CRYOGENETIC CATEGORIZATION OF PEAT AND MINERALCORED PALSAS IN THE SCHEFFERVILLE AREA, QUEBEC.

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Abstract

This paper presents results of an investigation on palsas in the Schefferville area of Quebec and focuses on surface and subsurface characteristics. Eighteen palsa sites were identified and four palsas were investigated in detail. They ranged from 12 to 59 m in length and up to 1.1 m in height. Combinations of bare peat, xerophilic shrubs and lichens on the palsa surfaces indicate palsas in a stable stage of development. Where block failure and thermokarst hollows are present palsas are in a degradation stage of development. Peat thickness on and surrounding the palsa was not uniform at each site. It is suggested here that this results from deflation by winter and summer winds. The percent of surface vegetation cover was a major controlling factor in this process. Amounts and location of subsurface ice, peat and mineral soil varied greatly. Ground ice ranged from small discontinuous ice lenses within the peat and mineral soil to thick ice lenses at the peat/mineral soil interface and entirely confined within the mineral soil. This study demonstrates that palsas exist in the Schefferville area at different stages of development with distinctly different internal structure in a relatively close association.

Résumé

Cette communication présente les résultats de travaux qui ont été effectués sur des palses dans la région de Schefferville (Québec). Sur 15 sites de palses identifiés, 4 palses ayant entre 12 et 59 m de longueur et jusqu'à 1,1 m de hauteur ont fait l'objet d'études détaillées, notamment sur les caractéristiques des premiers décimètres de sol. Les associations de tourbe à nu, d'arbustes xérophiles et de lichen à la surface indiquent la stabilité des formes de terrain. Le stade de dégradation se manifeste par des affaissements localisés et des dépressions de thermokarst. L'épaisseur de la tourbe variait selon les sites et l'emplacement (sur les palses ou dans les dépressions). Cette différence apparaît imputable aux processus de déflation autant en hiver qu'en été. Le pourcentage de couvert végétal a une incidence déterminante sur ce processus. Les quantités et la distribution de la glace, de la tourbe et du sol minéral variaient grandement. La glace se distribuait sous forme de petits filaments discontinus incorporés dans la tourbe et le sol minéral. Dans le sol minéral, au contact avec la tourbe, la glace formait d'épaisses lentilles. La présente étude démontre que des palses rapprochées peuvent être à des stades de développement différents et avoir une structure interne variable.

Introduction

Palsas are a common permafrost landform occurring throughout most of the Canadian subarctic (e.g. Brown, 1968, 1975; Kershaw and Gill, 1979; Railton and Sparling, 1973; Zoltai and Tarnocai, 1971). Several studies on coastal Labrador-Ungava have been concerned with palsas (e.g. Allard and Seguin, 1987a, 1987b; Brown, 1975; Dionne, 1984, and Lagarec, 1982), but very little work has been published concerning palsas in the central Labrador-Ungava area (Cummings and Pollard, in press). This paper presents observations on surficial and internal characteristics of palsas occurring at four locations in the Schefferville area of Quebec and Labrador.

Background

The term palsa is a Fennoscandian word referring to a mound or hillock with a frozen core found in a bog or fen (Seppälä, 1972). Palsas are defined as peaty permafrost mounds possessing a core of alternating layers of segregated ice and peat or mineral soil (Associate Committee on Geotechnical Research, 1988). This is the definition used in this study. Implicit in this definition is the genetic distinction between palsas and other types of frost mounds. Confusion in the literature between palsas and other frost mound phenomena has arisen from the descriptive approach to landform classification. The current application of the term involves the use of descriptive modifiers within a genetic context (e.g. peat palsa) to better define mound character. Excellent reviews of the palsa literature are provided by Washburn (1983) and Seppälä (1988).

