hunt this impression was strengthened by having women and children run between the inuksuks. The Eskimo was thus helped to keep a migrating herd along a particular valley, and to run them past blinds or into a lake where they could easily be killed. Inuksuks occur widely throughout the Arctic in rocky ground, but have been in disuse since the Eskimo began to use rifles for hunting.

CACHES

Fish, caribou, and seal meat, are stored in caches against the depredations of wild animals. A cache may be partly excavated and piled over with rocks, or more frequently, merely a pile of rocks built over the meat. They are usually associated with tent rings, and as they indicate surplus food, are found in the better hunting and fishing locations. This illustration shows a fish cache on the southern shore of Ferguson Lake, Victoria Island.

FISH DRYING RACKS

Rows of stones are often found at lakeshore campsites where schooling fish may be speared in the spring. The fish are split and then hung to dry on poles laid along the stones. After the camp is broken the poles are removed. The illustration shows a fish rack and tent rings on the shore of Lake Hansteen, Boothia Peninsula.



FISH WEIRS

In good fishing rivers, stone weirs are built to cause the fish to pass through a narrow passage or to congregate in a shallow enclosure, where they may be speared. The weirs fall into disrepair rapidly as they are broken up by the ice each spring. The weir shown, is near the mouth of the river draining Middle Lake, Boothia Peninsula.

BLINDS

Blinds are built to provide concealment for hunters, and the most common type is a shallow trench with a row of boulders on either side. They are often associated with inuksuks.

Blinds may also be found on beaches, and have the form of pits several feet deep. They are used in hunting animals or in shooting wildfowl.

MAP NOTES

GLACIAL MAP OF CANADA. 1:3,801,600. Canada, Geol. Assn. Can., Toronto, 1958. Price $2.50.

Published in 1958, this multicoloured map has been compiled from many sources of information, mainly from maps and reports by federal and provincial departments and from published and unpublished material from several universities and mining companies. The association acknowledges contributions by the Geological Survey of Canada, the Defence Research Board, the National Research Council and the Geographical Branch. The legend includes a list of individuals who have provided geological data and the results of air photographic interpretation.

The map shows ice flow features such as eskers, moraines and melt water channels. It also shows the maximum extent of past marine submergence and the upper known limits of ice action. The present southern limit of permafrost and the boundaries of the un glaciated regions of western Canada are delineated, and the extent of major glacial lakes, marine overlap and some of the better formed, raised beaches are also shown.

An inset on a reduced scale, gives a generalized picture of rock outcrop and drift cover over the Canadian Shield. The map was compiled on a base supplied by the Map Compilation and Reproduction Division of the Department of Mines and Technical Surveys.

CANADA, NATURAL RESOURCES. 1:6,336,000. Canada, Dept. Mines and Tech. Surv., Surv. and Mapping Br., Ottawa, 1958. Price 25 cents.

This is the latest edition of the natural resources map previously published under the title: *Map of Canada, exclusive of Northern Regions, indicating Main Natural Resources.* The map is similar in form and content to the previous edition, but shows a radical change in style of presentation. Revisions have been made to the distributions of natural resources. Agricultural and forested areas are denoted by solid tints; other resources, with the exception of water power, are shown in different size of type, representing a quantitive value within the area of development or production. Producing and prospect minerals are differentiated on the map by the use of upright or sloping type; circular symbols of various sizes indicate approximate horsepower capacities of developed or undeveloped power sites. The distribution of natural resources in the arctic regions is now included in this new edition.

For the first time, the extent of the fishing banks off the Atlantic Provinces, including the Grand Banks, is outlined by the 50- and 100-fathom lines.

URANIUM IN CANADA; metallogenic map. 1:7,603,200. Canada, Dept. Mines and Tech. Surv., Geol. Surv. Can., Ottawa, 1958.

The main purpose of this map is to show the location of known uranium occurrences in Canada and to relate this information to the principal geological features. It is based on about 1,500 mining discoveries and properties in which uranium minerals have been found containing at least 0.05 per cent U_3O_8. Apart from serving as a source of information to prospectors, it will also serve as a reference for much of the literature on Canadian uranium deposits and their geology.

FOREST CLASSIFICATION OF CANADA. 1:6,336,000. Canada, Dept. Northern Affairs and Nat. Resources, Forestry Br. Ottawa, 1956. Price 50 cents.

Basically the map is the same as the 1952 edition. However, changes in its colour presentation have contributed much in bringing greater clarity and legibility to this new issue. The various forest classifications are represented by a new scheme of colours. Numbers within the classifications clearly differentiate the numerous sections or subdivisions.

