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ANALYZE

PERMAFROST INVESTIGATIONS ON TRUELOVE LOWLAND

by R.J.E. Brown, Division of Building Research, National
Research Council of Canada

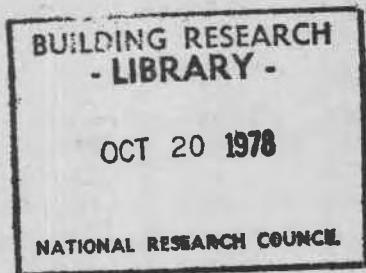
with an Appendix by A.S. Judge, Earth Physics Branch,
Department of Energy, Mines and Resources

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Earth Physics Branch

04715

SOMMAIRE

Le pergélisol, ou gélisol pérenne, se trouve partout sous la surface du sol de Truelove Lowland, situé dans la partie nord de la zone de pergélisol continue. La présence d'une forte épaisseur de pergélisol continu dans l'Archipel canadienne de l'Arctique est connue depuis longtemps, mais jusqu'à récemment les relevés se limitèrent à quelques endroits épars. Pendant ces dernières années, les observations augmentèrent considérablement, tout particulièrement dans les Queen Elizabeth Islands, grâce aux recherches pétrolifères entreprises. Le Canadian Tundra Biome Study de l'I.B.P. donna l'occasion de recueillir l'information sur les conditions du pergélisol dans les principaux types de terrains de Truelove Lowland. Aucune mesure du pergélisol n'avait été effectuée sur Devon Island auparavant. Une indication préliminaire des conditions du pergélisol a été obtenue à partir des observations faites à Resolute T.N.-O., à 320 km au sud-ouest sur Cornwallis Island, l'île voisine de Devon Island. A cet endroit, le pergélisol descendait à environ 400 m de profondeur et avait une température de -12.5°C à une profondeur du niveau d'amplitude thermique annuelle zéro.

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Permafrost investigations on Truelove Lowland

R.J.E. Brown

Introduction

Permafrost, or perennially frozen ground, occurs everywhere beneath the land surface of Truelove Lowland, which is situated in the northern part of the continuous zone (Brown 1967). The presence of thick continuous permafrost throughout the Canadian Arctic Archipelago has been known for a long time, but until recently investigations have been limited to a few scattered locations (Brown 1970, Brown 1972a). During the past few years, observations have increased considerably, especially in the Queen Elizabeth Islands, with the onset of petroleum explorations (Judge 1973). The Canadian Tundra Biome Study of the I.B.P. provided an opportunity to obtain information on permafrost conditions in the major terrain types at Truelove Lowland. No permafrost investigations had been carried out previously on Devon Island. A preliminary indication of permafrost conditions was available from observations at Resolute, N.W.T., 320 km to the southwest on adjacent Cornwallis Island. At this location permafrost was found to be about 400 m thick with a temperature of -12.5°C at the depth of zero annual amplitude (Cook 1958, Misener 1955).

Methods

A preliminary reconnaissance was made in August 1970 to survey surface features associated with permafrost, to obtain measurements of thickness of the permafrost active layer in the major terrain units in the Lowland, and to select sites for the installation of thermocouple cables. A drilling program was carried out in June and July 1971 to obtain information on the perennially frozen soils and bedrock and to install thermocouple cables for monitoring ground temperatures in the permafrost. A total of ten holes (nine in the Lowland and one on the adjacent upland plateau to the east) were drilled in six of the major terrain units to varying depths down to 9 m using a two-man portable Packsack 10 hp diamond drill (Fig. 1, Table 1). Holes in the gravelly soils were limited in depth to less than 3 m by the lack of sufficient power to drill casing. Holes in bedrock were deeper, but limited to depths of 8 to 9 m because of the very cold ground temperatures which caused freezing problems in the drilling. The restriction of logistical support to light aircraft at this remote location in the High Arctic prevented bringing in a sufficiently heavy duty drill rig for the installation of deeper holes.

Table 1. Soil and rock profiles at thermocouple cable sites, Truelove Lowland, Devon Island, N.W.T.

