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Permafrost presence and distribution in the Chic-Chocs Mountains, Gaspésie, Québec
L’existence et la répartition du pergélisol dans les monts Chic-Chocs, Gaspésie, Québec
Dauerfrosfexisfenz und-Verteilung in den Chic Chocs Bergen, Gaspésie, Québec

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Résumé de l'article

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PERMAFROST EXISTENCE AND DISTRIBUTION IN THE CHIC-CHOCS MOUNTAINS, GASPÉSIE, QUÉBEC

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ABSTRACT Ground temperature studies, begun in 1977, revealed the presence of permafrost at the summit of Mont Jacques-Cartier (1270 m), in Gaspésie. Temperature profile data to a depth of 30 m in a drill hole indicates an active layer slightly thicker than 5.75 m, overlying a permafrost body extending beyond the base of the hole. Downward extrapolation of the profile, based on heat flow data and thermal conductivity *measurements* show that this permafrost body is from 45-60 m thick. That the permafrost is contemporary is indicated by the proximity of the permafrost table to the surface, by the low mean annual air temperature for the site (−3°C to −5°C), and by the lack of a thick insulative blanket of snow in the winter. A mean annual ground surface temperature of −1°C to −1.5°C is estimated for the site. The Mont Jacques-Cartier data enabled a regional lower limit of 1,000 — 1,100 m to be established for extensive permafrost in the Chic-Chocs Mountains in treeless exposed situations. A limited amount of ground temperature data from Mont Logan and Mont Albert tends to confirm the validity of this regional limit, which was then used, in association with our knowledge of the vegetation cover, to map the distribution of extensive permafrost bodies for the entire eastern Chic-Chocs Mountains. Although not observed in this study, permafrost may exist below this regional limit, in either coarse debris accumulations, or in organic terrains at high altitudes subject to sufficiently thick accumulations of peat.

RÉSUMÉ *L'existence et la répartition du pergélisol dans les monts Chic-Chocs, Gaspésie, Québec.* Les études sur la température du sol, entreprises en 1977, ont révélé la présence d'un pergélisol au sommet du mont Jacques-Cartier (1270 m). Le profil thermique, dressé à partir d'un trou de forage d'une profondeur de 30 m, démontre qu'une couche active épaisse de 5,75 m recouvre un pergélisol plus profond que le trou de forage. Basée sur les calculs de flux de chaleur et les mesures de conductivité thermique, l'extrapolation du profil thermique à une plus grande profondeur évalue l'épaisseur du pergélisol de 45 à 60 m. La contiguïté du niveau supérieur du pergélisol et de la surface, la température moyenne annuelle du site (−3 à −5°C) et l'absence d'un couvert nival épais témoignent de la contemporanéité du pergélisol. La température moyenne annuelle du sol est de −1 à −1,5°C. Les études faites sur le mont Jacques-Cartier permettent de fixer la limite inférieure du pergélisol continu à 1000-1100 m d'altitude dans les Chic-Chocs, là où il n'y a pas d'arbres. Un petit nombre de mesures de température du sol au mont Logan et au mont Albert attestent la valeur de cette limite régionale. Jointes à nos connaissances du couvert végétal, ces quelques mesures ont également servi à faire la cartographie de la répartition des masses importantes de pergélisol de la partie orientale des Chic-Chocs. Le pergélisol peut aussi exister en-dessous de cette limite régionale, dans des accumulations de débris grossiers ou dans des terrains organiques élevés où la tourbe peut facilement s'accumuler.

ZUSAMMENFASSUNG *Dauerfrostexistenz und-Verteilung in den Chic Chocs Bergen, Gaspésie, Québec.* Bodentemperaturmessungen, 1977 begonnen, haben das Vorhandensein von Dauerfrost auf dem Gipfel des Mont Jacques-Cartier (1270 m) in der Gaspésie verraten. Temperaturprofil Daten bis zu einer Tiefe von 30 m in einem Bohrloch zeigen, dass die Auftauzone wenig mehr als 5,75 m beträgt, sie liegt auf einem Dauerfrostkörper, der die Tiefe des Loches an Dicke übersteigt. Eine Tiefenextrapolation des Profils, auf Wärmeflussdaten und Wärmeleitungsmessungen begründet zeigen, dass dieser Dauerfrostkörper von 45-60 m dick ist. Das der Dauerfrost der Gegenwart angehört, lässt sich aus seiner Nähe zur Oberfläche ersehen und aus den tiefen järlichen Durchschnittstemperaturen (−3°C bis −5°C) für den Ort und durch den Mangel an einer dikken, isolierenden Schneedecke im Winter. Eine jährliche Bodendurchschnitts temperatur von −1°C bis −1,5°C wird für den Ort angenommen. Die Daten vom Mont Jacques-Cartier ermöglichten eine regionale Grenze von 1000 bis 1100 m für ausgedehnten Dauerfrost in den Chic Chocs Bergen in baumlosen, ausgesetzten Situationen zu bestimmen. Eine begrenzte Menge Bodentemperaturmessungen vom Mont Logan und Mont Albert bestätigten die Gültigkeit der Annahmen dieser regionalen Grenze, welche dann im Zusammenhang mit unserer Kenntnis der Vegetationsdecke, zur Darstellung der Verteilung von ausgedehnten Dauerfrostkörpern für die ganzen östlichen Chic Chocs Berge verwendet wurde. Wenn auch nicht in dieser Studienarbeit beobachtet, könnte Dauerfrost auch unterhalb dieser regionalen Grenze bestehen.

INTRODUCTION

Despite the relative accessibility of the Chic-Chocs Mountains and the numerous field studies of glacial geomorphology in the region over the past 100 years, there has been little discussion of the periglacial landforms and even less mention of the possible existence of permafrost or perennially frozen ground. This, despite the cold climate and treeless nature of the highest summit domes and plateau. Passing reference was made by McGERRIGLE (1952) to the probably widespread distribution of permafrost in the eastern Chic-Chocs Mountains (in the vicinity of Mont Jacques-Cartier). McGerrigle was actually able to prove the existence of frozen ground at only one location, however.

"This was close to the base of the valley wall east of the Salmon Branch of Grand Cascapedia River where the Bathurst Company Road turns to cross the branch. Here, talus from adjacent cliffs lies under a cover of moss and scrubby tree growth. The upper four feet of the talus deposit was too tightly bound by frost (August 1947) to be removed by bulldozer. The depth of the frozen ground is not known. The elevation is 975 feet" (McGERRIGLE, 1952, p. 49).

Subsequently de RÖMER (1977), while commenting on such periglacial features as stone nets and stripes near the summit of Mont Jacques-Cartier in the eastern Chic-Chocs Mountains, and on rock glacier-like lobes and semi-permanent snow banks on several of the eastern slopes, indicated that he was "reasonably sure that there are no large areas of perennially frozen ground". No positive proof for the validity of this statement is brought forward however, by de Römer, although he did state that the periglacial environment with its frost generated features could reflect cold climates without necessarily implying permafrost.

During separate visits to the summit of Mont Jacques-Cartier, the present authors were struck by the treeless nature of the plateaux, resembling very closely the tundra and rock desert surfaces of northern Canada underlain by contemporary permafrost. They were also impressed by the periglacial features in the summit regions and decided that it would be useful to undertake studies of the ground temperature regime to establish definitely the existence of permafrost. It was clear that a strictly morphostratigraphic study of the periglacial landforms themselves, while providing useful indices of a severe frost climate, could not provide unequivocal answers concerning the existence, nature or contemporaneity of permafrost. This paper presents the first significant results of these investigations in this regard and indicates the direction of future fieldwork in the area.

THE STUDY AREA

The Chic-Chocs Mountains form the backbone of the northern Gaspé Peninsula (Fig. 1). The area of high summits, exceeding 900 m, extends for 80 km from the

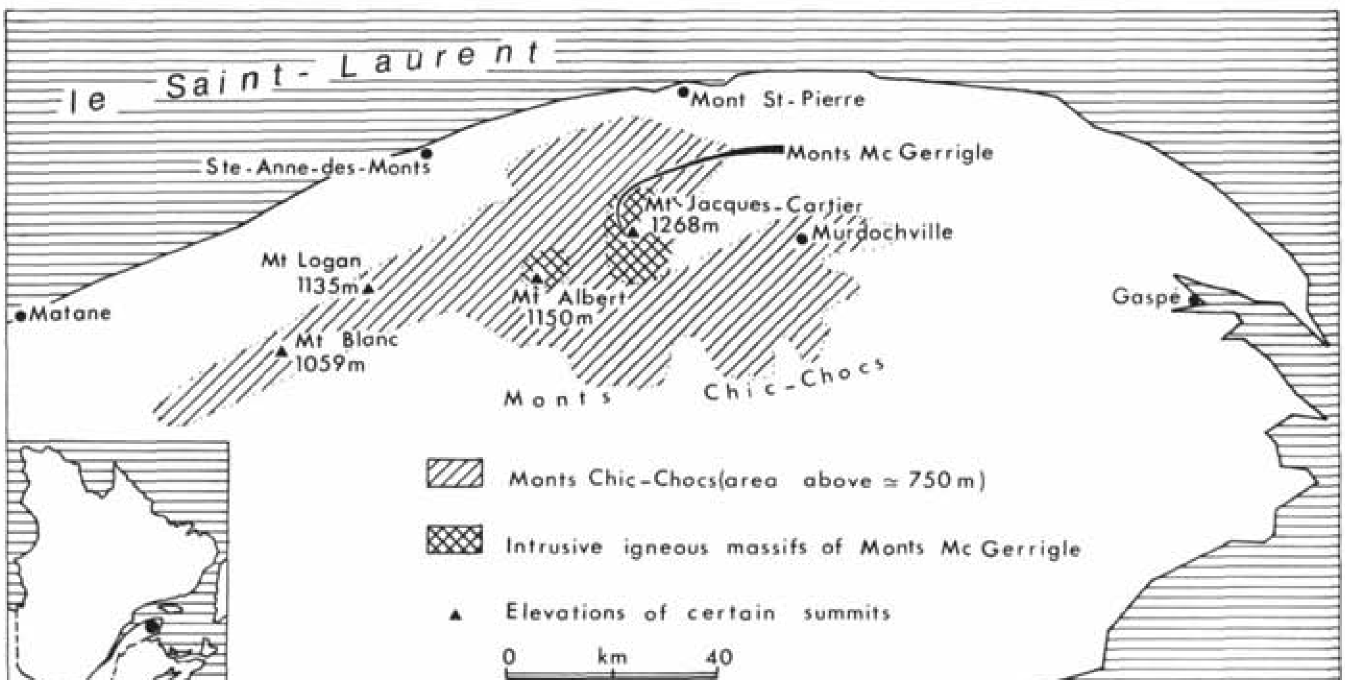

FIGURE 1. Location of the study area in the Gaspé Peninsula. *Carte de localisation de la région étudiée.*

vicinity of Matane to the eastern front of the McGerrigle massif. The mountain range follows the Appalachian structural trend from WSW to ENE and is for the most part composed of Cambrian to Devonian rocks of sedimentary and volcanic origin, intruded locally by magmatic material. The largest of these intrusions, at the eastern end of the range, is the McGerrigle pluton, composed in part of granitic, and in part of hybrid rocks — particularly syenite, monzonite and granodiorite. A second intrusive mass, of peridotite composition, forms the Mont Albert plateau. These geological contrasts, reflected in the topography, divide the range into three convenient study units: — the McGerrigle Mountains, the Mont Albert massif and the Chic-Chocs Range, proper, to the west of Mont Albert.

