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Distribution of peatlands

J.M. Aylsworth[1] and I.M. Kettles[1]

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Abstract: The Mackenzie valley is characterized by vast peatlands dominated by two classes, bog and fen; the former is generally frozen and ground ice is common, the latter is unfrozen. Large peatlands are associated with broad featureless glaciolacustrine or till plains while smaller ones occur in low-lying areas between till or eolian ridges. Based on the compilation map, approximately 27 600 km^2 of bog and 10 000 km^2 of fen are estimated to occur in the Mackenzie valley. Although fens comprise only about 27% of the peatlands of the region as a whole, the proportion of fen to bog increases greatly in some areas. For example, close to Fort Simpson the ratio of fen to bog is 63:37. Peat thickness, based on information from the 'Mackenzie Geotechnical Borehole Database', increases towards the south.

Résumé : La vallée du Mackenzie est caractérisée par la présence de vastes tourbières qui sont attribuées principalement à deux classes : les tourbières oligotrophes (bogs) et les tourbières minérotrophes (fens). Les tourbières oligotrophes sont généralement gelées et contiennent de manière habituelle de la glace de sol, alors que les tourbières minérotrophes ne sont pas gelées. Les grandes tourbières sont associées à de vastes plaines de sédiments glaciolacustres ou de till dépourvues d'éléments géomorphologiques, tandis que les petites tourbières occupent des terres basses entre des crêtes de till ou de sédiments éoliens. Selon la carte de compilation, il existe environ 27 600 km^2 de tourbières oligotrophes et 10 000 km^2 de tourbières minérotrophes dans la vallée du Mackenzie. Les tourbières minérotrophes ne constituent que 27 % environ des tourbières de la région; cependant, leur proportion augmente de façon marquée dans certains secteurs. Par exemple, près de Fort Simpson, le rapport entre les tourbières minérotrophes et les tourbières oligotrophes est de 63/37. L'épaisseur de la tourbe, d'après les données géotechniques recueillies dans les sondages, augmente vers le sud.

[1] Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8

INTRODUCTION

Peatlands are areas where the soils consist of partially decomposed organic materials dominated by mosses and sedges and, to a lesser degree, shrubs and trees. The Mackenzie valley is characterized by vast peatlands across both the continuous and discontinuous permafrost zones. The presence or absence of permafrost in these peatlands has important implications for predicting ground behaviour in the event of continued climate warming. Thaw subsidence of the surface and release of greenhouse gases are two possible consequences of the thawing of permanently frozen peatlands. A knowledge of the distribution and nature of the peatlands is needed before potential effects of warming can be assessed. Accurate mapping of peatlands and knowledge of peat thicknesses, ground-ice content, and ground temperatures are necessary for predicting future changes in peatlands. The purpose of this paper is to show the distribution of peatland types and to discuss the thickness of peat and the permafrost conditions in the peatlands of the Mackenzie valley.

THE NATURE OF PEATLAND IN THE MACKENZIE VALLEY

Two major classes of peatland, bog and fen, are found in the Mackenzie valley (Tarnocai et al., 1995). Each has distinctive vegetation assemblages, morphologies, water regimes, and thermal conditions, with bog being typically frozen and fen unfrozen (Table 1).

Peatlands are characterized by layers of poorly to moderately decomposed organic materials at the surface and more thoroughly decomposed materials near the base. Macrofossil analysis of peat shows that bogs commonly developed from fens, which in turn, formed as organic materials accumulated in lakes or poorly drained depressions. In many peat plateaus only the top 50 cm is *Sphagnum* peat, covering fen peat (Zoltai and Pollett, 1983). Finally, collapse scars in degrading peat plateaus may develop into fens.

Bogs and fens take a number of distinct forms. Within the Mackenzie valley, the most prevalent bog form is the peat plateau, which is elevated 1–2 m above adjacent fens and covers a few square kilometres to several hundred square kilometres (Fig. 1, 2; Zoltai and Pollett, 1983). Another form is polygonal peat plateau, which is similar to a peat plateau, but contains polygonal ice-wedge trenches, the product of winter frost cracking. In the southern part of the Mackenzie valley, some areas of unfrozen bogs, formed from degraded peat plateaus, have been noted (S.D. Robinson, pers. comm., 1997). Also present are flat bogs and palsas; the first are featureless surfaces occurring in broad, poorly defined depressions, and the second are frozen mounds of peat, less than 100 m in diameter, which rise 1–7 m above the surrounding fen.