CANADA, Showing the Establishments of the Hudson's Bay Company. 1:6,336,000. Canada, Hudson's Bay Co., Winnipeg, 1958.

Compiled on a blue and white base, this map gives an interesting picture of the fur trade by showing the location of fur trade posts, merchandise depots and raw fur departments, owned by the Hudson's Bay Company. Main roads and railroads are also indicated.

CARTE GLACIAIRE DE QUEBEC. 1:2,026,520. Québec, Université Laval, Faculté des Sciences, Géologie et Minéralogie, Québec, 1957.

Le Département de Géologie et de Minéralogie de la Faculté des Sciences de l'Université Laval vient de publier une carte glaciaire du Québec.

Cette carte couvre quatre régions principales: le Québec méridional, la région de l'Abitibi et celle au sud-ouest du lac Mistassini, la fosse du Labrador et tout le pourtour de la province.

Trois séries de phénomènes ont été indiqués: les formes d'accumulation (eskers, drumlins et blocs erratiques), les sédiments (glacio-marins, varvés), les régions physiographiques (Bouclier Canadien, Basses Terres du St-Laurent et la région des Appalaches).

GEOLOGICAL MAP OF YUKON TERRITORY. 1:1,267,200. Canada, Dept. Mines and Tech. Surv., Geol. Surv. Can. Ottawa, 1957.

Derived mainly from published or unpublished maps and reports from the Geological Survey of Canada, this multicoloured map is the first attempt to portray, on a comprehensive scale, geological formations of the Yukon Territory. Geological information is not available for the whole territory for areas such as Arctic or Porcupine Plateaux, Ogilvie Range, St. Elias and Pelly mountains.

(J.P.C.)

BOOK NOTES

Royal Commission on Canada's Economic Prospects

Mining and Mineral Processing in Canada. By John Davis. Canada, Queen's Printer, 1957, 400 pp., tables, graphs, append. Price $4.50.

Many individual products of mining, such as iron ore, gold and nickel, have received detailed study in past literature. However, few attempts have been made to discuss the mining sector of the Canadian economy as an integrated whole. This report of the Gordon Commission attempts it, and is eminently successful. The basic data have been numerous submissions by company research groups, government departments, Crown companies and individuals interested in the topic.

It is the opinion of the Commission that the mining industry, together with its related processing activities, is likely to become an even more influential sector of the Canadian economy. It may expand from three to four times its present size between now and 1980. In another 25 years, it may account for 33 per cent of the nation's commodity exports, compared with 9 per cent in 1929 and 25 per cent in 1955. In addition, Canada's mineral economy will be both broadened and deepened; the trading pattern for minerals will change both in character and in country of destination.

The Commission has little doubt that Canada possesses the necessary resources to sustain much higher levels of output. Proven resources are adequate to support present levels of production in most mines for 20 or 30 years. Less than one-third of the nation's favourable land area has so far been covered by geological reconnaissance mapping.

The Outlook for the Canadian Forest Industries. By John Davis, et al. Canada, Queen's Printer, 1957. 261 pp., graphs., tables. Price $3.00.

Canada's forest industries have constituted a major sector of the national economy for more than a century, and will continue to do so over the next 20 to 30 years. The total amount of wood utilized in North America today is about the same as it was in 1900, although there have been major variations in the uses served by wood in its different forms. The demand for fuel-wood and for such primary products as fence posts, pitprops and piling, has declined. On the other hand there has been a large enough increase in requirements for pulp and paper, sawn lumber, and for such manufactured commodities as fibreboard, plywood and veneer, to offset the decline in demand for fuel-wood and primary products.

It is estimated that Canada's lumber production will show a volume increase of approximately 55 per cent during the 25-year period under study. Most of this increase will originate in British Columbia. About half of the total will be sold for domestic consumption. Meanwhile, a somewhat larger proportion of all Canadian lumber exports will be sold in the United States.

The Canadian production of softwood plywood, hardboard, insulation board and other sheet materials, is expected to rise most rapidly; perhaps in the next quarter century, output may reach two or three times its present level. Pulp and paper production in Canada may more than double over the next quarter century. Little change is expected in the geographical distribution of pulp exports; the United States will probably continue to take about three-quarters of the total, with the United Kingdom accounting for most of the remainder. Some changes are expected in the distribution of newsprint export. Exports to the United States may rise by about 50 per cent, whereas exports overseas may increase by as much as 400 per cent. Consumption of fuel-wood should continue to drop as it becomes a less important source of fuel supply.