Study area

Schefferville is located at 54°50'N, 66°40'W, approximately 525 km north of Sept-Iles (Fig.1). It is situated in the Labrador Trough, which is characterized by a strong ridge

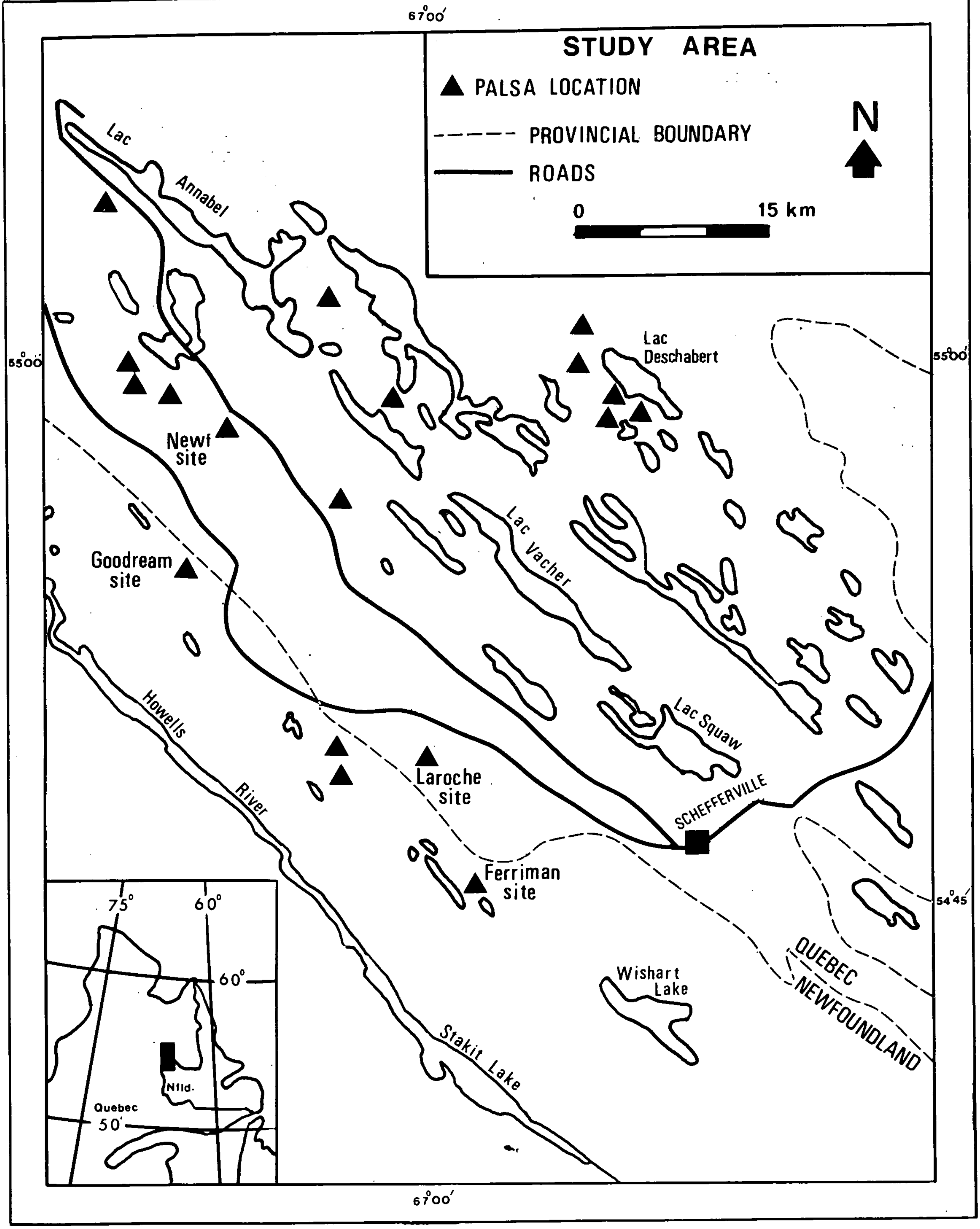

Figure 1. Location map of study sites.

and valley topography aligned in a northwest-southeast direction. Peatlands occupy many topographic depressions of the Labrador-Ungava region. In the Schefferville area, fens occupy approximately 10-15 % of the land surface (Allington, 1961) with many of these peatlands containing palsas. This area was overridden by a thick ice sheet during the maximum of the Wisconsinian glaciation about 18 000 years BP (Ives, 1979). Most researchers (Bryson et al., 1969; Ives, 1979) believe that the eastern centre of Laurentides ice was at the current location of Kivivic Lake, 40 km northwest of Schefferville. Radiocarbon dating suggests initiation of peatlands occurred approximately 6000 yrs. BP (Grayson, 1957).

The mean annual air temperature for Schefferville is -4.9 °C with a maximum mean annual temperature of -2.7 °C and a minimum mean annual temperature of -7.9 °C, approximately 90 frost-free days and mean annual precipitation of 785 mm of which 378 mm is water equivalent of snow (personal communication, D. Barr, McGill Subarctic Research Station). In the Schefferville area, mining operations have encountered permafrost to a depth of 60 m beneath exposed tundra ridges (Ives 1960).