The common fen forms are the horizontal fen and northern ribbed fen. The former is characterized by a very gently sloping, featureless surface, which occupies broad, often poorly defined depressions. The latter have low, narrow peat ridges that cut across the fen at right angles to the direction of water movement, and form gentle arcs across the fens

Table 1. Comparison of physical and chemical characteristics of bogs and fens in the Mackenzie Valley, based on legend notes accompanying regional surficial geology maps.

FEATURE	BOG	FEN
Topography and morphology	Flat or very gently inclined plains; usually raised about 1 m above surrounding fens, or as peat filling slight depressions in the landscape. Commonly pocked with numerous steep-sided depressions (collapse scars) occupied by thaw ponds or small fens, or by steep-sided trenches that act as seepage channels connecting the depressions	Flat to very gently inclined plains. Commonly featureless plain; some have reticulate network of low (<50 cm) ridges
Typical peat thicknesses	64°-68° = 2–4 m thick; 60°-64° = 1.5–7 m thick	64°-68° = 2–3 m thick 60°-64° = 2–3 m thick
Surface vegetation	Cover of sphagnum moss and heath shrubs. May be open or forested by scattered to closed cover of black spruce.	Cover dominated by sedges; grasses and reeds may be found in local pools. May be open or forested by shrubs and scattered tamarack or black spruce trees.
Drainage pattern	Poor; numerous small ponds	Drainage mainly by subsurface seepage. Water table at surface during summer months; occasional small pools.
Acidity	Surface peats and waters are strongly acidic.	Fen peats and waters are less acid than in bogs
Permafrost	Commonly frozen 0.3-0.5 m below the surface; peat in wet depressions may be unfrozen to depths of more than 1 m. Segregated ice widespread within the peat (up to 80%) and in underlying sediment. Growth of segregated ice elevates surface of bog over surrounding fen; ice degradation forms collapse scars.	Generally unfrozen. In the south some relic permafrost may occur at depths exceeding 3 m or more. In the north, channel fens and small fens within bog complexes may be underlain by permafrost at depths exceeding 0.5 m.

(Fig. 2). The ridges are better drained and may be underlain by permafrost. There are several other forms, defined by their topographic location (basin, stream, channel, and shore fens) or permafrost history (collapse scar fens; *see* Fig. 1; Zoltai et al., 1988a, b).

Canada has been divided into wetland regions where specific wetland forms develop in locations that have similar topography, hydrology, and nutrient sources (Zoltai, 1988). Three wetland regions, High Boreal, Low Subarctic, and High Subarctic (Fig. 3), are contained in the Mackenzie valley. High Boreal wetland is characterized by small wooded peat plateaus, flat bogs, and palsas, with fens, including northern ribbed, collapse scar, basin, and shore forms (Zoltai et al., 1988b), whereas Low Subarctic wetland is characterized by peat plateaus, palsas, and northern ribbed, horizontal, channel, and shore fens (Zoltai et al., 1988a). Polygonal peat plateaus with local basin fens and shore fens are the principal forms of High Subarctic wetland (Zoltai and Pollett, 1983). In the High Boreal and Low Subarctic wetland regions, permafrost is associated with peat plateaus and palsas, but fens and their underlying sediments are unfrozen. In the High Subarctic region, permafrost underlies all peatlands, except portions of shore fens located within a few metres of a lake (Zoltai and Pollett, 1983). In many places in all three wetland regions, fens, and bogs are closely associated.

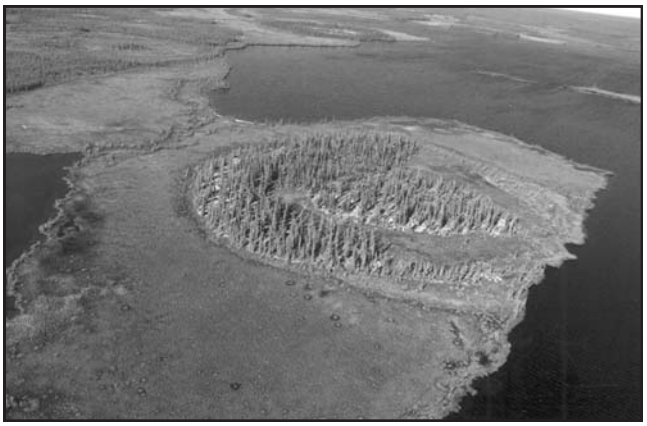

Figure 1. *An isolated, round peat plateau, 225 m in diameter, within a fen (62°43′N, 121°06′W). A collapse-scar fen, approximately 30 m wide and 60 m long has formed within the peat plateau. Photograph by S.D. Robinson. GSC*