Topographically the McGerrigle Mountains consist, in reality, of a large interior plateau at an altitude of 900 m to 1100 m from which several summit domes rise to altitudes of *circa* 1200 m. Mont Jacques-Cartier, the highest summit in southeastern Canada, attains an elevation of 1268 m. The Mont Albert massif is a large undulating plateau ranging in elevation from 900 m to 1150 m. The Chic-Chocs Range proper, to the west, consists of a succession of dome-like summits rising to 900-1100 m from the broad interior plateau described by McGERRIGLE (1952) as the Gaspé Upland. The highest of these summits is Mont Logan situated at 1130 m. Topographic contrasts in all three study units are accentuated by glacial erosion, which has carved out large cirques and steep sided valleys on the margins of the highland massifs.

THE TREE LINE IN THE CHIC-CHOCS MOUNTAINS

Previous permafrost studies have placed considerable emphasis on the role of forest and shrub growth with respect to permafrost distribution and development, through their effects on snow cover and radiation input in summer (IVES, 1974, 1979; BROWN, 1966). Some comments are therefore in order, concerning the altitude and character of the treeline in the high mountains of Gaspésie. Studies by BOUDREAU and PAYETTE (1974) in the Mont Jacques-Cartier area have demonstrated that a climatically controlled transition from a subalpine white spruce *(Picea glauca)* dominated forest to an alpine tundra takes place through a transitional zone of krummholz. The transitional zone which extends from about 1000 m to 1100 m is characterized by very tightly packed stands of stunted white spruce *(Picea mariana)* and balsam fir *(Abies balsamea)*. As one moves from the true forest to the true tundra, individual stands become increasingly isolated and individual trees more stunted (Fig. 2). In the true alpine tundra the clumps of krummholz are very sparsely distributed, covering less than 1% of the terrain. Despite the absence of trees, the surface cover in the tundra zone is very varied, depending to a large extent on the nature of the surface sediment cover. Large surfaces consist of coarse frost shattered debris with a sparse moss and lichen cover (Fig. 3). Where a finer grained sediment mantle exists, grasses and flowering plants grow, albeit, subject to disturbance associated with frost churning in the soil (Fig. 4). In the more humid depressions characterized by late-lying snow patches a continuous turf cover has been able to develop, giving true alpine meadow characterized by various herbaceous species (Fig. 5).

The Mont Albert massif is characterized by a dramatic transition from forest cover to an alpine tundra at 1000 m near the north rim of the plateau (Fig. 6). The sharp transition without change of altitude, the relationship to a lithological boundary betwen amphibolite to the north and peridotite to the south, and the generally low elevation of the transition, compared with the Mont Jacques-Cartier area, indicates that climate alone is not responsible for the treeline. The high concentrations of olivine in the soils of the peridotite zone are toxic to tree growth, suggesting that an edaphic contrast is the main reason for the sharp transition from forest to tundra. As a result most of the plateau of Mont Albert is treeless.

In the western zone very few summits attain the climatically controlled treeline and as a rule are covered by dense, almost impenetrable, krummholz. The tundra zone is reached only on the highest and steepest summit domes such as Mont Logan.

In all three zones in the high mountains of Gaspésie, another treeless situation may occur locally, where contemporary or recently operative geomorphic processes have inhibited colonization by vegetation. Such areas are found generally on and below glacially steepened slopes characterized by cliffs and coarse debris accumulations such as talus cones and rock glaciers.

CLIMATE

Climatic records for this mountainous region are sparse and of short duration. The Meteorological Service of the Ministère des Richesses naturelles du Québec studied the regional climate of the western Chic-Chocs Mountains between 1966 and 1969 by implanting numerous semi-automatic stations at various altitudes (GAGNON, 1970). Apart from these records, there are data of varying quality from a few isolated stations throughout the mountainous region. This includes records for the summit of Mont Jacques-Cartier (1268 m) between 1943 and 1945, compiled by the Canadian Armed Forces and cited in BOUDREAU and PAYETTE (1974); for the summit of Mont Logan (1135 m), 55 km to the west, between 1963 and 1973; for the Mines de la Madeleine (850 m), 10 km to the west, between 1974

FIGURE 2. Krummholz zone on east flank of Mont Jacques-Cartier. Note the stone stream in the foreground. The turf embankment beyond the terminus of the feature is an indicator of the gravitational movement of the boulders downslope.

Zone de krummholz sur le versant est du mont Jacques-Cartier. À remarquer la coulée de pierres au premier plan. La levée de terre derrière la coulée est un indice de la force de gravitation qui entraîne les pierres vers le bas.

FIGURE 3. Frost shattered bedrock in the tundra zone on the east flank of the summit dome of Mont Jacques-Cartier.

Gélifracts dans la zone de toundra sur le versant est du sommet en dôme du mont Jacques-Cartier.

FIGURE 4. Frost sorted polygons on the Mont Jacques-Cartier summit plateau. Note the thin herbaceous cover in the polygon centres subject to periodic frost churning.

Polygones avec triage sur le plateau sommital du mont Jacques-Cartier. À remarquer au centre des polygones le mince couvert végétal soumis à la cryoturbation.

FIGURE 5. Alpine meadow at 1150 m on the eastern slope of Mont Jacques-Cartier. This zone is subject to an annual snow accumulation of 3 m.

Pré alpin à 1150 m d'altitude sur le versant est du mont Jacques-Cartier. Dans cette partie, les précipitations neigeuses peuvent atteindre 3 m.

and 1977; and for Murdochville (550 m), 40 km to the east, between 1952 and 1976[1].

Among the most significant elements from the point of view of the ground temperature regime, may be cited temperature and precipitation parameters, particularly mean annual air temperature and the build-up of snow cover. The mean annual air temperature for Mont Jacques-Cartier for 1943-1945 was −3°C; that of Mont Logan for the period 1963-1973 was −3.7°C. If one takes into account the mean adiabatic lapse rate of 0.6°C/100 m, calculated very accurately for the region by GAGNON (1970), it is possible to extrapolate the Mont Logan data to the summit of Mont Jacques-Cartier. A mean annual air temperature of −4.5°C is thereby obtained for the latter summit for the decade 1963-1973. It can be concluded that the mean annual air temperatures of the Gaspesian summits in the tundra zone are within the approximate range of −3°C to −5°C.

Gagnon's maps (GAGNON, 1970) indicate a total annual precipitation of more than 1,600 mm for the sum-

1. The data from Mont Logan, Mines de la Madeleine and Murdochville were available from records of the Québec meteorological service.

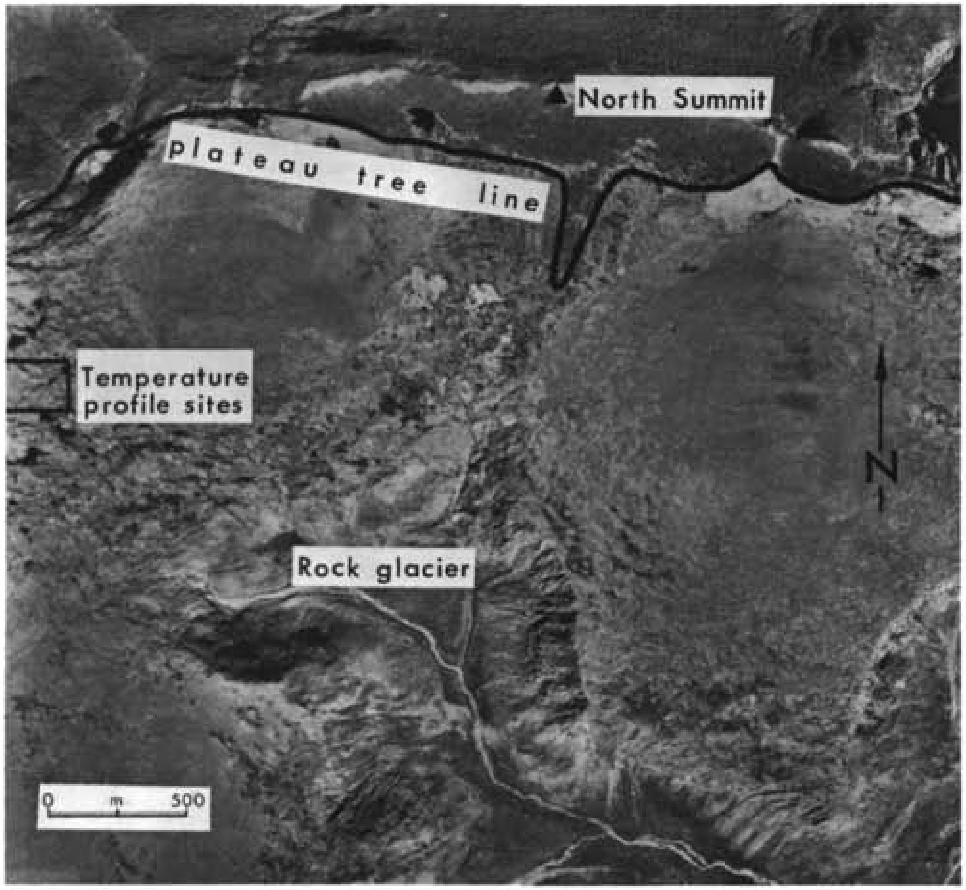

FIGURE 6. An aerial view of the northern side of the mont Albert plateau showing the sharp transition from krummholz to tundra along the lithological boundary between amphibolite and peridotite bedrock.