The aims of this study were threefold: 1) to document permafrost landforms in the peatlands of the Schefferville area, 2) to describe surface and subsurface characteristics of these palsas, and 3) to evaluate this information with reference to cryogenetic classification.

Methodology

Field reconnaissance and aerial photograph interpretation led to the identification of 18 palsa sites within a 35 km radius of Schefferville (Fig. 1). This paper focuses on four sites that are accessible on mine roads. The results presented in this paper are based on field work in February, and from April to September, 1989. Peat cores, used for analysis of stratigraphic characteristics, were obtained using a CRREL permafrost coring kit. Vegetation cover on each palsa is based on analysis of four, 1 m^2 selected quadrats. Unfrozen peat depths in the fens surrounding the palsas were obtained with a 3 m steel probe. Tree age was determined by removing a cross-section of the tree just above the root crown. This was sanded and examined under 10x magnification. Snow depths were obtained using a Mount Rose snow sampler. A YSI needle probe was used to measure snow pit temperatures.

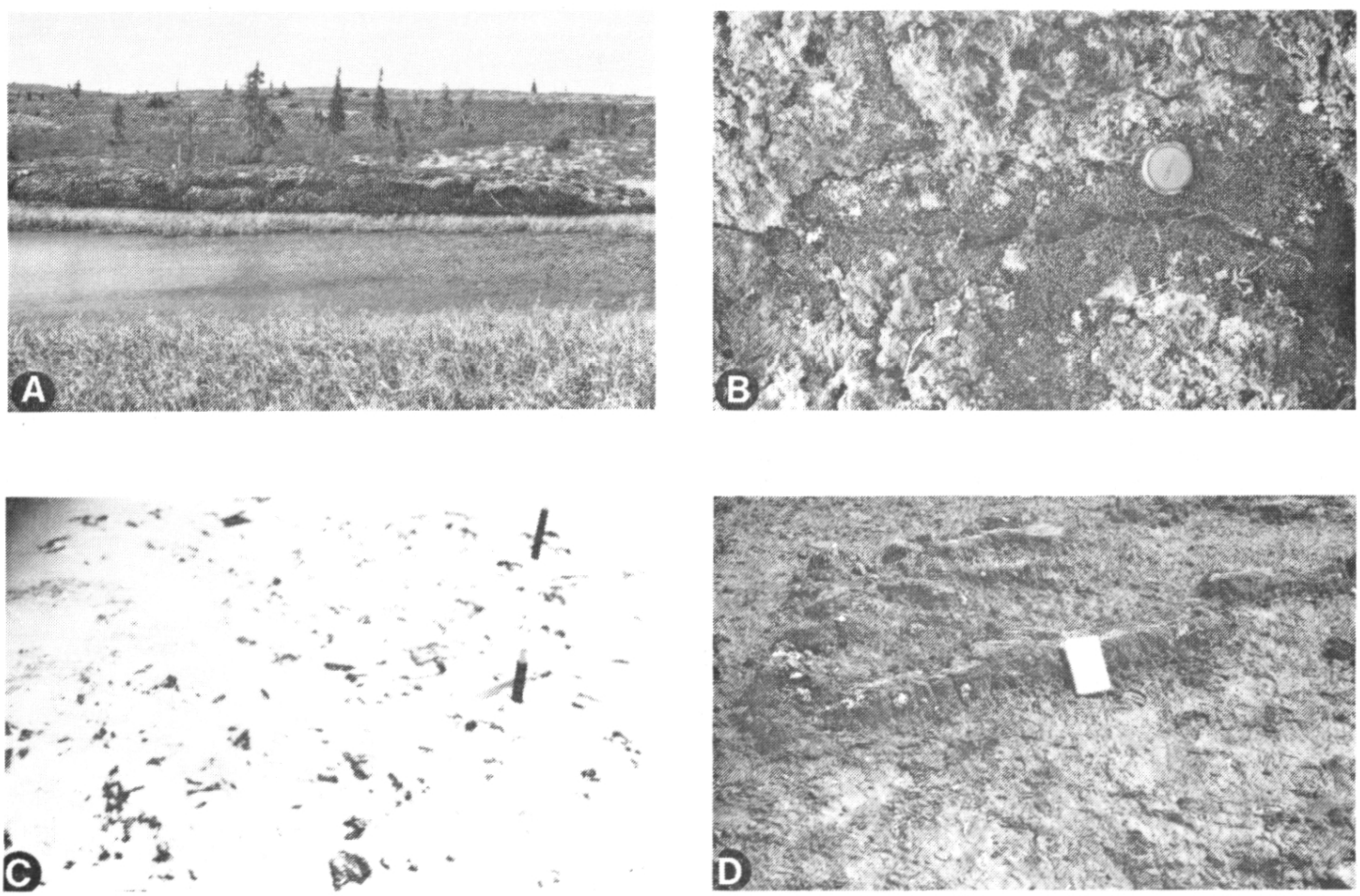

Figure 2. (a) Block failure on west face of Goodream palsa. Blocks range from 0.75 to 2 m long.
(b) Cracks in surface peat at Ferriman palsa. This seems to initiate block failure.
(c) Ferriman palsa surface winter, 1989. Much of the palsa surface (micro-hummocks) is free of snow.
(d) Surface of Laroche palsa. Isolated blocks of peat resulting from winter wind erosion stand 18 cm above the surrounding unvegetated surface.

Site description and surface morphology

At the Goodream site, two palsas occur in a small valley at 718 m a.s.l. located between two till covered bedrock ridges. Both palsas are bound on three sides by standing water ranging from <0.5 to >2 m deep. The fourth side consists of a thin floating mat of peat with *Carex* spp. and *Sphagnum* spp. being co-dominant. The largest palsa is 28 m long, 15 m wide and 1.1 m high (all heights are measured relative to the water table). It is oval-shaped with its long axis trending northeast-southwest. It appears to be degrading by block failure along its perimeter (Fig. 2a), similar to those described by Salmi (1968). As well, patches of bare peat are exposed on the surface (Table I) and large cracks up to 15 cm wide and 30 cm deep traverse the entire palsa.