Figure 2. *Peat plateau, marked with collapse scars (right), and northern ribbed fen (left) approximately 100 km north of Fort Simpson. Photograph by S.D. Robinson. GSC 2000-026B*

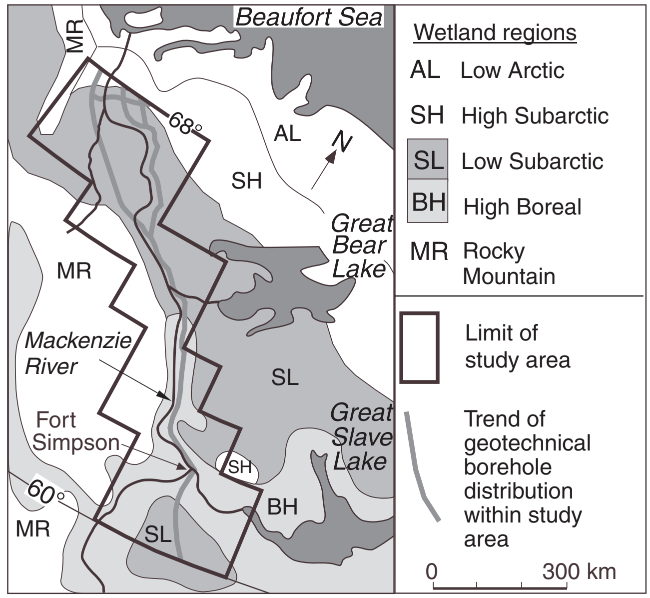

Figure 3. *Wetland regions (*from *National Wetland Working Group, 1988) and location of geotechnical boreholes within study area.*

DISTRIBUTION OF PEATLANDS IN THE MACKENZIE VALLEY

Peatlands, delimited mainly by airphoto interpretation, are shown as distinct terrain units on surficial geology maps of the Geological Survey of Canada. Due to the prevalence of peatlands in the Mackenzie valley, surficial mappers have depicted not only the boundaries of major peatlands, but have also indicated on the maps the extent of more discontinuous, minor peatlands. On the published maps, discontinuous peatlands are shown either as minor components of other surficial units (e.g. unit ‘siLp-pO’, meaning silty lacustrine plain with 16–49% of the surface covered with peat bog in Rutter et al. (1980c)) or as symbol overlays covering parts of other surficial units (e.g. Duk-Rodkin and Hughes, 1992f). Where peat exists solely as a veneer, not masking the underlying sediments, it is not mapped. The accompanying map (Fig. 4, in pocket), which shows the distribution of peatland in the Mackenzie valley, was compiled and generalized from 1:125 000 and 1:250 000 scale, regional surficial geology maps (Fulton, 1970; Hanley, 1973; Hanley et al., 1975; Rutter and Boydell, 1979, 1980 a, b, c, 1981; Rutter et al., 1980a, b, c, d, e, f; Duk-Rodkin and Hughes, 1992a, b, c, d, e, f, g, h, 1993a, b, in press a, b).

It is estimated that there are approximately 27 600 km^2 of bog and 10 000 km^2 of fen in the Mackenzie valley, based on Figure 4. Because the map is a generalization, the land surface represented by individual map-unit boundaries is unlikely to be covered completely by peatlands. The authors estimate, for the purposes of this calculation, that 1) 70% of the surface area of the 'extensive peatland' units and 20% of the 'discontinuous peatland' units are actual peatlands, and 2) the ratio between the two peatland classes is 2:1 for bog-dominant or fen-dominant mixed peatland units, and 1:1 for undifferentiated mixed peatland units. In general, large peatlands have formed on the extensive glacial-lake plains which cover the central axes of the Mackenzie valley and several tributary valleys. Where eolian deposits cover the glacial-lake sediments, peat has commonly accumulated in low-lying areas between sand dunes. Peatlands have also developed on the broad, featureless surfaces of till plains or in low-lying areas between drumlins or in depressions in hummocky moraines. Smaller accumulations of peat are found in depressions in alluvial or glaciofluvial deposits. In the mountainous areas bordering the plains and plateaus of the Mackenzie valley, peatlands are restricted to small accumulations on valley bottoms.