Vue aérienne de la partie nord du plateau du mont Albert qui illustre le brusque changement entre les zones de toundra et de krummholz le long de la limite lithologique entre l'amphibolite et la péridotite.

mits above 1,100 and an annual snowfall in excess of 6,250 mm. The snow cover lasts for 260-290 days, appearing between the 15th and 30th of September and disappearing between the 15th and 30th of June. The plateau surfaces above treeline are windswept in the winter and snow accumulation is relatively minimal. Snow surveys were carried out on the summit dome of Mont Jacques-Cartier by the senior author in the spring of 1978 and 1979, successively very high and very low snow accumulation years in the region. Average snow depths in these two years were respectively 66 cm and 38 cm. Individual values ranged from a few centimetres to 120 cm for 64 sample points in the two years, variations within each year's sample population being mainly due to topographic irregularities and to contrasts in aspect. Despite these variations, the difference between the snow accumulation in the two years is statistically significant at a confidence level of 99.9%. This comparison excludes the moderate to steep slope on the eastern, leeward side of the summit ridge where snow annually accumulates to a depth of several metres, and may occasionally persist through the summer season into the following winter, as was the case in 1977 (Fig. 7). Below treeline the krummholz and subalpine forest

FIGURE 7. A late spring snow patch on the east slope of Mont Jacques Cartier 70 m below the summit. This patch survived the 1977 summer but disappeared in 1976, 1978 and 1979.

Plaque de neige persistante sur le versant est du mont Jacques-Cartier. Cette plaque a pu résister durant l'été 1977, mais a disparu pendant les étés de 1976, 1978 et 1979.

are characterized by a thicker snow cover than was observed for the summit of Mont Jacques-Cartier in the tundra zone. An eleven point transect carried out over a distance of 300 m in the Lac à René area, 2 km north of the summit, at an elevation of about 1,125 m, in the spring of 1979, gave snow depths ranging from 95 cm up to 235 cm, with a mean depth of 150 cm.

FIELD PROGRAMME

Initial measurements of the ground temperature regime were made by Gray in September 1976 on the summit plateaux of Mont Albert and Mont Jacques-Cartier. Temperature profiles were obtained to depths of 1 m in fine grained sediments using rigid temperature probes designed at the Defence Research Establishment, Ottawa by PICHETTE and PILON (1978). Flexible multi-thermistor cables were used to obtain profiles of 4 m from old shallow drill holes in bedrock. The results of the pilot measurements were inconclusive because of the short distances penetrated, but the strong negative temperature gradients beyond the zone of diurnal fluctuations, measured towards the end of the summer thaw period, suggested convincingly that permafrost might be located at several sites.

This promising beginning led to the concerted planning of a drilling programme for Mont Jacques-Cartier, and in September 1977, a 22 mm diameter hole was drilled through 3 m of weathered bedrock, and a further 27 m into the underlying competent bedrock at a site close to the summit cabin. A 30 m multi-thermistor cable was installed in the freshly completed waterfilled hole, and readings taken at the time of the installation and throughout the summer of 1978 and 1979.

A second 30 m cable was installed in a 15 cm diameter well near the summit of Mont Logan, in the same month, and readings taken at intervals since the installation. In addition sporadic temperature readings were obtained with flexible cables and rigid probes in old drill holes on Mont Notre-Dame, Mont Jacques-Cartier and Mont Albert.

Thermal conductivity and heat production analyses were carried out on core samples by A. S. Judge, Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa.

In an effort to relate the thermal data to terrain factors and to determine the probable permafrost distribution, snow surveys were carried out in April 1978 and in January and April 1979.

Finally, long term air temperature records were examined for stations within a 250 km radius of the field area to determine whether or not any long term trends of significance to permafrost fluctuations could be established.

DERIVATION OF SIGNIFICANT GEOTHERMAL PARAMETERS FROM THE MONT JACQUES CARTIER DATA

Temperature profiles have been obtained on twelve occasions over the two year interval since cable installation at the summit of Mont Jacques-Cartier. To date, all readings have been obtained for spring, summer and fall conditions, with the exception of one late winter reading, obtained in mid-April 1979. Severe winter conditions, with the frequent passage of storm systems bringing blowing snow and poor visibility have so far hampered access to the summit in midwinter. Nevertheless, analysis of the large body of data available will permit several valid conclusions concerning the thermal regime in the ground.

Figure 8 depicts four of these temperature profiles, and clearly demonstrates the presence of a permafrost body at the summit of Mont Jacques-Cartier. The drilling process appears to have caused minimal disturbance, and a rapid return to thermal stability is indicated by the convergence of the lower parts of the profiles. The wide variations in the top few metres of the profiles (with the exception of two profiles logged immediately after the cessation of the drilling operation), are related to seasonal temperature fluctuations at the surface and not to drilling disturbance.

Analysis of all the available data permits definition of several important thermal parameters, which can then be used to derive conclusions on the thickness of the permafrost and the associated active layer, as well as on its spatial extent and contemporaneity. These parameters are: — the depth of zero annual amplitude, the geothermal gradient, and the mean annual ground surface temperature.

1. DEPTH OF ZERO ANNUAL AMPLITUDE

This is the depth beyond which seasonal temperature fluctuations are virtually non-existent. It will be useful if this level can be detected in the profiles, in order that summer data from greater depths can be employed as reasonably representative of the mean annual temperature regime. Figure 9 plots temperatures at various depths in the profile from August 10th to October 21st 1978. This data and subsequently available logs from the spring and summer of 1979 reveal seasonal fluctuations, in the order of only 0.1°C, beyond the 11 m depth. The limited precision of the temperature bridges used, even when frequently calibrated (±0.1°C), and the lack of winter data, make accurate derivation of the level of zero annual amplitude difficult, but 11 m represents a reasonable approximation.

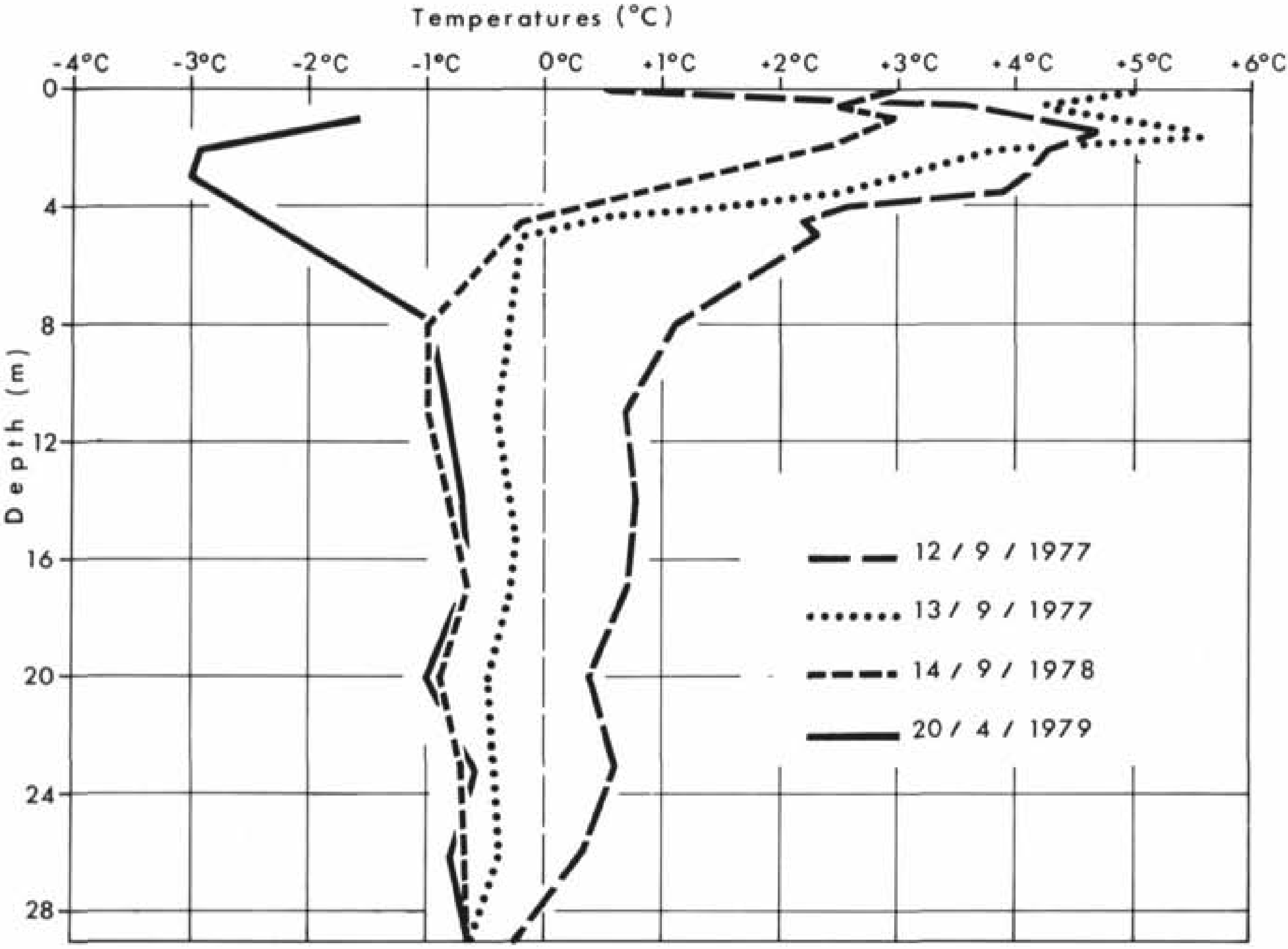

FIGURE 8. Temperature profiles in the 30 m drill-hole at the summit of Mont Jacques Cartier.

Profils thermiques obtenus à partir du trou de 30 m de profondeur foré au sommet du mont Jacques-Cartier.

2. GEOTHERMAL GRADIENT

The geothermal gradient may be calculated directly from the temperature data, or it may be derived indirectly from a number of geothermal parameters. The direct approach simply graphs observed ground temperatures against depths (Fig. 10) and reveals a geothermal gradient of 22°C/km (or 0.022 km^{-1}). In the indirect approach, the geothermal gradient must be derived from available estimates of the geothermal flux in the Appalachian structural province, and from analysis of the thermal conductivity of the local bedrock.

The geothermal flux is the heat flow from the mantle through the crustal rocks to the surface, supplemented by heat production due to radioactive decay of elements within the crustal rocks. Broad limits of 48-64 mWm^{-2} for the geothermal flux for the Appalachian structural province can be estimated from data compiled by HYNDMAN *et al.* (1979, Fig. 8), given measured heat production values of 1.97 μWm^{-3} for a core sample from the Mont Jacques-Cartier drill hole. Thermal conduc tivity values for core samples from the Mont Jacques-Cartier drill hole are shown in Table I. Taking the lower three series of samples as representative of the crystalline bedrock, a range of values of 2.47-2.95 $Wm^{-1}K^{-1}$, with a mean value of 2.65 $Wm^{-1}K^{-1}$, is obtained.