A.* Beach Ridge—South Slope (38 m above sea level)	
0 to 3 cm	Organic material
3 cm to bottom of hole (1.45 m)	Well graded sandy gravel (beach material)
A. Beach Ridge—Top (38 m above sea level)	
0 to bottom of hole (1.20 m)	Well graded sandy gravel (beach material)
A. Beach Ridge—North Slope (38 m above sea level)	
0 to 5 cm	Organic material
5 cm to bottom of hole (0.75 m)	Well graded sandy gravel (beach material)
B. Ice-Wedge Polygon—Centre (30 m above sea level)	
0 to 40 cm	Peat
40 cm to bottom of hole (1.35 m)	Ice with scattered peat stringers
B. Ice-Wedge Polygon—Trench (30 m above sea level)	
0 to 8 cm	Peat
8 cm to bottom of hole (1.65 m)	Ice
C. Tundra-Meadow (53 m above sea level)	
0 to 1.5 m	Peat
1.5 m to 2.4 m	Stony clayey silt (till) with granite boulders up to 30 cm diameter
2.4 m to bottom of hole (2.80 m)	Medium sand
D. Limestone-Coast (1 m above sea level)	
0 to 4.5 m	Pitted (vesicular) limestone (porosity—3%; thermal conductivity**—11 to 12, 4.62 to 5.04)
4.5 m to bottom of hole (8.70 m)	Mottled brownish green grey dolomitic limestone (porosity—7 to 13%; thermal conductivity—10 to 11, 4.20 to 4.62)
E. Limestone-Inland (9 m above sea level)	
0 to 3.9 m	Pitted (vesicular) limestone (porosity—3%; thermal conductivity—11 to 12, 4.62 to 5.04)
3.9 m to bottom of hole (6.90 m)	Mottled brownish green grey dolomitic limestone (porosity—7 to 13%; thermal conductivity—10 to 11, 4.20 to 4.62)
F. Granite Gneiss (75 m above sea level)	
0 to bottom of hole (6.45 m)	Granite-gneiss (porosity—0.3%; thermal conductivity—6, 2.52)
G. Upland Plateau (306 m above sea level)	
0 to 1.5 m	Stoney clayey silt
1.5 m to bottom of hole (7.90 m)	Fissured sandstone and dolomite (porosity—3 to 10%; thermal conductivity—7.4 to 8.6, 3.11 to 3.71)

*See map (Fig. 1).

**First values in CGS units— $\text{m cal cm}^{-1}\text{sec}^{-1}\text{C}^{-1}$. Second values in SI units—watts per metre kelvin ($\text{W m}^{-1}\text{K}$). Thermal conductivity determination by Geothermal Studies Section, Seismology Division, Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, Ontario.

The first ground temperature measurements were taken in July 1971 and monthly readings were continued until the end of the field season in October when the Base Camp operation was discontinued for the winter (Brown 1972b, Brown 1973). Monthly observations were resumed in May 1972 and continued through the winter of 1972-73 to August 1973 when the program was terminated. The depth of snowcover was also noted monthly at a snow stake at each site during the observation periods.