At the Ferriman site, one palsa occurs at 750 m a.s.l. in a topographic setting similar to the Goodream site . This palsa is surrounded by a deep (>2 m) "moat". It is circular in plan shape with a diameter of 12 m and a height of 0.7 m. This palsa also appears to be degrading as there are cracks, (up to 10 cm wide 40 cm deep) traversing its entire surface (Fig. 2b) along with thermokarst depressions.

The Laroche site contains two oval palsas located in a small valley (661 m a.s.l.) with a bedrock ridge to the east and till covered bedrock to the west. The till surface is marked by non-sorted circles. The fen surrounding these palsas is dominated by *Carex* spp. vegetation with the water table located 5 cm below the surface. A small pond (50 m in diameter) lies to the northwest of the palsas. The largest palsa is 58.7 m long (northwest-southeast axis) and 21.6 m wide, with a height of 1.0 m.

The Newf site contains nine palsas ranging from 5.6 to 21.0 m in length, 2.4 to 12.0 m in width and 0.5-0.8 m in height. The surface of the fen surrounding the palsas consists of a thin *Carex* spp. and *Sphagnum* spp. floating peat mat. This site is topographically different from the previous sites. There is no definite valley but rather gently sloping open lichen and feather moss forests surrounding the peatland. There are no large open water bodies, only small pools ($2m^2$). The palsa studied is 17.4 m long, 8.0 m wide and 0.8 m high.

The surface vegetation characteristics for the four palsa sites are shown in Table I. At the Ferriman and Laroche sites, 70% of the palsa surfaces are free of vegetation. Bare peat, shrubs and lichen dominate the surface of Goodream palsa. The Newf site has the lowest percentage area of bare peat with lichen dominating the palsa surface. Trees were present at the Laroche site only. A larch tree 1.5 m high and 122 years old was found on the northwestern edge of the palsa. The very low percentages of sedges on all palsas and the absence of dead hydrophilic species indicate that their surfaces are relatively dry and have not been submerged recently.

Peat thickness overlying the mineral soil substrate, both on and surrounding the palsa, is summarized in Table II. The surface peat at the Laroche site is anomalously thin compared to the Goodream and Ferriman sites, while the thickness of the peat surrounding the palsa at the Laroche site, is similar to these two. At the Goodream and Ferriman sites the peat is thinnest at the edge of the fen and becomes thicker towards its center.

Table I. Surface vegetation cover of the four palsa sites.