The geothermal gradient is then calculated by dividing the estimated geothermal flux (in mWm^{-2}) by the measured thermal conductivity of core samples (in $Wm^{-1}K^{-1}$) (JUDGE, 1973).

With the given ranges of values for thermal conductivity and geothermal flux, mean, maximum and minimum values for geothermal gradient are respectively 21°C/km, 26°C/km and 16°C/km.

These indirectly derived geothermal gradients are then linearly plotted on Figure 10 and show a general correspondence with the directly observed temperature

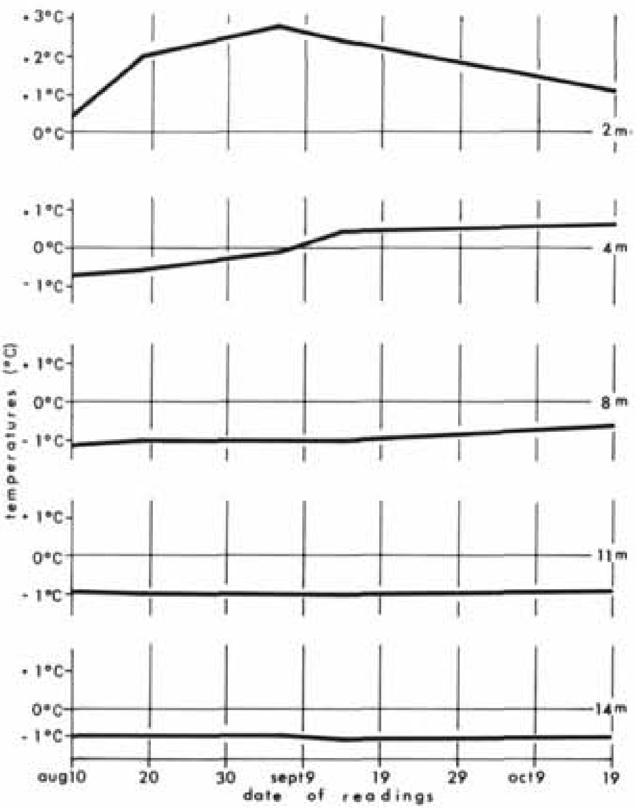

FIGURE 9. Temperature fluctuations at various depths in the Mont Jacques-Cartier drill-hole throughout the summer of 1978.

Les variations de température à différentes profondeurs du trou de forage, durant l'été 1978.

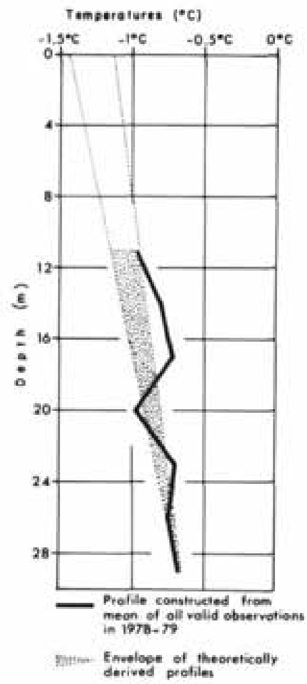

FIGURE 10. Geothermal gradients for the Mont Jacques-Cartier drill-hole between 11 m and 29 m.

Gradients géothermiques mesurés entre 11 m et 29 m dans le trou de forage du mont Jacques-Cartier.

gradient. The small scale fluctuations evident in the latter are the result of small cumulative shifts in ground surface temperatures in a positive or negative sense over time spans exceeding one year, and are, perhaps, also the result of non-recorded variations in thermal conductivity.

3. MEAN ANNUAL GROUND SURFACE TEMPERATURE

A mean annual ground surface temperature of 0°C, measured over several years, is critical for the existence of contemporary permafrost. It was felt that, if this parameter could be estimated for the summit of Mont Jacques-Cartier, reasonable projections to lower altitudes, using statistically determined lapse rates, could then form a basis for establishing lower altitudinal limits of permafrost for similar terrain conditions.

The very short term record of surface temperatures at the cable site, coupled with the lack of winter data do not permit direct calculation of the mean annual ground surface temperature. Furthermore, the latter cannot be derived indirectly from air temperature data due to the absence of information on microclimatic factors such as albedo, snow cover and evapotranspirative effects on heat exchange.

The only recourse, therefore, is to the subsurface temperature data. The previously determined mean, maximum and minimum geothermal gradients for the lower section of the drill hole may reasonably be extrapolated upwards to the surface through the zone subject to seasonal temperature fluctuations. If no correction to these gradients is made to allow for a change in thermal conductivity associated with the 3 m of frost shattered debris at the surface, mean maximum and minimum values of −1.2°C, −1.4°C and −1.2°C are obtained (Fig. 10). If allowance is made for a reduction in thermal conductivity by a very liberal estimate of 50% for this topmost zone due to an entrapped mixture of air, fine debris, and moisture, the values suffer an insignificant reduction of about 0.1°C. Thus, within reasonable error limits, a mean annual ground surface temperature of −1°C to −1.5°C can be assessed for the Mont Jacques-Cartier site. It is interesting to note that this range of values is 2°C to 3.5°C higher than the mean annual air temperatures for the site derived earlier in this paper.

PERMAFROST AND ACTIVE LAYER THICKNESS ON THE SUMMIT PLATEAU OF MONT JACQUES-CARTIER

The average level to which the frost table descends at the end of the summer thaw period simultaneously

TABLE I

Density porosity and thermal conductivity values for core samples from the drill hole at the summit of Mont Jacques-Cartier (analyses by courtesy of A. Judge, Earth Physics Branch, Ottawa).

Depth (m)	Sample No.	Density Wet gm cm-3	Density Dry gm cm-3	Porosity %	Thermal Conductivity $Wm^{-1}K^{-1}$
7.5	1	2.72	2.72	0.1	1.79
		2.72	2.73	0.7	1.92
	2	2.76	2.76	0.3	1.92
		2.76	2.77	0.7	1.98
15	1	2.63	2.63	0.2	2.73
		2.63	2.63	0.7	2.79
	2	2.65	2.65	0.3	2.50
		2.65	2.65	0.5	2.56
22.5	1	2.64	2.64	0.3	2.47
		2.64	2.64	0.8	2.59
	2	2.50	2.50	0.2	2.74
		2.50	2.50	0.7	2.95
30	1	2.60	2.61	0.9	2.52
	2	2.65	2.65	0.2	2.61
		2.65	2.65	0.7	2.72

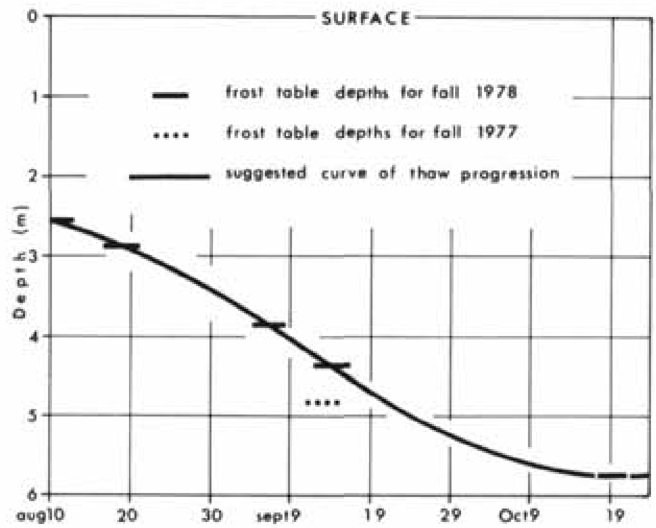

FIGURE 11. Active layer progression during the fall of 1978 at the summit of Mont Jacques-Cartier.

Évolution de la couche active au sommet du mont Jacques-Cartier au cours de l'automne 1978.

defines the upper surface of the permafrost body and the thickness of the active layer. Temperatures below this level remain below freezing all year round until the base of the permafrost is reached, at which point the ground temperature profile recrosses the 0°C isotherm. In order to define the thickness of the permafrost body it is therefore important to calculate the active layer thickness and the depth to the permafrost base.

1. ACTIVE LAYER THICKNESS

Temperature observations taken through the fall of 1978 indicate downward progression of the thaw zone to a depth of at least 5.75 m in late October (Fig. 11). The surprising element here is the relatively rapid late fall progression of the thaw front, despite the small positive, and sometimes negative, heat flux into the ground after early September. The explanation is probably to be found in the passage of the thaw front in the fall, from frost shattered bedrock, with a fine sediment fraction and a moderate ice content, into competent bedrock, with a very low moisture content (as indicated by the porosity values recorded in Table I). The phase change from ice to water then becomes of insignificant importance in absorbing latent heat, and hence in retarding penetration of the thaw front. No fall readings were available after late October and so 5.75 m represents only a reasonable minimum value for the active layer thickness at the site.

2. DEPTH TO THE PERMAFROST BASE

When the indirectly derived geothermal gradients are linearly extrapolated downwards from the observed temperature at the base of the hole, one year after installation of the cable, the 0°C isotherm is encountered within a depth range of 52-65 m (Fig. 12).

Although subject to some potential criticism, the short range of the extrapolation suggests that these values are reasonable for the permafrost base, although some error may be introduced by temperature disturbance due to climatic change or by variations in thermal conductivity at depth.

Considering the effects of climatic change first, it proved fruitful to examine the data on air temperatures and snowfall from the nearby climatic station at Murdochville[2] (Fig. 13). This data shows no evidence of a cumulative shift in air temperatures or snowfall values and, by implication, in ground surface temperatures over the last 25 years. This is certainly valid evidence in support of the suggested linearity of the temperature gradients for the upper few tens of metres at the Mont Jacques Cartier site. Previously occurring climatic fluctuations, discussed later in this paper, may have given

2. This proved to be the most suitable climatic station for the purposes of comparison because of its good records, proximity to Mont Jacques-Cartier and location in the Gaspé Highlands at a similar distance from the coast.