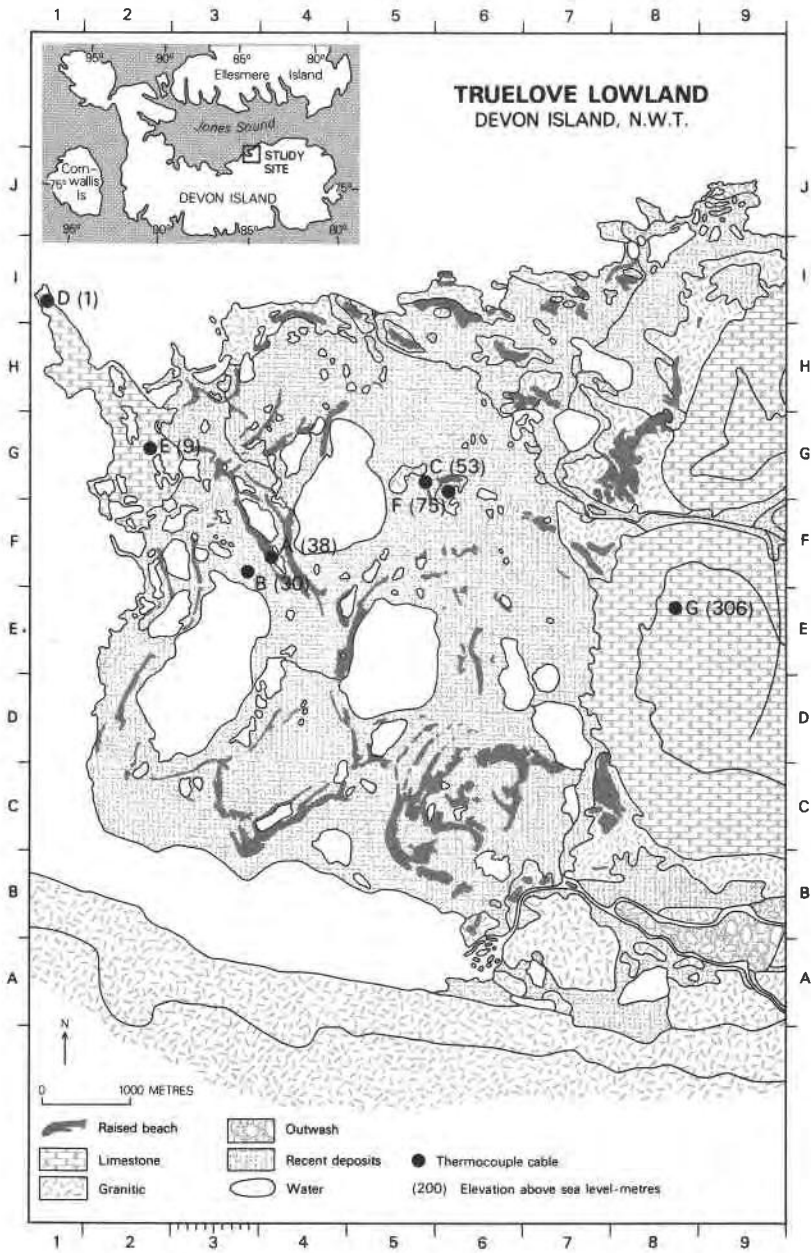


Fig. 1 Location of thermocouple cable sites on Truelove Lowland.



Fig. 2 Beach ridge thermocouple cable sites—north slope on left, top in centre, south slope on right, July 1971.

Terrain characteristics of thermocouple cable sites

Three thermocouple cables which have sensors at 15 cm intervals were installed on the south slope, top, and north slope of a beach ridge (designated as the Beach Ridge Site) southwest of Base Camp similar to the Intensive Raised Beach Site (Fig.2). Two cables, also with sensors at 15 cm intervals, were placed in a nearby area of high centre ice-wedge polygons (Ice-Wedge Polygon Site), one cable in the centre of a polygon, and the other in a trench (see Fig. 5 Muc and Bliss this volume). One cable which has sensors at 0.75 and 1.5 m

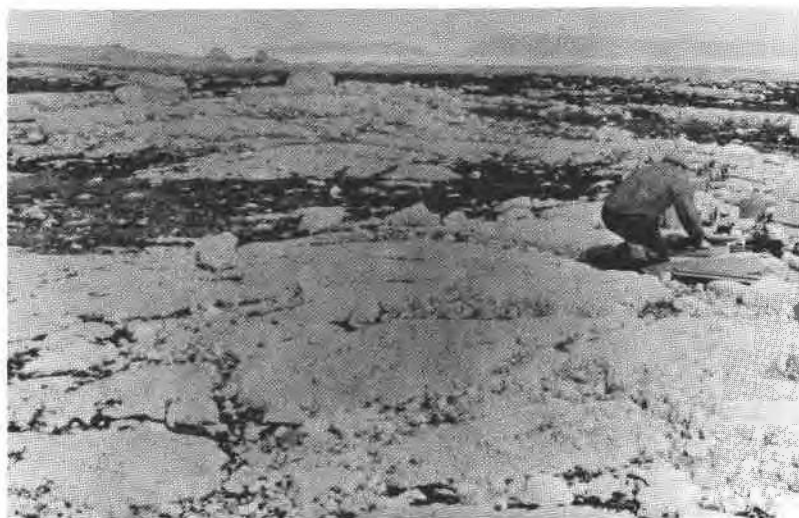


Fig. 3 Limestone-inland thermocouple site, July 1971.

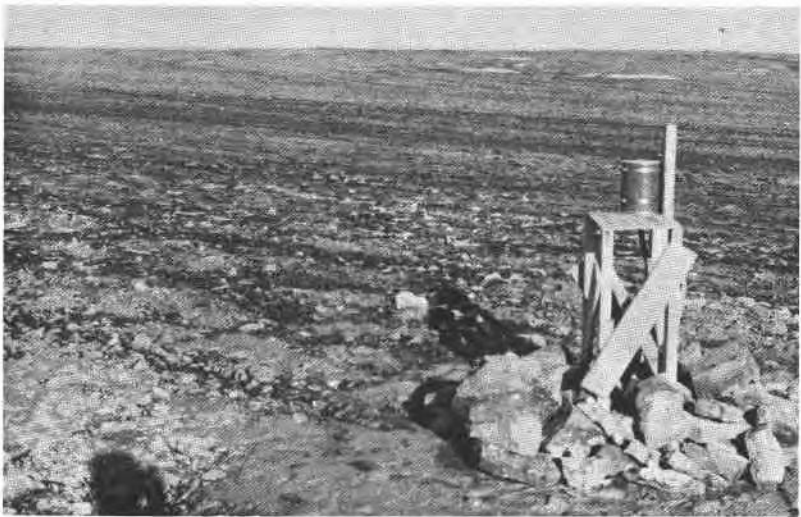


Fig. 4 Upland plateau thermocouple cable site, July 1971.