Surface vegetation	percent coverage Goodream	Ferriman	Laroche	Newf
Bryophytes				
Dicranum spp.	4	5	3	2
Polytrichum spp.	9	5	0	7
Sphagnum spp.	5	0	0	1
TOTAL	**18**	**10**	**3**	**10**
Shrubs				
Betula glandulosa	17	4	4	5
Ledum groenlandicum	0	2	11	3
Vaccinium vitis-idaea	5	0	0	0
V. uliginosum	3	5	2	2
Empetrum nigrum	2	3	3	0
Rubus chamaemorus	5	0	0	0
TOTAL	**32**	**14**	**20**	**10**
Sedges				
Carex spp.	0	0	0	2
Scirpus spp.	0	2	2	0
E. chamissonis	0	2	2	2
TOTAL	**0**	**4**	**4**	**4**
Lichen				
Cladonia spp.	**20**	**4**	**4**	**75**
Trees				
Larix larcina	**0**	**0**	**1***	**0**
Bare peat	**30**	**70**	**70**	**3**

*-122 years old

Table II. Peat depths for three palsa sites. The peat depth on the surface of Laroche palsa is thinner than in the surrounding fen. At the Goodream and Ferriman sites the peat depth is thickest on the palsa

PEATDEPTH (M)	Goodream Site	Ferriman Site	Laroche Site
Onthe palsa	2.60	2.44	0.66
Surrounding the palsa	1.54-2.00	1.03-2.24	1.03-1.67

INTERNAL CHARACTERISTICS

In the absence of long term process studies, the investigation of palsa structure provides one approach to the interpretation of mound genesis. In this study, stratigraphic observations are based on the analysis of cores up to 3.0 m long. Of particular interest to this study was the morphology and distribution of ground ice and the depth and nature of organic material and mineral soil.

The internal structure of 4 palsas is summarized in Fig. 3. A variety of ice types are present, but segregated lens ice, in various geometric arrangements, is most common. The largest and greatest total thickness of lens ice is associated with the contact between the sedge-peat unit and underlying mineral soil. Approximately 32% of the total ice