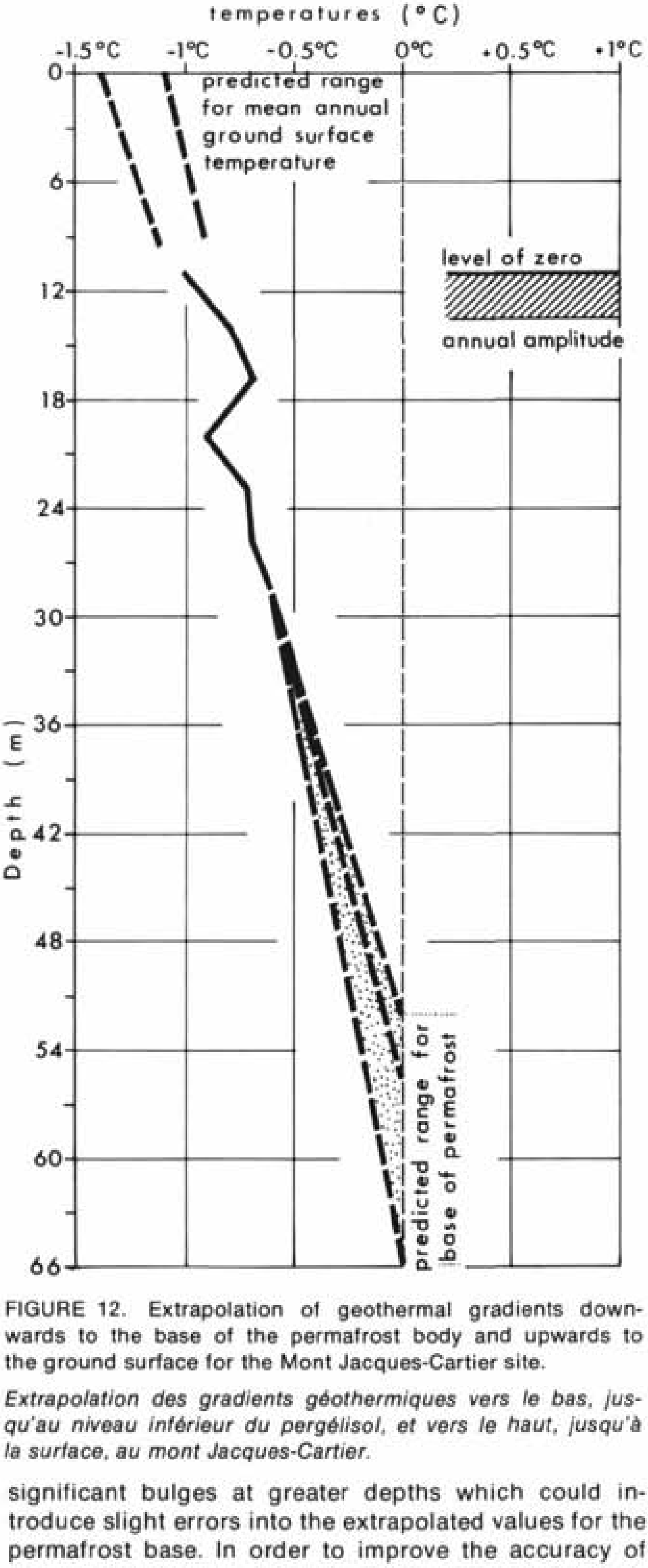

FIGURE 12. Extrapolation of geothermal gradients downwards to the base of the permafrost body and upwards to the ground surface for the Mont Jacques-Cartier site.

Extrapolation des gradients géothermiques vers le bas, jusqu'au niveau inférieur du pergélisol, et vers le haut, jusqu'à la surface, au mont Jacques-Cartier.

significant bulges at greater depths which could introduce slight errors into the extrapolated values for the permafrost base. In order to improve the accuracy of these values it may be possible in the near future to use mathematical models of thermal diffusion to calculate the downward progress of the thermal disturbance initiated by these climatic fluctuations.

The error potential in using a limited number of thermal conductivity values from the upper 30 m to derive thermal gradients for only slightly greater depths is probably insignificant. The summit of Mont Jacques Cartier is not on the margin of the batholith and the limited variations in rock density and crystalline composition anticipated, do not likely result in large departures from these thermal conductivity values and hence in large departures from a linear geothermal gradient.

3. THICKNESS OF THE PERMAFROST BODY ON MONT JACQUES-CARTIER

This parameter is then readily determined by subtracting the depth of the active layer from the total depth to the permafrost base. Permafrost thickness on Mont Jacques-Cartier is thus calculated to be in the range of 45-60 m.

SPATIAL EXTENT OF THE MONT JACQUES-CARTIER PERMAFROST BODY

If we use the adiabatic lapse rate of 0.6°C/100 m in association with the mean annual surface temperature at the summit of Mont Jacques-Cartier to assess the lower limits of the permafrost body on this mountain, a hypothetical altitude of 1000-1100 m. above sea level is obtained. However, this assumes that terrain factors (degree of exposure, surface materials, vegetation cover and snow cover) remain constant. The Mont Jacques-Cartier summit plateau is not very extensive and exhibits considerable topographic contrast around the margins. This fact, coupled with the effect of the altitudinal transition from tundra through krummholz to forest vegetation (Fig. 14), calls for a more sophisticated delineation of the permafrost body.

The surface conditions of the plateau are maintained with considerable uniformity in a long narrow zone extending from NNE to SSW but elevations drop off rapidly towards the ESE, where an important lee situation, favourable to a very deep winter snow cover, exists just below the summit dome.

This zone of heavy snow accumulation favours highei ground temperatures in winter. The aspect and moderate inclination of the slope also favour relatively high ground temperatures in summer (except where the snowbanks are deepest and persist until mid or late summer). Thus, permafrost is probably absent from this zone, despite its high altitude. The total absence of ground ice right to the base of a 4 m deep pit, excavated for soil studies by Payette beneath an alpine meadow on this slope late in August 1978, lends support to this conclusion.

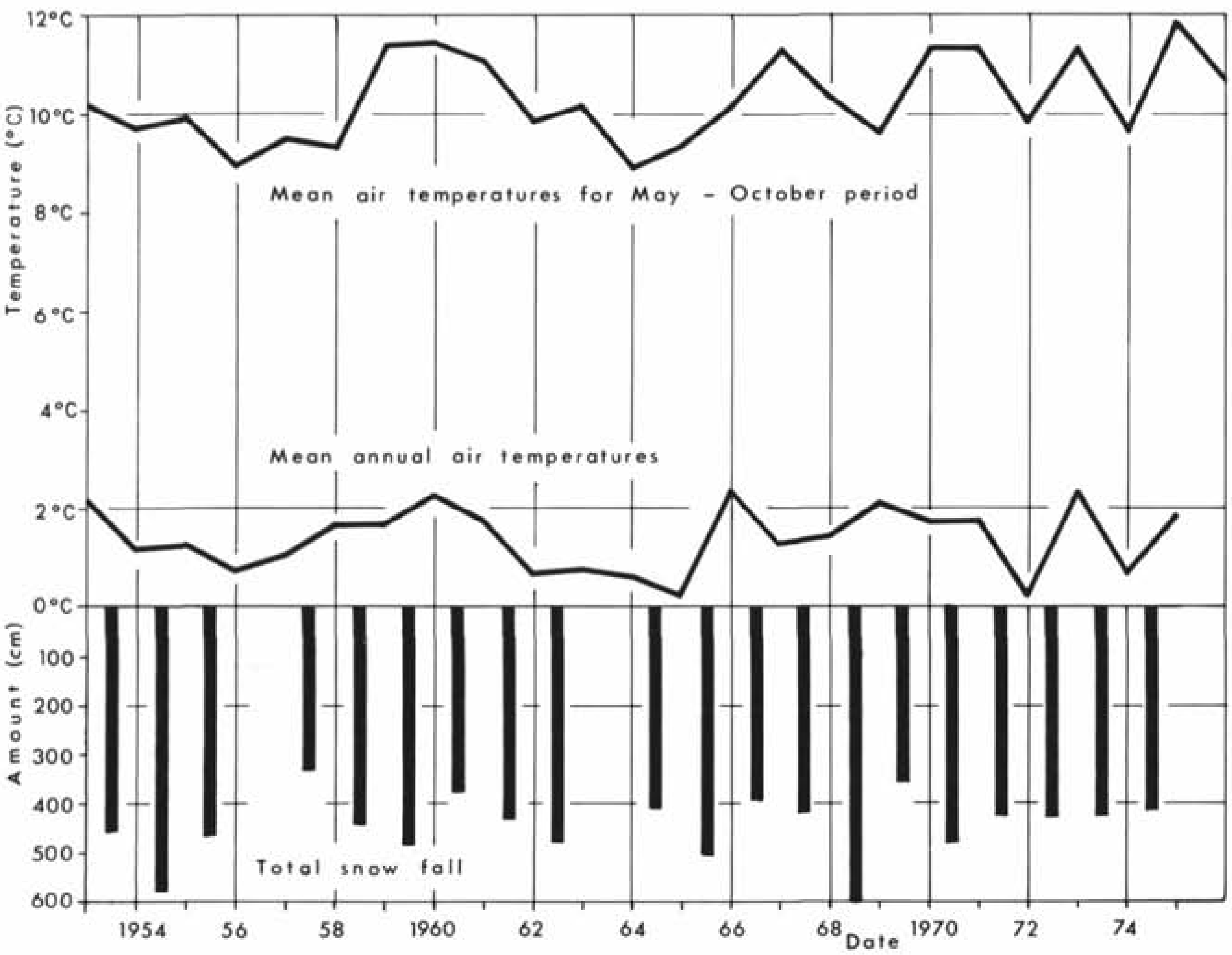

FIGURE 13. Temperature and snow fall data for Murdochville over the period 1953-1975. This station is situated at 550 m elevation about 30 km east of Mont Jacques-Cartier.

Données de température et de précipitations neigeuses à Murdochville, de 1953 à 1975. La station météorologique est située à 30 km à l'est du mont Jacques-Cartier, à 550 m d'altitude.

Below this zone, conditions become even more unfavourable for permafrost because of the dense krummholz vegetation which traps the snow, giving accumulations in excess of 2 m, even in low snowfall winters such as 1978-1979.

The boundary on the northern, northwestern and southwestern sides of the summit plateau is probably related much more to the rapid increase in thickness of the snow cover associated with the descent below treeline than to any other single factor. Previously cited snow depths in the Lac à René area for April 1979 at a mean altitude of 1150 m in the lower krummholz and subalpine forest zones are about 4 times those of the summit plateau. Figures 15 and 16 graphically illustrate this contrast. In addition, one winter's data tend to suggest that the snow pack is essentially complete towards the end of January, thus providing maximum insulation during the coldest period of the winter.

On these slopes the probable permafrost boundary has therefore been traced along a line where the krummholz becomes relatively continuous. It is possible however that tiny permafrost islands also exist at lower altitudes on rocky slopes with a northern exposure and with poor vegetative cover due to the low radiative input in the summer and the lack of insulation afforded by a low snow cover in the winter.