intervals was installed in a hummocky sedge-moss meadow adjacent to the Intensive Meadow Site. Four thermocouple cables with the same sensor intervals were installed in exposed bedrock. Two of these were located in the limestone area in the northwest section of the Lowland, one at the coast at Rocky Point (Limestone-Coast Site), and the other 0.5 km inland (Limestone-Inland Site) (Fig. 3). One hole was drilled in a granite gneiss outcrop (designated as the Granite Gneiss Site) near the Intensive Meadow Site. The fourth was installed on the 300 m high upland plateau surface (Upland Plateau Site) east of the Lowland (Fig. 4). Data on the ground (soil/ rock) profiles, depth of thermocouple cables, elevation above sea level, and rock thermal conductivity values are given in Table 1.

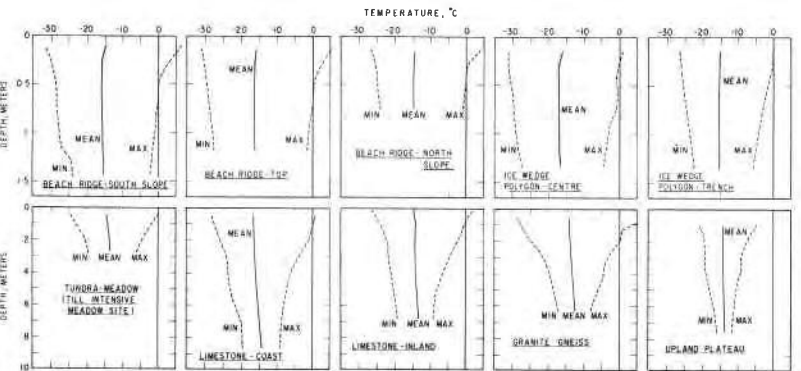


Fig. 5 Ground temperature envelopes of thermocouple cable sites.

Table 2. Active layer (depth of thaw) at thermocouple cable sites, Truelove Lowland, Devon Island, N.W.T.

Site	Active layer (cm) 1971	Depth of thaw (cm) 1972		Depth of thaw (cm) *1973 July
		July	August	
Beach Ridge—South Slope (A) ¹	110	49	40-70	88
Beach Ridge—Top (A)	91	52	46-76	not available
Beach Ridge—North Slope (A)	61	34	46	55
Ice-Wedge Polygon—Centre (B)	30	21	16-30	46
Ice-Wedge Polygon—Trench (B)	30	12	16	46
Tundra-Meadow (C)	70	30	37	not available
Limestone-Coast (D)	122	58	46-122	91
Limestone-Inland (E)	140	55	16-91	116
Granite Gneiss (F)	223	146	137	168
Upland Plateau (G)	<30	<30	30	not available

*August 1973 not available.

¹See map.

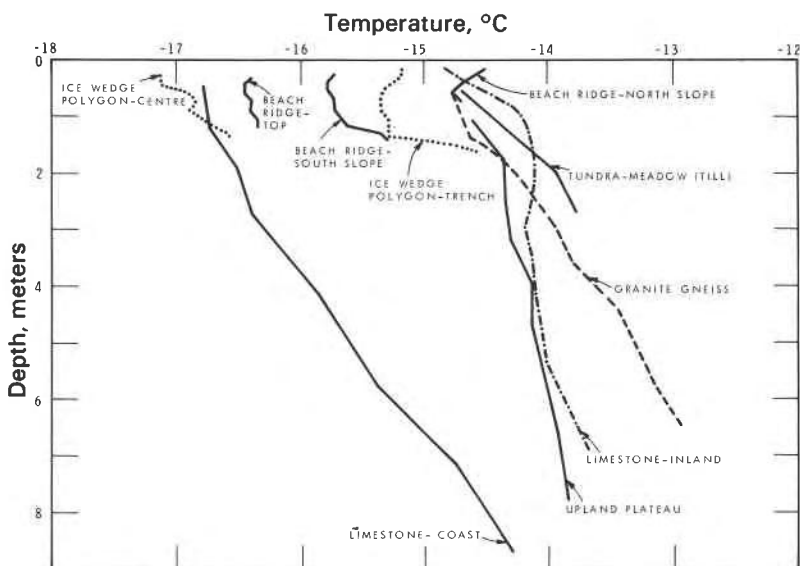


Fig. 6 Mean annual ground temperature graphs at thermocouple cable sites.