The total roundwood production in Canada (merchantable quantity of standing timber needed to meet the above requirements) may increase from 3.1 billion cubic feet in 1954 to 4.9 billion cubic feet in the next quarter of a century, an increase of about 60 per cent. The physical resources necessary for this increased production, appear to be available in Canada.

Progress and Prospects of Canadian Agriculture. By W. Drummond and W. MacKenzie. Canada, Queen's Printer, 1957. 424 pp., tables, maps. Price $4.50.

This extremely valuable study attempts to describe the way in which the agricultural industry will develop in Canada in the next 25 years. The report is prepared in four parts. Part I deals with the changing structure of the agriculture industry. Part II includes a number of studies designed to bring out regional differences. Part III is concerned with marketing and farm incomes. The final part consists of a discussion of problems that may persist, but for which workable solutions may be found.

Among major topics discussed are agricultural output, regional specialization in production, organization of farm business, and demand, both domestic and foreign, for Canadian farm products. The report shows the pattern of land use in Canada, the possibilities of expansion into undeveloped areas, government policies toward settlement, the increased intensity of land use, and conservation of agricultural resources. Among prospective changes in the structure of Canadian agriculture for the next quarter century, will be a considerably increased emphasis on livestock production; whereas the growth in the physical volume of total agricultural output will expand at a slightly slower rate than the rate at which the population increases. Regional specialization of production is unlikely to shift in directions not already evident.

The amount of new land that may be brought into agriculture within the period is not large, perhaps a total of six million acres, almost completely in western Canada. On the other side of the ledger, a net decline of 4.1 million acres of occupied land area in eastern Canada reduces the net gain to 1.9 million acres. Improved land, as opposed to occupied land, is expected to increase from 96.9 million acres in 1951 to 102.7 million acres in 1980.

The number of farms should continue to decrease, but the rate of decline is unlikely to be as great as in the 1941-51 period. The process of mechanization brought about a decline in the number of farms through consolidation of some of the farms and abandonment of others which were unsuited to mechanical production. The slower rate of mechanization in the future, linked to the rising demand for livestock and livestock products, will tend to slow down the rate of farm abandonment and also the rate at which farms can be consolidated. It is estimated that the number of farms will decrease by 20 per cent by 1980, whereas farm size will increase by 29 per cent.

The labour force employed in agriculture cannot continue to decline at the rate at which it has been falling during the last few years. A drop of only 2.5 per cent is estimated to 1980. However, an increasing population will result in a smaller proportion of all workers employed in Canada; dropping from 15.3 per cent in 1955 to only 7.4 per cent of those gainfully employed in 1980.

Final Report. Canada, Queen's Printer, 1957. 509 pp; tables, maps, append. Price $3.00.

This report is the summation of the findings of a commission appointed . . . "to inquire into, and report upon, the long-term prospects of the Canadian economy, that is to say, upon the probable economic development of Canada and the problems to which such development appears likely to give rise".

It is an invaluable record of the considered opinion of many hundreds of organizations and individuals who contributed briefs or testimony on all aspects of the Canadian economy.

(F.A.C.)

History Of the Great Fishery of Newfoundland. By Robert de Loture, Marine Academy, Paris. U.S. Dept. Interior, Fish and Wildlife Serv., Sp. Scientific Rept.—Fisheries No. 213, Washington, 1957. 147 pp., processed.

This interesting history of the Newfoundland fishery carries the reader briskly along from the eleventh century Viking ship to the twentieth century trawler, and ends with the outbreak of World War II. Down through the years, the difficult life of the fisherman is sympathetically portrayed against the background of an industry which offered many hardships and few rewards. The French fishery is the main concern of the author, but the activities of the English, Portuguese and other do not pass unnoticed.

The tiny French colony of St. Pierre and Miquelon has long been intimately associated with the cod fishery. Its inhabitants, in common with many of those engaged in the fishery, were the frequent victims of British-French rivalry. Since 1903 the colony has been in a state of economic decline, although the American prohibition opened new avenues to prosperity during the years following World War I.

Translated from the French by the U.S. Fish and Wildlife Service, this publication is one of a series "intended to aid or direct management or utilization practices and as guides for ministrative or legislative action".

(E.D.R.)

THE ATLANTIC PROVINCES. By Nelson Mann. Atlantic Provinces Economic Council, Halifax, 1957. 23 pp., mimeo.