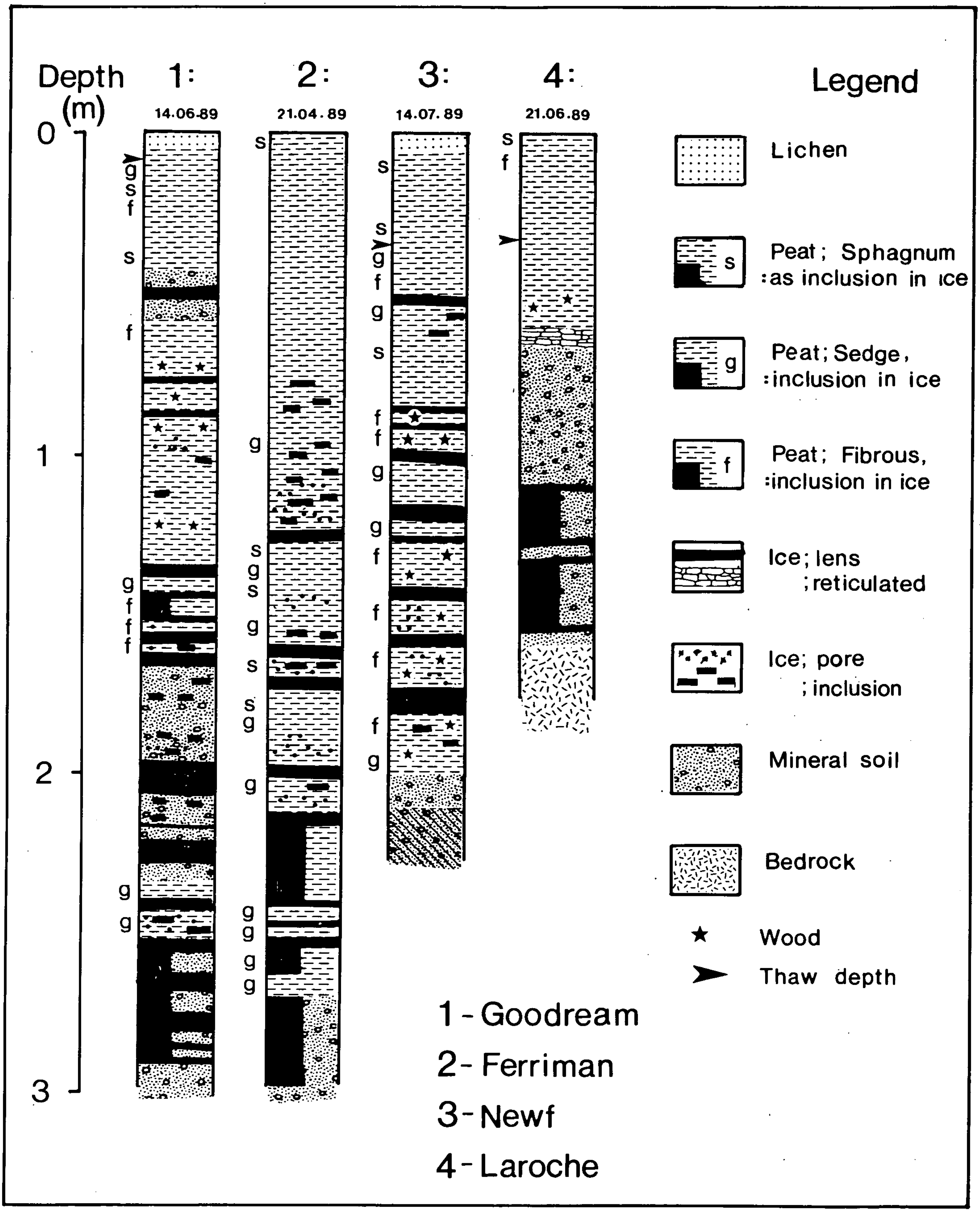

Figure 3. Detailed core logs from the four palsa sites.

thickness were found at this location, 23 % of total ice lenses is found within sedge peat and 17 % within the mineral soil. An average of 73 % of palsa height can be accounted for by accumulated ice lens thickness.

The size of pore ice crystals varied considerably. Two size categories are proposed, (1) small ice crystals less than 1 mm in diameter, termed pore ice, and (2) larger crystals 1–20 mm in diameter, termed inclusion ice. This distinction is entirely morphologic and does not imply a genetic difference. Both sizes of ice crystals occurred in all types of peats but not in mineral soil. In one case, reticulated ice veins occurred within the mineral soil at the Laroche site . The origin of this cryotexture is not completely understood; however, it is known to be associated with ice segregation processes (Mackay, 1974).

Ice coatings occurred mainly on wood fragments in frozen fibrous peats. In all cases, the ice coatings were thickest on the upper wood surface. At the Goodream and Ferriman sites, brecciated inclusions of highly decomposed organic silt occurred within large segregated ice layers. These inclusions ranged from 5-22 mm in length and were horizontally oriented.

Winter characteristics

Snow conditions were investigated at the Goodream, Ferriman and Laroche sites during February 1989. Snow depths on the palsas, were measured at 36 points, and ranged from 0 to 45 cm deep and average 10 cm. In the fen surrounding the palsa snow depths were measured at 48 points and ranged from 44 to 175 cm with an average depth of 69 cm. The differences in snow depth produce marked differences in ground-snow interface temperatures. With an ambient air temperature of -31 °C (February 18, 1989) the ground-snow interface temperature beneath 11 and 78 cm of snow was -20 °C and -3.5 °C respectively.

A linear regression was developed to predict ground/snow interface temperatures from: depth, density, water equivalents of snow and ambient air temperatures. A step-wise regression showed that the only significant variable at 85 % confidence interval was snow depth. The equation produced is:

$$\ln|GSI| = 1.80 - 0.595(\ln DP) \qquad (1)$$

where: $\ln|GSI|$ is the natural log (natural logs were used to linearize data) of the absolute value of the ground/snow interface temperature (°C). $\ln DP$ is the natural log of snow depth (m).

An R^2 value of 0.89 is achieved, with a low mean square error (0.079). A two tailed t-test showed that the independent variable is significant at 98 % confidence interval.

As much as 20 % of the palsa surface at the Ferriman site was free of snow (Fig. 2c), a similar value was observed at the Goodream site. The exposed surfaces are susceptible to deflation via wind erosion. Small fragments of windblown peat, lichen and leaves were identified both on the snow surface and in snow pits in the lee of the palsas.