Ground temperature measurements

Although ground temperature measurements were taken monthly for a 16 month period from May 1972 to August 1973 inclusive, some unavoidable gaps and readings of questionable accuracy in the summer of 1973 necessitated restricting the data used for calculating mean annual ground temperature values to the period of May 1972 to May 1973 inclusive. Within this period, values for missing readings were interpolated as the arithmetical mean between the two adjacent monthly observations. Mean annual temperature values were obtained for each thermocouple junction for 12 monthly readings for the two periods of May 1972 to April 1973 and June 1972 to May 1973. The average of

Table 3. Snowcover (cm) at thermocouple cable sites (May 1972-May 1973), Truelove Lowland, Devon Island, N.W.T.

<i>Site</i>	<i>May</i>	<i>Jun</i>	<i>Jul</i>	<i>Aug</i>	<i>Sep</i>	<i>Oct</i>	<i>Nov</i>	<i>Dec</i>	<i>Jan</i>	<i>Feb</i>	<i>Mar</i>	<i>Apr</i>	<i>May</i>
Beach Ridge—South Slope (A) ¹	20	23	—	—	—	15	18	15	15	13	18	18	13
Beach Ridge—Top (A)	30	25	—	—	—	10	18	13	15	10	18	18	15
Beach Ridge—North Slope (A)	53	48	—	—	—	20	28	28	30	30	36	36	30
Ice-Wedge Polygon—Centre (B)	10	10	—	—	—	10	15	3	5	10	8	10	—
Ice-Wedge Polygon—Trench (B)	84	86	—	—	—	53	58	61	61	61	71	69	69
Tundra-Meadow (C)	46	46	—	—	—	10	*15	20	25	30	30	30	30
Limestone-Coast (D)	28*	33*	—	—	—	10	*18	25	15	23	30	30	33
Limestone-Inland (E)	28	33	—	—	—	23	*24	25	25	25	28	30	41
Granite Gneiss (F)	15	—	—	—	—	10	*7	3	15	13	23	5	10
Upland Plateau (G)	38	36	—	—	—	10	28	*27	25	25	30	36	30

*Interpolated Values.

¹See map.



Fig. 7 Polygonal crack (snow covered) and peat wedge in active layer in Base Camp beach ridge, August 1970.



Fig. 8 Polygonal cracks in limestone near limestone-inland site, July 1971.

these two annual means and the maximum and minimum temperatures of each depth were used to plot the ground temperature envelope for each site shown in Fig. 5. The same mean annual ground temperature values for all sites are plotted on one graph to provide a visual comparison of them (Fig. 6). Active layer and depth of thaw determinations at all sites for the three summers of 1971, 1972, and 1973 are listed in Table 2. The depth of snowcover at each site is shown in Table 3.

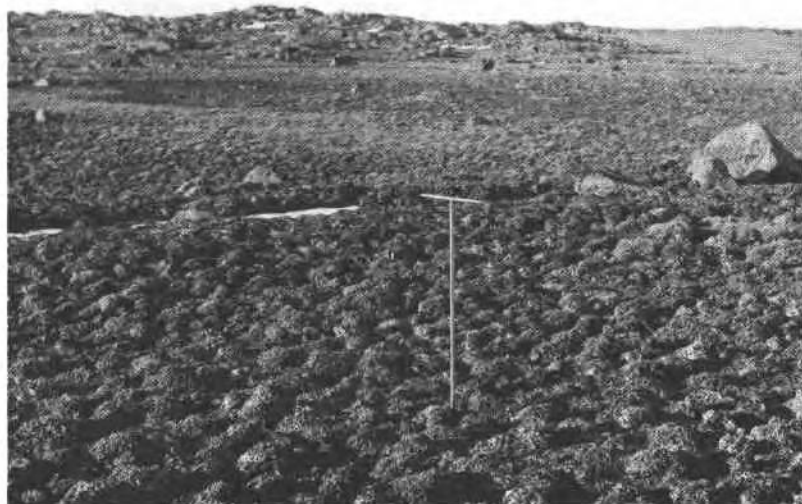


Fig. 9 Turf hummocks near ice-wedge polygon site, August 1970.

Results and Discussion

Surface features characteristic of high latitude continuous permafrost conditions are prevalent in the Lowland. Polygons and polygonal cracks due to thermal contraction occur in the beach ridges (Fig. 7), meadows, and even the weathered limestone where the surface is fragmented (Fig. 8). Surface features associated with severe frost action in the active layer of fine-grained soils are also widespread (Washburn 1973). They include nonsorted circles (stony earth circles), stone nets, and turf hummocks (Fig. 9).