Figure 17 is a tentative cross section of the permafrost body from ENE to WSW across the summit of Mont Jacques-Cartier. The relatively thin nature of the permafrost body suggests that the transition from permafrost to no permafrost at the lateral margins should be relatively rapid with minimum lateral heat transfer.

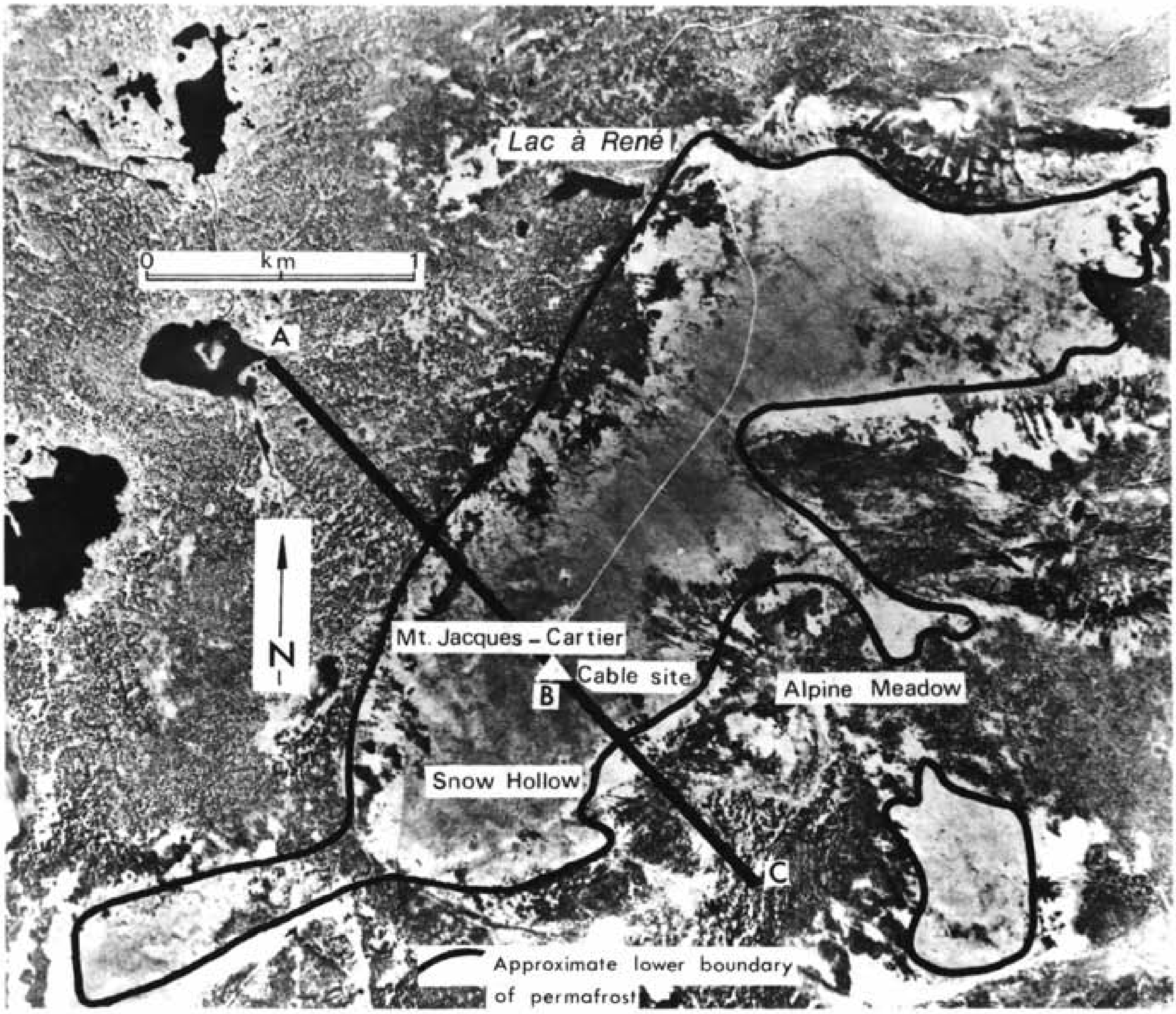

FIGURE 14. Plan view of the summit plateau of Mont Jacques-Cartier.

Vue en plan du plateau sommital du mont Jacques-Cartier.

CONTEMPORANEITY OF THE PERMAFROST ON MONT JACQUES-CARTIER

The available evidence indicates clearly that the permafrost is contemporary and not relict in nature. In the first place the permafrost table is only 5 to 6 m below the surface. If the permafrost body had developed only in response to a colder phase than that prevailing at the present day, (such as during the historically recent "little ice age"), thermal diffusivity of the bedrock would have been sufficiently great for a rapid descent of the permafrost table, far beyond 5-6 m, within only a few decades of the onset of a warming trend.

In the second place, the mean annual surface temperature of −1°C to −1.5°C deduced above for the site, and the mean annual air temperature of −3°C to −5°C, clearly support the conclusion that the present day climate favours contemporary permafrost on the summit plateau.

Of course, this does not deny the fact that a cooler climate in the "little ice age" would have resulted in a thicker, colder permafrost body. In this case the altitudinal limit for permafrost would also have been lower, but only where suitably exposed treeless terrain exists.

FIGURE 15. Snow cover in the krummholz zone near Lac à René on north flank of Mont Jacques-Cartier in April 1979.

Couvert nival dans la zone de krummholz en avril 1979, près du lac à René, sur le versant nord du mont Jacques-Cartier.

FIGURE 16. Snow cover on the summit plateau of Mont Jacques-Cartier in April 1979.

Couvert nival au sommet du mont Jacques-Cartier, en avril 1979.

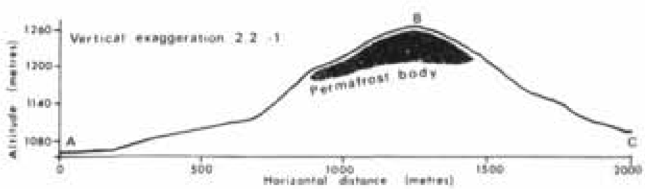

FIGURE 17. Cross section of the permafrost body beneath the summit of Mont Jacques-Cartier.

Coupe de la masse de pergélisol au sommet du mont Jacques-Cartier.

A summary analysis of long term mean monthly temperatures for four stations within 250 km of the Chic-Chocs summits does reveal considerable climatic variation within the last century (Fig. 18). A major warming trend from the late 19th century up to about 1910 was followed by a marked dip in temperatures until about 1930 and then by another warming trend up to 1950. The latter is in the approximate range of 1.5°C to 2°C, and will very likely be shown up in the subsurface temperature profiles, if and when data for deeper holes can be acquired for the region.

MAPPING PERMAFROST DISTRIBUTION IN THE CHIC-CHOCS MOUNTAINS

The previously described data from Mont Jacques-Cartier, when coupled with more summary data obtained from an old well hole on Mont Logan and from short exploration drill holes on Mont Albert enable predictions to be made of permafrost distribution in the Chic-Chocs Mountains.

The Mont Logan site is at an elevation of 1100 m on a small rocky bench with a north facing slope about 30 m below the summit. Figure 19 shows the temperature profiles obtained one week and one year after installation of a temperature cable in oil filled tubing in the well hole. The lowest temperatures at the 32 m level appear to indicate the absence of permafrost at the site. Certain facts suggest, however, that the ground temperatures may be artificially high. In the first place the site is within 3 m of the corner of a heated building used by Radio-Canada as a television relay station. This favours a lateral flow of heat throughout the year towards the cable site. Using appropriate nomograms for thermal disturbance due to heated buildings (JUMIKIS, 1977) it is possible to deduce that ground temperatures at a depth of 20-30 m have been artificially raised by about 0.5°C to 1°C. In the second place, snow cleared from the drive-way in front of the building is piled above the cable site to a height of

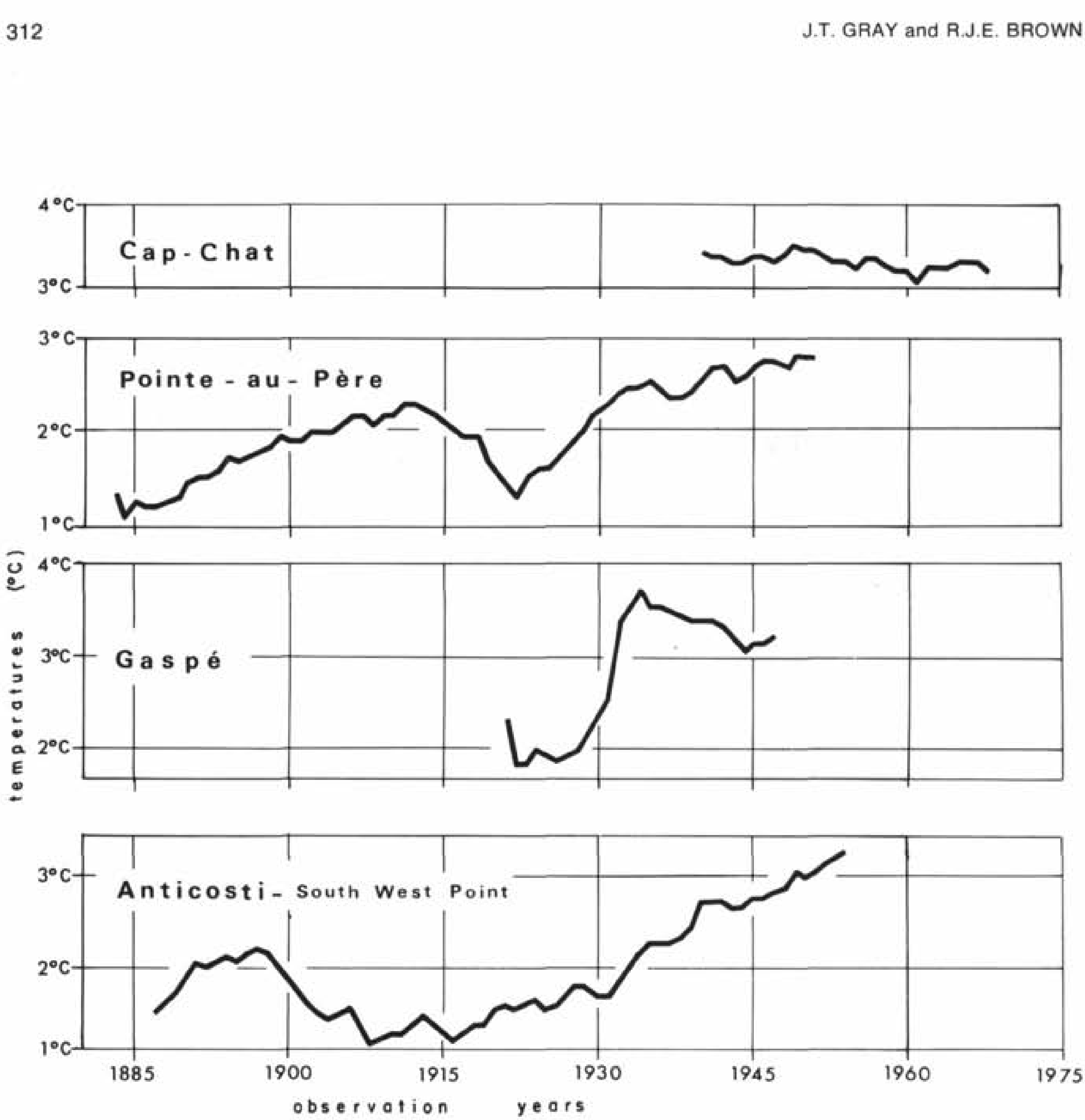

FIGURE 18. Climatic data from 4 stations within 250 km of the study region. Data is plotted on the basis of 10 year running means.