Discussion and conclusions

Surface conditions

The vegetation species present at all four sites are very similar. However, the percent cover varies between sites. In earlier studies, the absence of surface vegetation was used to infer stage of development (e.g. Salmi, 1968; Brown, 1968). In this study, the analysis of the type and percent of surface vegetation cover is used to develop a simple stage-process categorization which can be applied to either peat or mineral soil palsas. Using examples from Schefferville, we are attempting to demonstrate that palsa condition is simply a reflection of site specific permafrost processes. The three conditions proposed parallel the evolutionary stages of palsa development defined by Seppälä (1986), where he distinguished between embryonic, mature and old [collapsing] palsas. We recommend however, that terms having an evolutionary context do not clearly communicate the significance of the dynamic permafrost condition and may suggest age, without the appropriate data. The terms aggrading, stable and degrading when used as a modifier of the term palsa imply the proper cryogenetic significance.

All palsas studied have varying percentage of bare peat. However, the presence of other cover types, especially shrubs lichens and in one instance a mature larch tree, suggests that these palsas have been above the water table for a sufficient period of time to allow a succession of xerophilic species to colonize the palsa surface. Hence, one conclusion of this study is that these palsas are past the aggradational phase of development. Furthermore, the presence of a mature tree, thermokarst hollows, areas of bare peat and block failure suggest that the Goodream, Ferriman and Larouche sites are all degradational palsas. The palsa at the Newf site did not display any degradational characteristics, it had a low percentage of bare peat and maintained a high percentage cover of lichens and shrubs. This suggests a stable palsa.

Peat depth and winter characteristics

The variable relationship between peat depths on the palsa and in the surrounding fen was not anticipated. At the Goodream and Ferriman sites, peat depth is thickest on the palsa. This seems appropriate because the fens appear to be formed in former small lakes, and lake infill is the dominant peat forming process. Lake infill also seems to be the peat forming process at the Laroche site, but peat depths are thinner on the palsa. Zoltai and Tarnocai (1975) have suggested that the palsa form is associated with ice lens growth in the mineral soil. This appears to be the case at the Laroche site, where the largest ice lenses are contained within the mineral soil.

It is hypothesized that in the past, the surface peat was much thicker on the Laroche palsa. Successive years of winter and summer wind erosion can remove a significant amount of surface material. During the winters of 1987-88 and 1988-89, approximately 18 cm of surface peat was eroded from the surface of Laroche palsa surface. This occurred on the most exposed portion of the palsa and is displayed in Fig. 2d. The albedo of unvegetated surfaces is generally lower than surrounding areas of lichen (Railton and Sparling 1973). In theory, more solar radiation is absorbed and the surface peat layers become wetter (Wright, 1981), thus increasing the thermal conductivity of the peat. This combination of factors could produce deeper active layers and possible surface thermokarst. From this we conclude that wind abrasion is responsible for significant amounts of surface peat loss leading to degradation of the permafrost core.

There is a strong relationship between snow thickness and ground thermal regime (Nicholson, 1976). Clearly, where snow is absent, or thin, the ground surface is much colder than in the surrounding fen where the snow is much thicker. This permits maintenance of the permafrost core within the palsa. However, summer conditions also have a strong influence on the ground thermal regime. From April to October the temperature at 3 m below the surface at the Ferriman site rose from -1.6 to -0.6°C. With combinations of anomalously high or low snow fall, and warm or cold summers respectively, temperatures at depth may be significantly altered. Where snow is thinnest on the palsa surface frost penetration is more intense and rapid, contributing to maintenance of colder temperatures throughout the summer.

This may seem to contradict the theory of winter wind erosion causing deeper active layers, as described above. However, our findings suggest that removal of surface peat by deflation does not occur at all sites, rather, it is selective and sporadic. The controlling factor appears to be the amount of unvegetated surface or bare peat. Areas of bare peat are more likely to be eroded than the vegetated areas. The result is a positive feedback system where unvegetated sections of the surface are more susceptible to erosion than the vegetated ones and wind erosion creates larger areas of bare peat, which are more readily eroded. This is the case with the degradational palsas at the Ferriman and Laroche sites. Hence, the amount of bare peat is significant to cryogenetic conditions of palsas.

The third conclusion also relates to the internal structure. Coring revealed that both mineral and peat cored palsas are found in relatively close association. In this study, neither mineral or peat cored palsas exhibit a greater tendency for degradation. However, we speculate that as erosion of the peat surface over a mineral cored palsa continues, it is probable that a threshold point will be reached at which the peat cover is no longer thick enough to preserve the permafrost core and a degradational palsa will result.

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