Although it is risky to generalize on the permafrost ground temperatures on the basis of such a short observation period, some broad patterns appear to exist. The Granite Gneiss Site had the highest mean ground temperatures for the one-year observation period of the exposed bedrock areas and the Limestone-Coast Site the lowest. The Upland Plateau Site had the smallest gradient in the study area. The Granite Gneiss and Limestone Sites had comparable ground temperature envelopes, the former being slightly larger, but the Upland Plateau displayed much smaller amplitudes of maximum to minimum temperatures. The Tundra-Meadow Site (hummocky sedge-moss meadow) was the warmest of the other sites and in fact it was warmer than the Granite Gneiss Site on the basis of the mean annual ground temperatures. There was wide variation among the three Beach Ridge Sites depending on slope orientation. The same was true of the Ice-Wedge Polygon Site, the centre being colder than the trench. At all sites the mean annual ground temperatures were slightly closer to the minimum temperatures in the envelopes than to the maximum.

Thickness of the active layer and depth of thaw varied greatly among the sites and from one summer to another (Table 3). Difficulties with temperature observations in the summers of 1972 and 1973 prevented an accurate assessment of active layer thickness similar to 1971. The general patterns indicated, however, that the Granite Gneiss Site had consistently the thickest active layer (depth of thaw), and the Upland Plateau had the thinnest of the

rock sites. For the other sites, the thickness of the active layer at the Beach Ridge Sites was similar to the Limestone Sites; the Tundra-Meadow Site had a thinner active layer, and the peat at the Ice-Wedge Polygon Sites the least, being similar to the Upland Plateau Site. The ground began to thaw from the surface in mid-to-late June as soon as the snow melted. By mid-September all thawed ground above the permafrost table was refrozen. Ground thawing was deepest in 1971, almost as deep in 1973, and much shallower in 1972.

The depth of snowcover was quite variable among the sites. The Granite Gneiss Site had the thinnest snowcover of the rock sites and the Limestone-Inland the thickest. The centre of the Ice-Wedge Polygon Site had the least snowcover, and other exposed sites such as the Beach Ridge top and the Limestone-Coast also had less snowcover than the other sites.

Permafrost environmental relationships

Despite the short observation period, irregular readings, and shallowness of the thermocouple cables, some broad correlations are evident in the relationships between the permafrost and environmental factors.

Air temperature data were not available for Truelove Lowland at the time of writing, so observations at Resolute were used to provide a general idea of yearly comparisons. The summers of 1971 and 1973 were considerably warmer than 1972. Degree days of thawing, based on monthly mean air temperatures for June, July, and August, were 255 in 1971, 116 in 1972, and 272 in 1973. January and February mean monthly air temperatures in the winter of 1971-72 were nearly 3°C colder than in 1972-73, about -19.5°C in January and February 1972, and about -16.8°C in January and February 1973. Variations in the active layer (depth of thaw) were considerably less in 1972 than in the other two summers (Table 2). It was also found that for May and June 1972 the ground temperatures were 2-3°C colder than those of May and June 1973 as would be expected from colder air temperatures in the winter of 1971-72.

Snowcover is an important environmental factor throughout the permafrost region and its influence in Truelove Lowland was very marked during the observation period. Variations in mean annual ground temperatures from one site to another due to snowcover were particularly evident at the Beach Ridge Sites and Ice-Wedge Polygon Site. The north slope of the Beach Ridge had the highest mean annual ground temperatures, due apparently to its having twice the depth of snow as the top and south slope. This ameliorating influence of the winter snowcover more than compensated for the lower ground temperatures near the surface and lesser depth of thaw that would be expected for a north slope in summer. At the Ice-Wedge Polygon Site, winter ground temperatures were higher in the trench, where snow accumulated to considerable depth in contrast to the centre which was windblown. In summer, the temperatures in the trench were similar to those in the centre and the depth of the thaw was the same at both locations.

The type of soil and rock has an important influence on the thickness of the active layer and the thickness of the permafrost. At the Tundra-Meadow Site and Ice-Wedge Polygon Site the surface peat layer was responsible for the thin active layers due to the insulative properties of this earth material. The dolomite (limestone) was found to have a higher thermal conductivity (11-12 m cal cm⁻¹sec⁻¹C⁻¹ or 4.20 to 4.62 W m⁻¹k⁻¹) than the granite gneiss (6 m cal cm⁻¹sec⁻¹C⁻¹ or 2.52 W m⁻¹k⁻¹) (Brown 1973, Table 1). The decrease in amplitude of ground temperature with depth was more rapid for the Granite Gneiss Site as would be expected because of this factor.