Données climatiques de quatre stations météorologiques situées à l'intérieur d'une zone de 250 km autour de la région étudié. La représentation graphique des données résulte de moyennes mobiles de 10 ans.

several metres each winter and this undoubtedly insulates the site from winter heat loss, thereby raising its temperature.

It is thus possible that, prior to recent disturbance by man, the thermal regime of the site may have very closely approached permafrost conditions. Indeed, when the well was drilled in the 1960-1970 period, a pump was lost through being encased in ice at the bottom of the hole, leading to its abandonment. Coupled with the fact that the summit of Mont Logan protrudes about 30 m above the krummholz cover, is extremely windswept and characterized by a mean annual temperature of −3.7°C over the decade 1963-1973, these arguments suggest that the summit of Mont Logan lies slightly above the regional permafrost limit. This conclusion accords well with the limit of 1000-1100 m deduced previously from the Mont Jacques-Cartier data for exposed treeless surfaces. It is very likely that permafrost will eventually be restored at the cable site if and when the Radio-Canada building is abandoned.

The Mont Albert data was obtained in September 1979 from four shallow drill holes at an elevation of 1005 — 1020 m in the col between the south and north

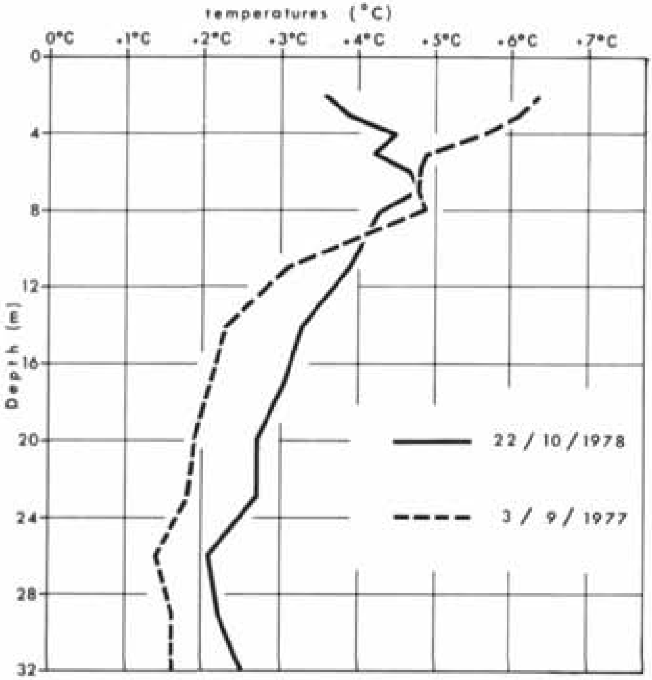

FIGURE 19. Temperature profiles in a 32 m deep disused well near the summit of Mont Logan.

Profils thermiques obtenus à partir d'un puits désaffecté près du sommet du mont Logan.

summits and is shown in Figure 20. The micro-topography at the sites varied considerably; profiles 1 and 2 were obtained in drill holes in an exposed rock knob subject to very low winter snow accumulation; profiles 3 and 4 from depressions filled with snow in the winter. This explains why profiles 1 and 2 are from 2°C to 4°C cooler than profiles 3 and 4 at a depth of 5 m.

The form of the profiles, particularly profile 1, indicates that permafrost is absent at the site. A minimum value of 1.0°C is attained at a depth of 8.7 m for profile 1, beneath which, temperatures increase to the base of the hole. Permafrost conditions probably prevail over large expanses at only slightly higher altitudes on the treeless windswept plateau.

Combining information on the treeline gleaned from a series of false colour air photographs, with this newly established lower permafrost limit of 1000-1100 m for exposed surfaces, it has proved possible to map permafrost distribution for the eastern Chic-Chocs Mountains (Fig. 21). The western Chic-Chocs Mountains are not included in this map since only a few summits, notably Mont Logan, protrude above either the treeline or the regionally established limit. Permafrost in this western zone is therefore restricted to very few, small bodies, impossible to represent on a map.

In Figure 21 the permafrost boundary usually corresponds to the climatically controlled treeline and not

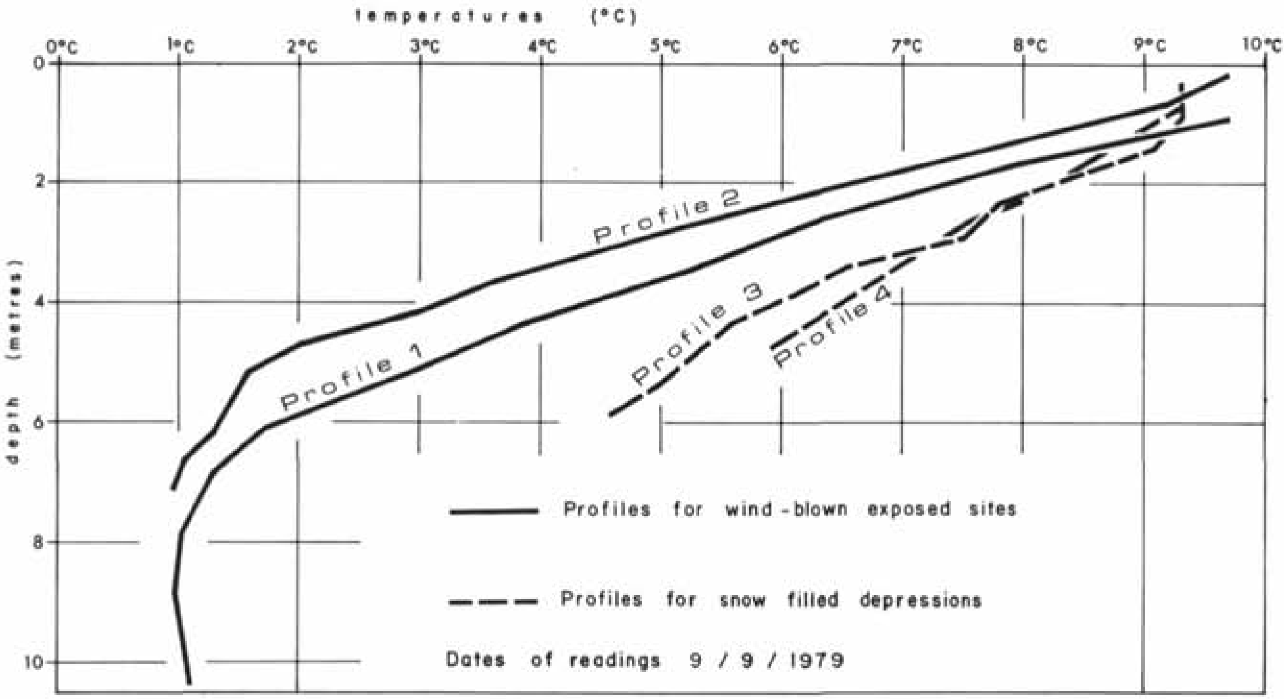

FIGURE 20. Temperature profiles for four old drill-holes at 1000 m in the col between the south and north summits of Mont Albert.

Profils thermiques obtenus à partir de quatre vieux trous de forage situés à 1000 m d'altitude dans le col entre les sommets nord et sud du mont Albert.