In the lower Mackenzie valley (64–68°N), which lies mainly within the Low Subarctic region, there are two major peatlands (Fig. 4). The first, dominated by bog, crosses the Arctic Red River and is adjoined by other large areas characterized by a discontinuous cover (<50%) of fen and bog. The second prominent peatland, dominated by bog or a mixture of bog and fen, is in the vicinity of the Great Bear River. Elsewhere in the lower Mackenzie valley, peatland distribution is more sporadic. Many long, narrow, stream fens occupy small valleys in the northeast, but they are too small and discontinuous to be shown on Figure 4.

In the upper Mackenzie valley (60–64°N), prominent peatlands dominated by fen lie in the central axis of the valley in the vicinity of Fort Simpson and eastwards (Fig. 4); these peatlands overlie glacial-lake plains and till plains within the High Boreal region. At higher elevations, away from the central axis of the valley, the till plains are characterized by extensive peatlands consisting of bog or of mixed peatland (bog with lesser amounts of fen). These bogs lie mainly within the Low Subarctic region.

Although fens constitute about 27% of the peatlands of the Mackenzie valley as a whole, the proportion of fen to bog increases greatly in some areas. For example, close to Fort Simpson the ratio of fen to bog is 63:37 (northwest quarter of NTS 95 H).

PEAT THICKNESS BASED ON BOREHOLE DATA

Typical peat thicknesses based on legend notes accompanying regional surficial geology maps are shown in Table 1. Other scientists have investigated peat depths associated with specific forms of bog and fen in the different wetland regions in the Mackenzie valley. In the Low Arctic region, peat is commonly 1.5 m thick under high-centre polygons, but only 50 cm under polygon fens (Tarnocai and Zoltai, 1988). Peat has accumulated in excess of 2 m, and up to 4 m thick, in peat-plateau bogs of the Subarctic region, while thicknesses of 0.4 m to an average of over 3 m have been recorded in channel fens, and 0.3–1.5 m in veneer bogs and collapse-scar fens (Zoltai et al., 1988a). In the Boreal region, peat thicknesses in peat-plateau bogs are commonly in excess of 2 m, but seldom more than 5 m, while accumulations in palsas may be over 4 m. In the same region, depths in excess of 1 m are reported in northern rib fens, 1 m to more than 6 m in basin fens, and 1–2.5 m in spring fens (Zoltai et al., 1988b).

The following section is not limited to mapped areas of peatland, but applies to the surface organic layer which may be present in a variety of terrain types. Most of the information is derived from the 'Mackenzie Geotechnical Borehole Database' (updated from Lawrence and Proudfoot, (1976)). This database contains records of over 12 000 boreholes drilled along the Mackenzie valley between 60°N and the Beaufort Sea primarily for pipeline- and road-route selection and design. The database is a compilation of information supplied by private industries from boreholes drilled, logged, and sampled for geotechnical purposes using a variety of drilling or coring methods. Drilling generally occurred in winter from winter roads. Stratigraphy was commonly logged in 0.5 foot increments. In most records, peat and highly organic soils (a mix of organic and mineral sediments dominated by the former) were grouped as one unit because they have much the same impact on construction. For the remainder of this section, peat and highly organic soils will be referred to as organics. Where the surface unit was logged only as organic soils without mentioning peat, the records were not used.

The data set is not a completely objective sampling of the regional organic depths because the boreholes are located within narrow linear corridors (the planned pipeline and highway routes) that were situated to avoid extensive peatland areas as much as possible. Also, the majority of boreholes are located in the northern half of the valley and often their specific location was intended to test for aggregate accumulations. Nevertheless, the borehole data set provides a useful indication of regional organic-layer thickness and allows a comparison between organic thickness and various environmental factors (latitude, underlying sediment type, and wetland region).

A shallow organic cover is common over much of the Mackenzie valley. For example, approximately half (6686) of the boreholes in the database noted surface organic thicknesses of at least 0.06 m. From the database, only organic thicknesses of at least 1.5 ft. (0.46 m), the closest measurement to the defined minimum thickness for peatland of 0.4 m (Tarnocai, 1980), were selected for the following analysis. It is recognized that the minimal thickness quoted by Tarnocai refers to peat alone, whereas the data set used here includes highly organic soils within the organic unit. Surface organics, ranging from 0.46 m to a maximum of 14.6 m thick, were recorded for 2708 holes, approximately 23% of the database. It is possible that some or many of the 2708 boreholes with organic-layer thicknesses greater than 0.46 m may not be located in recognized peatland.