Before the temperature observation program was initiated it was anticipated that the ground temperatures at the Upland Plateau Site would be lowest of all the sites because of its elevation, 300 m above Truelove Lowland. The Limestone-Coast proved, however, to have the lowest average annual ground temperature (-16.8°C) and the Upland Plateau the highest (-14.6°C). The slope of the former was much steeper than of the latter and the curves probably intersect a short distance below the bottom depth of the thermocouple cables. The proximity of the Limestone-Coast site to the cold coastal seawater probably affected the summer ground temperatures. Amelioration of winter ground temperatures were possibly reduced with the formation of thick sea ice. The Upland Plateau Site ground temperature graph had the smallest temperature change with depth (smallest temperature gradient) of all the sites, which may indicate the thickest permafrost is at this location.

Acknowledgments

The author wishes to thank Dr. L.C. Bliss for inviting him to participate in the Devon Island Project which afforded the opportunity of obtaining permafrost information in the Canadian Arctic Archipelago. It would not have been possible to carry out these investigations, especially the drilling program, at such a remote location without the support facilities existing there. The Devon Island Project provided invaluable assistance in shipping equipment to the site. Thanks are due both to the International Biological Programme (I.B.P.) and the Arctic Institute of North America (A.I.N.A.) for providing accommodation and support services. In this regard the assistance of Dr. G.M. Courtin, I.B.P. Field Director and Mr. Ward Elcock, A.I.N.A. Camp Manager is particularly appreciated.

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Calculations of permafrost thickness

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The equilibrium state and its perturbations

The simplest model of the thermal condition of the earth's crust is to consider a semi-infinite homogeneous body with a constant surface temperature and a constant terrestrial heat flow from below. In this case the surface temperatures, and hence the permafrost thickness, are dependent only on the above factors and the thermal conductivity of the rocks present:

$$T_z = T_s + \frac{q}{k} \cdot z \quad (1)$$

where T_z represents the temperature at any depth z , T_s is the surface temperature, q the terrestrial heat flow and k the thermal conductivity. In a multilayer media this can be generalised by rewriting k as:

$$k = \frac{1}{z_n} \sum_{i=1}^n \frac{\Delta z_i}{k_i} \quad (2)$$

With the exception of highly contorted, complexly faulted, or folded areas the spatial variation of rock lithology, and hence thermal conductivity and equilibrium terrestrial heat flow, is small. Surface temperatures may vary considerably across the half space, however, due to such terrain factors as variations in elevation, exposure and vegetation, and presence of nearby bodies of water. If each of these features is assumed to have been present and possessed its present temperatures for an infinite time, then the change to the subsurface temperature at a point from that for an infinite half space with constant surface temperature (assumed to be collar temperature) is proportional to the solid angle subtended by the feature Ω and its temperature difference from the collar temperature V , and is given by:

$$\Delta T_z = \sum_i \frac{\Omega_i}{2\pi} \cdot \Delta_i V \quad (3)$$

Analytical results for Ω are available in polar coordinates, which is the simplest configuration to use when estimating or predicting temperatures measured in a borehole or below a point on the earth's surface. A simple polar grid is established following the method of Jeffreys (1940).

It is again reasonable to assume a constant equilibrium terrestrial heat flow and thermal conductivity for many temporal problems outside of young volcanic areas or areas with rapid sedimentation or erosion. Surface temperatures have changed considerably with time in response to fluctuations in the Pleistocene ice sheets, postglacial marine submergence and emergence, and changes in terrain features. These variations can be represented by a simple step function and becomes:

$$T = 1 - \operatorname{erf} [Z_{/2(\kappa t)}^{1/2}] \quad (4)$$

where κ is the thermal diffusivity of the medium.

Thermal parameters

Surface temperatures at the thermocouple cable sites on Truelove Lowland and adjacent upland are shown in Table 4. They vary from -16.8°C at the Limestone-Coast Site near sea level to -14.6°C at the Upland Plateau Site with an elevation of 306 m. Little difference is noted between the latter location and inland sites on the Lowland. Seawater temperatures were not measured at the Lowland but water temperatures at another location at the same latitude and where the sea remained largely ice-covered in the summer averaged -1.7°C . Temperatures in the lakes and ponds are not available either and so have been assumed to be slightly above 0°C , i.e., 1°C .

Measured average thermal conductivities range from $2.51 \text{ W m}^{-1}\text{K}^{-1}$ for the granite gneisses, 3.35 for the sandstones, and 4.5 for the dolomitic limestones. Local undisturbed equilibrium heat flow in that locality is unmeasured but following Judge (1973) probably varies between 62.7 mWm^{-2} and 83.6 and thus calculations have been carried out using both values. Lithological characteristics at each of the sites at which calculations were made are shown in Table 1.