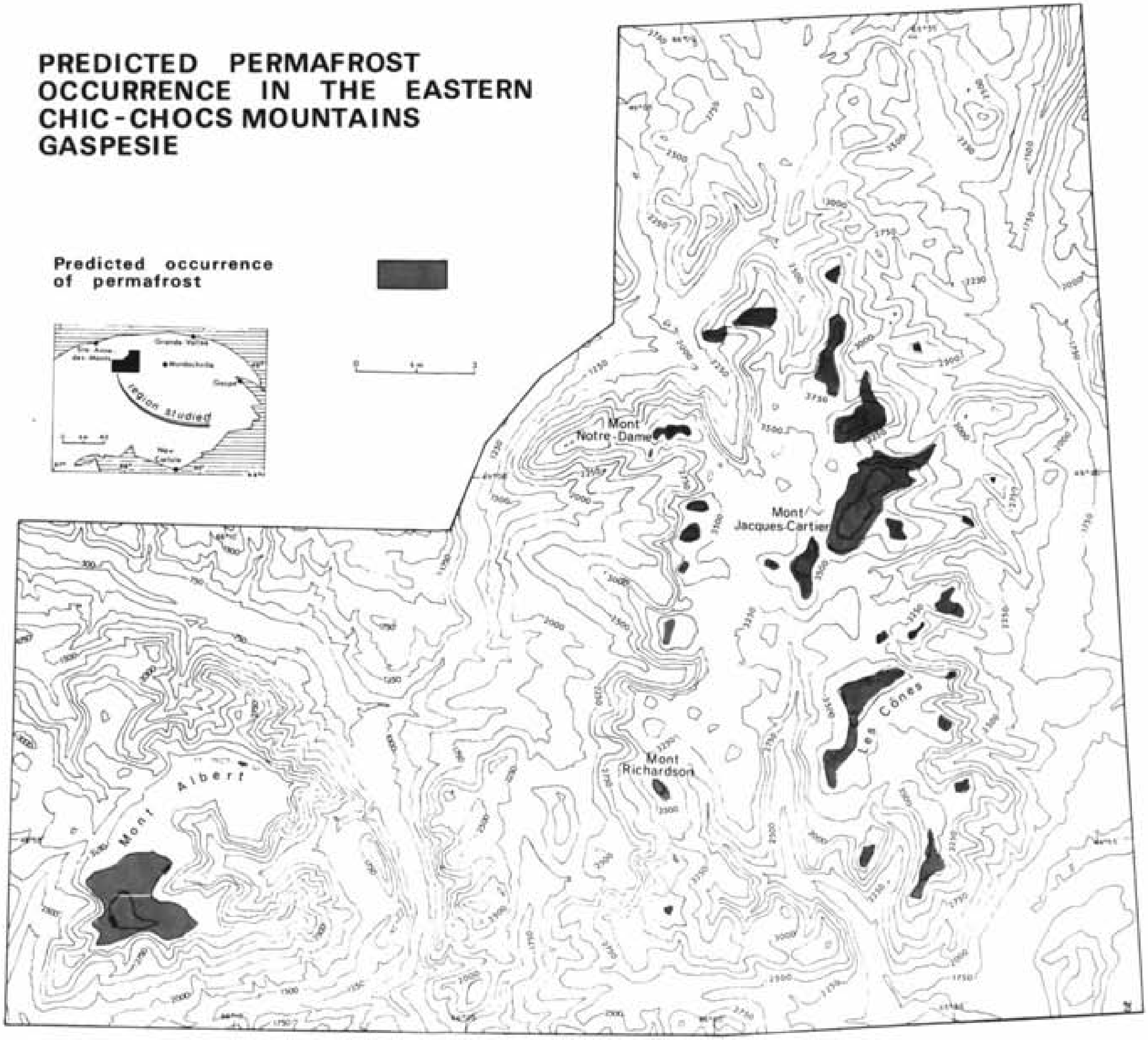

FIGURE 21. Probable distribution of extensive permafrost bodies in the eastern Chic-Chocs Mountains, Gaspésie.

Répartition probable des îlots importants de pergélisol dans la partie orientale des Chic-Chocs, Gaspésie.

to the somewhat lower limit calculated for exposed surfaces. The entrapment of snow by the krummholz and forest cover reduces heat loss in the winter and thereby raises the mean annual temperature above that which would be predicted for a treeless surface at that elevation. An exception, of course, is the Mont Albert plateau where as indicated above, the permafrost boundary is within the tundra zone, at 1000-1100 m.

It must not be assumed from Figure 21 that permafrost is universally present above this limit, nor that it is totally absent below the limit. Local variations in topography and aspect influence the distribution of permafrost bodies on individual summits due to variations in solar radiation received and/or contrasts in snow accumulation. Man's disturbance of the thermal regime, leading to an anomalously positive regime, has already been indicated for a site at Mont Logan. The case of Mont Notre-Dame in the McGerrigle Mountains could also be mentioned. This summit is at an elevation of 1170 m, is above the local treeline, and should be characterized by permafrost. Limited evidence to date indicates that this may not be the case. The most probable explanation is that the thermal regime has been profoundly altered by the mining activities of the Mines de la Madeleine. Mont Notre-Dame has been riddled with mining adits and air ducts and is no longer to be considered as a natural situation. Given all of the above considerations, and taking into account the fact that the permafrost bodies are relatively thin, with a thermal regime close to 0°C, they are bound to be laterally very discontinuous in nature.

Below the regional limit, permafrost islands probably occur in several situations where special terrain factors operate. Such bodies are likely to be only a few metres thick, however, and a few square metres up to a few tens of square metres in extent. Two examples come to mind.

On the steep north facing slopes of glacially carved cirques, mass wasting in the form of rockfalls, avalanches, and debris flows have led to the buildup of coarse debris accumulations. In some instances the lobate form of these debris accumulations suggest rock glacier-like flow during the Holocene period (Fig. 22). This implies the presence of ice and hence of permafrost conditions during at least part of the Holocene period, down to altitudes as low as 800 m. It remains to be determined which, if any, of these forms are active at the present day. But, in any case, a low ground temperature regime is indicated by the shaded nature of the sites, and by the fact that the cold air which penetrates into the interstices between the boulders in winter is probably dislodged with difficulty by the overlying warmer and less dense air layer produced in the early summer. This is the effect described by THOMPSON (1962) as Balch ventilation. Scattered islands of permafrost and ice bodies may well be present. This conclusion would substantiate McGerrigle's discovery of frost bound talus at an elevation of only 297 m, alluded to at the beginning of this paper (McGERRIGLE, 1952). It is also very interesting in the light of the recent discovery through deep drilling by Hydro-Québec personnel of a thick zone of buried interstitial ice in a rock glacier at 540 m in the Parc des Laurentides, north of Québec City (GRUMICH and THIBEAULT, 1979).

The second terrain situation, worth investigating for permafrost existence below the regional limit, is in the peat bogs found in extensive depressions on plateau surfaces. If snow accumulation is not excessive on these bogs, then the better insulative properties of fibrous peat in the unfrozen state in the summer, in contrast to its much poorer insulative properties in the frozen state in the winter, may give rise to small thin permafrost bodies. As a word of caution, however, it should be noted that frost mounds — such as palsas or low peat plateaux — usually associated with thin, laterally bounded permafrost in organic terrains, have not been observed to date in the Gaspé Peninsula.

FIGURE 22. Rock glacier like accumulation below the north facing slope of one of the cirques on the eastern margins of the McGerrigle massif, approximately 4 km to the north of Mont Jacques-Cartier.

Accumulations semblables à celles des glaciers rocheux sous le versant exposé au nord de l'un des cirques, bordure est des monts McGerrigle, à 4 km au nord du mont Jacques-Cartier.

CONCLUDING REMARKS

A permafrost body, approximately 60 m thick, underlies the summit of Mont Jacques-Cartier in the Chic-Chocs Mountains, Gaspésie. Temperature measurements, heat production and conductivity data, available to a depth of 29 m, indicates that the permafrost is contemporary and that a mean surface temperature of −1°C to −1.5°C can be estimated. The altitude, extent and probable form of the permafrost body on Mont Jacques-Cartier was outlined on the basis of temperature lapse rates and terrain factors. This type of analysis was then applied throughout the region, leading to a map of the treeless summits of the eastern Chic-Chocs which are potentially underlain by permafrost. For such exposed situations, 1000-1100 m appears to be the critical lower limit for extensive permafrost. But sporadic areas of thin permafrost may exist below the regional limit, in either coarse debris accumulations at shaded sites with a northerly aspect or in organic terrain situated in slight depressions on the plateau surfaces.

Whilst the Chic-Chocs Mountains probably possess the most extensive and thickest bodies of permafrost in the Appalachian region, certain other summits in New England and in Newfoundland protrude above the treeline, and a few of these summits may be underlain by permafrost. In New England, this is definitely the case for Mount Washington, which attains an elevation of 1915 m in the Presidential Range of the White Mountains of New Hampshire. There, the mean annual air temperature is −2.8°C, and below freezing temperatures were measured at considerable depths in a deep well drilled at the summit (HOWE, 1971). Mount Katahdin, in Maine, and Mount Marcy, in the Adirondack Mountains in New York State, the only two other mountain areas of New England which attain elevations in excess of 1500 m, are, nonetheless, 300 m below the altitude of Mount Washington, and permafrost probably does not underlie their summits. In Long Range, in western Newfoundland, initial measurements of ground temperatures have been obtained by Brookes and Brown (pers. comm.) for an 18 m deep drill-hole at an elevation of 550 m. Ground temperatures decreased steadily with depth to 1.5°C at the base of the drill-hole, suggesting that the freezing point may be very closely approached at slightly greater depths, and therefore, that the highest summits, at altitudes of almost 800 m, may be underlain by permafrost.

ACKNOWLEDGEMENTS

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REFERENCES

BOUDREAU, F. and PAYETTE, S. (1974): Le mont Jacques-Cartier, Parc de la Gaspésie, *De toute urgence*, Vol. 5, No. 1, p. 3-18, Québec.

BROWN, R. J. E. (1966): Influence of vegetation on permafrost, in *Proceedings of 1st International Conference on Permafrost*, Nat. Acad. Sci., Nat. Res. Council Pub. 1287, p. 20-25.

—— (1970): *Permafrost in Canada*, Toronto Univ. Press, 234 p.

DE RÖMER, H. S. (1977): *Région des Monts McGerrigle*, Rapport géologique n° 174, Min. des Richesses naturelles, Québec, 233 p.

GAGNON, R. M. (1970): *Climat des Chic-Chocs*, M. P. 36, Service de la Météorologie, Min. des Richesses naturelles, Québec, 103 p.

GRUMICH, J. and THIBEAULT, L. (1979): *Projet Lac Louis — centrale à réserve pompée: Investigation géologique 1977-78*, Rapport du Service de géologie et géotechnique, Hydro-Québec, Montréal.

HOWE, J. (1971): Temperature readings in test bore holes. *Mount Washington Observatory News Bull.*, Vol. 12, No. 2, p. 37-40.

HYNDMAN, R. D., JESSOP, A. M. and JUDGE, A. S. (1979): Heat flow in the Maritime Provinces of Canada, *Can. J. Earth Sci.*, Vol. 16, No. 6, p. 1154-1165.

IVES, J. D. (1974): Permafrost, in *Arctic and Alpine Environments*, Ives, J. D. and Barry, R. G. (ed.), Methuen, London, p. 159-194.

—— (1979): A proposed history of permafrost development in Labrador-Ungava, *Géogr. phys. Quat.*, Vol. 33, Nos. 3-4, p. 233-244.

JUDGE, A. S. (1973): The prediction of permafrost thickness, *Can. Geotech. J.*, Vol. 10, No. 1, p. 1-11.

JUMIKIS, A. R. (1978): Graphs for disturbance — temperature distribution in permafrost under heated rectangular structures, in *Proceedings of 3rd International Conference on Permafrost*, Nat. Res. Counc., Ottawa, p. 590-596.

McGERRIGLE, J. W. (1952): Pleistocene glaciation of Gaspé Peninsula, *Trans. Roy. Soc. Can.*, Vol. 66, series 111, p. 37-51.

PICHETTE, D. R. and PILON, J. A. (1978): Sonde pour profils de température des sols du CRDO, *Centre de Recherches pour la Défense, Ottawa*, Note technique n° 78-17, 9 p.

THOMPSON, W. F. (1962): Preliminary notes on the nature and distribution of rock glaciers relative to true glaciers and other effects of the climate on the ground in North America, *Union géodésique et géophysique internationale, Assoc. intern. d'Hydrologie scientifique, Commission des Neiges et Glaces, Colloque d'Obergurgl*, p. 212-219.