To investigate the relationships between thickness of organics and latitude, thickness measurements for the 2708 boreholes were grouped by 0.25° increments of latitude. Maximum thicknesses of organic materials recorded for boreholes are found north of 66.5°N and between 64.5° and 65.25°N, however the greatest mean (4.8 m) and median (4.2 m) thicknesses lie south of 61.5°N (Fig. 5). The trend of increasing thickness of organic sediments to the south is confirmed by ditch-wall records for the Norman Wells to Zama pipeline (*see* Burgess and Lawrence, 2000).

Of the 2708 boreholes selected, 19% occur in the High Boreal wetland region (BH), 80% occur in the main Low Subarctic wetland region (SL-2), and 1% in the isolated area of Low Subarctic (SL-1) lying just north of the provincial border (Fig. 3). Only a small part of the study area lies in the High Subarctic zone and very few boreholes were located there. Each borehole record in the database notes the genetic class (organic, morainal, lacustrine and glaciolacustrine, colluvial, alluvial, fluvial and glaciofluvial, other) of the encompassing surficial geology unit, based on maps available at the time of drilling. Table 2 summarizes organic-cover statistics for each surficial unit within each wetland zone.

Thickness of the organic cover is generally greater in areas that were mapped as organic terrain, which in many locations overlie lacustrine deposits, and also in areas mapped as lacustrine (Table 2). The flat surfaces and poor permeability of lacustrine sediments impede drainage, which in turn fosters peatland development. Depths of organic materials are lower in colluvial areas, where the ground surface is unstable. Thicknesses associated with other surficial units are variable and probably reflect morphological controls. For example, accumulation of organics is common in low areas between drumlins and flutes in morainal terrain. In alluvial terrain, peat accumulation may be cyclic with sediment deposition; buried peat units were eliminated from this survey. When thicknesses of the organic layer for each genetic class are compared by wetland region, there is a general trend of increasing peat depths (mean and maximum values) from north to south through the Low Subarctic-2 to High Boreal to Low Subarctic-1 regions (Table 2).

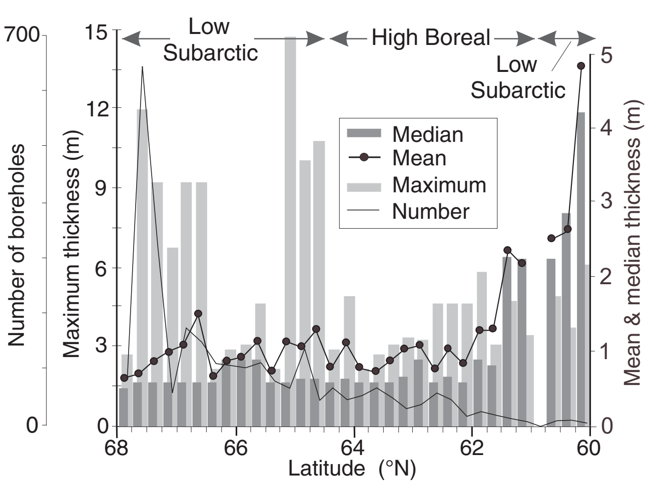

Figure 5. Thickness of peat by 0.25° latitude grouping. Statistical summary from 2708 boreholes recording peat and highly organic soil cover ≥0.46 m (1.5 ft.) in the 'Mackenzie Geotechnical Borehole Database' (updated from *Lawrence and Proudfoot (1976)). Note the three different y-axis scales.*

Table 2. Surface peat, including highly organic soils, for surficial geology units within three wetland regions: Low Subarctic-1 (SL-1), 60.00–60.75°N; High Boreal (BH), 60.75–63.75°N; and Low Subarctic-2 (SL-2), 63.50–68.00°N. Data set limited to records in which this unit ≥0.46 m. Extracted from 'Mackenzie Geotechnical Borehole Database' (updated *from* Lawrence and Proudfoot (1976)).