This short summary of the economic bases of New Brunswick, Newfoundland, Nova Scotia, and Prince Edward Island is designed to encourage businessmen and others to investigate the commercial opportunities of the Atlantic provinces. Beginning with a brief description of the four provinces, the author goes on to discuss the chief resource industries, the expanding population, the problems of transportation and distribution, the tourist industry, the regional market, provincial legislation and the tax structure, and ends with a list of sources of additional information and an appendix.

(E.D.R.)

ATLANTIC PROVINCES CHECKLIST. Maritime Library Association in co-operation with the Atlantic Provinces Economic Council. Publ. Halifax, Atlantic Provinces Economic Council, 1958. 86 pp., mimeo.

The Atlantic Provinces Checklist is an attempt to catalogue all available sources of current information about New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland, published during 1957. Compiled and edited by the Maritime Library Association, it is published and distributed by the Atlantic Provinces Economic Council.

(E.D.R.)

REPORT OF THE NEW BRUNSWICK FOREST DEVELOPMENT COMMISSION. FREDERICTON, N.B., June, 1957. 154 pp., map.

The Commission suggests that the value, to the people of New Brunswick, of their principal economic asset, their forest resource, could be doubled within half a lifetime, provided the forest operators, the government, and the public work together for mutual benefit. The temporary handicaps caused by the spruce budworm epidemic and the current levelling off of business activity should not be allowed to deter the Province from implementing constructive planning now.

The report deals with Crown and private timberlands, forest protection, development and administration, and concludes with a summary and the Commission's recommendations. There are also a list of proposals upon which the Commission took no action, lists of formal submissions and references, a number of tables, and a map of New Brunswick showing Crown and granted lands, and forest districts.

(E.D.R.)

LOGGING ATLAS OF EASTERN CANADA. By W. D. Bennett. Pulp and Paper Res. Inst. Can., Montreal, 1958.

This atlas is designed to provide a means for comparing the various logging systems now being used in eastern Canada. Local environmental factors are considered in separate sections of Newfoundland, Nova Scotia, New Brunswick, Quebec, Ontario, and Manitoba. There is also a section on the major forest regions of the Dominion and several maps, descriptive of some individual factors, which may or may not have had an influence on the choice of logging systems. The atlas is published in loose-leaf form to facilitate additions and revisions.

(E.D.R.)

INDUSTRIAL SURVEY OF TRURO, N.S. (WITH NOTES ON THE VILLAGE OF BIBLE HILL AND COLCHESTER CO.) Can. Nat. Rlys., Research and Development Dept. Montreal, 1958. 39 pp., maps, processed.

Truro's location near the geographic centre of Nova Scotia, together with its radiating system of highways and railway lines, has made it a natural distribution point for the Province. Lumbering and agriculture are important in the surrounding country-side, forty-three light industries employ much of the town's labour force. Truro's early foundation and its contemporary population, industries, and institutions are well described in this concise report.

(E.D.R.)

REPORT OF THE ROYAL COMMISSION ON RURAL CREDIT, 1957. Nova Scotia, Halifax, 1957. 91 pp., tables.

The task of the Royal Commission was to evaluate the adequacy of the farm credit system to meet the needs of farmers in Nova Scotia, because in recent years the volume of farm production has not expanded comparably to that of other provinces, and because there has been an apparent delay in the adjustment of farming in Nova Scotia, to changing conditions. The enquiry was limited to a study of the normal operation of farms, with no mention of funds for purposes such as emergency relief, or the rehabilitation and reclamation of land.

Of particular interest to geographers is the chapter concerning agriculture, land utilization, and trends in farming. The impact of technological changes upon agriculture is summarized in terms of farm production and farm labour force, and supported by tables based on census statistics.

The sources of credit for farmers are outlined and the recommendations of the commission presented.

(B.V.G.)

ANNUAL REPORT ON MINES, 1957. N.S. Dept. Mines, Halifax, 1958. 200 pp., maps, photos, tables.

Reports on coal mines, electrical equipment, industrial minerals, metalliferous mines, and core drills, are included in this annual report. In addition, there is a section on maps of Nova Scotia, which lists and describes maps of all types published by both the federal and provincial governments. There are also detailed statistics on mineral production, industrial accidents, coal production and shipments, and gold production, including comparative statistics in some cases.

(R.B.)

REPORT OF RECONNAISSANCE SOIL SURVEY OF CARBERRY MAP SHEET AREA. By W. A. Elrich, et al. Man. Soil Surv. Rept. No. 7, Canada, Dept. of Agric. 1957, 93 pp., tables, illus., maps.