Calculations

Assuming equilibrium conditions initially and the absence of any topographic features the distribution of permafrost would be Z_e as shown in Table 5. Permafrost thickness ranges from 592 to 700 m for a heat flow of 62.7 mWm^{-2} . The variations in thickness are due only to the lithological variations at different sites.

At each of the sites a polar grid was drawn with radii drawn at 10° intervals and 30 concentric rings around the borehole collar to a maximum radius of 2500 m. The resulting topographic information derived at each intersection of radius and circle presented a digital map of the land surface consisting of 1080 points which was used to calculate topographic corrections. Z_p in Table 5 shows the values of permafrost thickness corrected for the presence of topographic features appearing after the disappearance of glacial ice.

Finally and most important, changes of the surface with time must be taken into account. It is assumed using the data presented by Prest (1970) that at a time before 9000 years ago the glacial ice cover was complete across the area and that ice bottom temperatures were similar to present surface temperatures. This is reasonably consistent with the present measured ice

Table 4. Surface temperature, postglacial history, lithology of five rock thermocouple cable sites on Truelove Lowland, Devon Island, N.W.T.

	Surface temp. (°C)	Time ice free— years	Time of emergence— years	Lithology-depth (m)		
				Sandstone	Limestone	Granite Gneiss
Tundra-Meadow (C)	-14.8	9,000	6,500	—	—	near surface
Limestone—Coast (D)	-16.8	9,000	1,000	—	0-60	below 60
Limestone—Inland (E)	-14.9	9,000	3,000	—	0-30	below 30
Granite Gneiss (F)	-14.8	9,000	not submerged	—	—	from surface
Upland Plateau (G)	-14.6	9,000	not submerged	0-300	—	below 300

Table 5. Equilibrium permafrost thickness at five rock thermocouple cable sites on Truelove Lowland, Devon Island, N.W.T.

	Depth interval (m)	Temperature gradient °C km ⁻¹ ($q=62.7 \text{ mWm}^{-2}$)	Permafrost thickness Z_e^1 (m)	Permafrost thickness Z_p^2 (m)	Temperature gradient °C km ⁻¹ ($q=83.6 \text{ mWm}^{-2}$)	Permafrost thickness Z_e (m)	Permafrost thickness Z_p (m)
Tundra—	from						
Meadow (C)	surface	25	592	565	33	448	408
Limestone—	0-60	14			18		
Coast (D)	below 60	25	700	615	33	536	425
Limestone—	0-30	14			18		
Inland (E)	below 30	25	610	590	33	469	435
Granite	from						
Gneiss (F)	surface	25	592	588	33	448	442
Upland	0-300	19			25		
Plateau (G)	below 300	25	600	659	33	515	514

¹No consideration of topographic features.

²Correction for topographic features.

Table 6. Probable permafrost thickness at five rock thermocouple cable sites on Truelove Lowland, Devon Island, N.W.T.

<i>Site</i>	<i>Permafrost thickness (m) (q=62.7)</i>	<i>Permafrost thickness (m) (q=83.6)</i>
Tundra—Meadow (C)	525	385
Limestone—Coast (D)	250	210
Limestone—Inland (E)	470	340
Granite Gneiss (F)	588	442
Upland Plateau (G)	659	514

bottom temperatures in the Arctic (Paterson 1968, Hansen and Langway 1966). About 9000 years ago the ice was removed, but because of isostatic changes in land elevation and eustatic changes in sea-level any land at present below an elevation of 70 m is assumed to have been submerged and then to have slowly emerged according to Walcott's (1972) pattern of emergence for Jones Sound. The permafrost thickness values calculated for this effect are shown in Table 6 and these values should approximate fairly closely the thicknesses to be observed in Truelove Lowland. It should be emphasized that this is a very simplified set of circumstances to simplify the mathematical calculations. Further complications such as latent heat, zoning of lake temperatures with depth, zoning of ground surfaces according to snow cover, vegetation cover, aspect, etc., could be included as well as more complex surface history situations. The only limitations on the sophistication of the models is the available experimental data and the cost of computing.

Conclusions

Permafrost thickness at Truelove Lowland may be as thin as 210 m in coastal areas (Limestone-Coast Site) and as thick as 659 m on the adjacent upland (Upland Plateau Site). The presence of a nearby relatively warm sea has a highly modifying influence on coastal areas increasing the subsurface temperature at the Limestone-Coast Site by 6°C at a depth of 90 to 170 m. Likewise the uplift history and the time since emergence from the sea is highly significant causing a further modification of temperature at the stated depths by 2.5 to 4.8°C and causing a maximum disturbance at 400 m of 7.3°C. In contrast the permafrost thickness at the Upland Plateau Site has probably been little modified by either of these influences.

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