			Thickness of peat (m)		
Geological unit	Wetland zone	Number of boreholes	Mean	Median	95th percentile
Alluvial	SL-2 BH	83 82	0.97 0.61	0.61 0.61	2.13 1.22
Colluvial	SL-2 BH	91 32	0.63 0.86	0.61 0.61	1.31 1.83
Fluvial and glaciofluvial	SL-2 BH	140 24	0.80 1.06	0.61 0.61	1.83 1.83
Lacustrine and glaciolacustrine	SL-2 BH	299 138	0.99 0.99	0.61 0.61	2.44 2.74
Moraine	SL-2 BH SL-1	905 166 17	0.88 0.99 3.00	0.61 0.61 2.90	1.83 2.90 4.90
Organic	SL-2 BH	423 29	0.97 1.82	0.61 1.52	2.74 4.27
Other	SL-2 BH	238 41	1.21 0.91	0.61 0.61	3.00 1.22

IMPLICATIONS OF CLIMATE CHANGE ON PEATLANDS

Thaw settlement

Because of the association of permafrost with bog, the presence of one peatland class as opposed to the other has important implications for predicting ground behaviour in the case of rising ground temperatures. Thaw subsidence resulting from degradation of segregated ice in bogs and the compressibility of thawed peat presents serious problems for construction and maintenance of highways, pipelines, buildings, and other infrastructure on the extensive organic terrain of the Mackenzie valley. Poor drainage in fens and the high compressibility and low strength of fen peat make fens unsuitable for any development. The greater frequency of frozen/unfrozen interfaces along any route in the southern part of the valley further complicates construction (*see* Burgess and Lawrence, 2000).

In Aylsworth et al. (2000), calculations of settlement in the event of thaw are presented for representative boreholes in various sediments. These data indicate that peat layers have moisture contents (up to 872% in ice-rich samples) and thaw strains (24–28%) that are greater than any mineral soil. This significantly affects the sensitivity of this type of ground to thawing. For example, with a thaw strain of 28%, a layer of peat 1 m thick would settle 28 cm when thawed. It should be noted that ground ice is common in fine-grained sediments overlain by an insulating blanket of thick peat, and that significant thaw strains and thaw settlements have been calculated for these underlying deposits. Since ground ice is irregularly distributed in and under the peat of bogs, thaw settlement would occur nonuniformly. Thus thaw settlement, resulting from climatic or any other disturbance of the ground-temperature regime of peatlands, will have important consequences for development and maintenance of any infrastructure constructed upon the extensive organic terrain of the Mackenzie valley.

FUTURE EMISSION OF GREENHOUSE GASES

With climate warming, the release of greenhouse gases from peatlands will augment the degradation of permafrost. At present, the production of greenhouse gas is extremely limited within the frozen bogs, which constitute approximately 73% of the peatland area in the Mackenzie valley (*see* 'Distribution of Peatlands in the Mackenzie Valley', above). Within unfrozen fens, degrading peat may produce greater than 100 times more methane, a major greenhouse gas, than peat in nearby frozen areas, per unit area (Watson et al., 1990). For example, the mean seasonal flux of methane has been measured from some forms of peatland in the Fort Simpson area as follows: open poor fen, open fen, low shrub fen, and treed low shrub fen have a mean flux of 162.5, 63.5, 19.0, and 3.7 mg CH_4 per m^2 per day, respectively, and mean flux of a bog collapse scar is 109.5. In comparison, the mean flux of a frozen peat plateau is only -0.6 mg CH_4 per m^2 per day (Liblik et al., 1997). Emissions have also been measured for northern Manitoba, another boreal region in the discontinuous permafrost zone. In Manitoba, seasonal average fluxes from fens and collapse scars are 92–380 mg CH_4 per m^2 per day, whereas from forested peat plateaus and palsas only 0–20 mg CH_4 per m^2 per day are released (Bubier et al., 1995). These data suggest that major thaw of the areas of frozen peat would cause large increases in emissions of greenhouse gases from the Mackenzie valley peatlands. It should be noted that peat also has the ability to retard ground thaw and this may result in a lag in the response of peatlands to climate warming (Halsey et al., 1995).

CONCLUSIONS

Both the extent (area and volume) and the thermal state of peatlands in the Mackenzie valley are important for assessing potential ground behaviour in the case of climatic warming or other surface disturbances. Peatlands in areas of discontinuous permafrost are particularly significant as these areas are potentially most vulnerable to the effects of global warming (*see* Wright et al., 2000). Much is already known about the areal extent of bog and fen, but more field investigations are needed to accurately characterize the peat depths and ground temperatures associated with the different classes and forms of peatlands in boreal and subarctic regions.

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