This is the seventh of a series of reports devoted to the description of the soils of Manitoba, and covers an area of 3,780 square miles in the south-central part of the province. The report is divided into four parts. Part 1 gives a general description of the area, and includes population distribution and transportation and market facilities. Part 2 concerns the physiographic features affecting soil formation. Part 3 describes the soil associations, gives an estimate of their suitability for agricultural use, and on the basis of observed soil characteristics, groups the soils into land-use capability classes. Part 4 outlines the history of settlement and describes present land use.

The accompanying coloured soil map, at a scale of 1:126,720, indicates the distribution and area of the soil associations.

(B.C.)

REPORT ON THE ROYAL COMMISSION ON THE DEVELOPMENT OF NORTHERN ALBERTA. Edmonton, 1958, 115 pp., maps, tables, photos.

This report presents a detailed statement on the resources of northern Alberta, assesses the potential of the area, and includes the recommendations of the Commission for its future development. The final report was prepared from briefs submitted by organizations and professional associations, and from technical information supplied by provincial and federal government departments, and by private companies.

The body of the text consists of nine sections. Section 1 is concerned with geographical location, geology, climate and settlement. Section 2 sets out the "Present Status of Northern Alberta". It tabulates the present population and shows the degree of resources development that supports this population. Section 3 is an inventory of the known national resources of the area.

Having tabulated the resources of northern Alberta the report discusses future economy over the next 30 years, markets, and population trends. The text is well supported by tables, maps and indexes.

(B.V.G.)

ORGANIC TERRAIN ORGANIZATION FROM THE AIR (Altitudes less than 1,000 feet). By N. W. Radforth. Canada, Dept. of Nat. Def., D.R.B., Handbook No. 1, Rept. No. DR 95, Ottawa, 1955. 24 pp., tables, illus., offset.

ORGANIC TERRAIN ORGANIZATION FROM THE AIR (Altitudes 1,000 to 5,000 feet). By N. W. Radforth. Canada, Dept. of Nat. Def., D.R.B., Handbook No. 2, Rept. No. DR 124, Ottawa, 1958. 23 pp., tables, illus., offset.

An untrained observer finds it impossible to distinguish in 'organic terrain' (muskeg), patterns that may be used to assess the suitability of the ground for such purposes as road or airfield construction, vehicle movement, or military tactics. Out of much field and laboratory research, Dr. Radforth has produced two handbooks in which he organizes 'organic terrain' according to several classes of 'indicators'. Vegetal cover, colour, objects (such as boulders), topography, and texture, are all taken into account for low altitude inspection or photography. In the second handbook, the specific indicators are generalized into 'air form values', which are related to eight types of organic terrain recognizable on air photographs.

The development of these handbooks appears to have been largely self-contained, with little reference to other special fields of study; much new terminology has been devised. By these means, presumably, the methods will be available to users with no special qualifications. Many air photographs are included as illustrations without scales and not as stereo-pairs, and some clarity is lost in offset reproduction.

A third handbook for still higher altitude interpretation, is mentioned as in preparation.

(C.F.J.W.)

GREAT SLAVE LAKE AND MACKENZIE RIVER PILOT. Canada, Dept. of Mines and Tech. Surv., Can. Hydrographic Serv., Ottawa, 1958. 85 pp. Price $2.00.

This is the first edition of the Great Slave Lake and Mackenzie River Pilot. It combines the former preliminary edition of the Mackenzie River Pilot with a general description of Great Slave Lake. In addition to navigation information, the report includes a brief description of the area, its history and administration, and a note on inland ice conditions.

(F.A.C.)

WINDCHILL IN THE NORTHERN HEMISPHERE. U.S. Army, Headquarters, Quartermaster Res. Eng. Comm., Natick, Mass. Tech. Rept. EP 72. February, 1958. 13 pp., map, figure, table.

Windchill is a recent measurement. Although qualitative, measuring the cooling effect of a combination of wind and temperature on the human body, it has been adopted as a descriptive value for the severity of human environments. In practice, the index of windchill corresponds quite well with experience of coldness in the field, i.e., of the discomfort and tolerance of man in cold.

In 1941 a new formula for windchill was developed by Siple and Passel, from experiences in Antarctica, which measures the cooling power of wind and temperature in complete shade, without regard for evaporation. The resulting heat loss is expressed in kilogram calories per square meter of exposed skin surface, and this measure has become the standard measure of windchill. This short report discusses the method of computing windchill in considerable detail, and contains a map of the mean windchill for the coldest month of the year in the northern hemisphere. In computing the map, isopleths were drawn from monthly mean temperatures and wind speed data from more than 1,000 stations.

(F.A.C.)

THE QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1959